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Testimony of Keir Soderberg
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Date: **March 3, 2010**

Subject: **Boron Loading to the Mississippi River from Venice Ponds 2 and 3**

From: **Bruce Hensel**

Introduction

Boron loading to the Mississippi River from the inactive and dewatered Venice ash ponds was calculated in order to estimate the effect that this loading has on concentrations in the river. The loading rate was calculated by multiplying the volume of groundwater flowing into the river by the concentration of boron in the river.

L = C * Q and

Q = K * I * A

Where

C = boron concentration in groundwater. To be conservative, the highest single boron concentration in groundwater monitoring wells at the site was used in this calculation (Cmax), rather than an average or a median.

Q = the volume of groundwater discharging to the river.

K =the hydraulic conductivity of the aquifer. To be conservative, the highest hydraulic conductivity value recorded at site monitoring wells was used in this calculation, rather than a geomean.

I = a representative hydraulic gradient for the site.

A = the cross-sectional area through which this discharge occurs. To be conservative, it was assumed that the maximum concentration (Cmax) occurred over the entire thickness of the aquifer, and along the entire length of Ponds 2 and 3 parallel to the river, plus 500 feet north and south of the impoundment. In reality, concentration will decrease with depth in the aquifer and with distance north and south of the impoundment.

The loading rate (L) was then divided by the 7-day 10-year low flow ($Q_{7,10}$) at St. Louis, MO to estimate the incremental boron concentration increase (d_B) in the river due to discharge from the Venice ponds. Due to the size of the Mississippi River, it is unlikely that concentration would initially be distributed across the entire width of the river. Therefore, an additional calculation was performed to calculate the incremental boron increase assuming that mixing occurred within 50 feet of the shoreline. This calculation was performed by multiplying d_B by 2,100/50 (2,100 feet being total river width and 50 feet being the assumed mixing width).

The result of this calculation (Table 1) is a very conservative estimate of the increase in boron loading to the Mississippi River. This result (0.0019 mg/L) is lower than the instrument detection limit for boron as listed by the United States Environmental Protection Agency in method SW-846, 6010c, and is therefore not measurable.

This result can be applied to other constituents that may have been released to groundwater from the Venice ash ponds. However, because boron almost always has higher concentration in coal ash leachate than any other trace or minor element (i.e., excluding the major ions Ca, Mg, K, Na, Cl, HCO_3, and SO_4), it can be assumed that these constituents will have concentrations even lower than the 0.0019 mg/L conservatively calculated for boron. For example, arsenic also has concentrations in groundwater that are higher than Class I groundwater quality standards, although there are numerous data indicating that the ash ponds are not the source of arsenic exceedances.[1] Inserting the highest arsenic concentration observed in any groundwater monitoring well[2] into the loading rate calculation yields a mixed concentration of 1.0E-5 mg/L (0.01 ug/L), which is again much lower than laboratory analytical limits.

[1] Two lines of evidence indicate that the arsenic exceedances are not due to a release from the ash ponds: first, the distribution of arsenic and boron differ, with arsenic concentrations being relatively low in the two monitoring wells with the highest boron concentration; and second, the maximum arsenic concentration measured in two leachate wells screened in the coal ash was 0.029 mg/L, which are much lower than concentrations observed in most groundwater monitoring wells.

[2] The database contains one concentration higher than the value of 0.215 mg/L used in this calculation; however that value is a statistical outlier and all other arsenic results from this well are an order of magnitude lower than the outlier value.

Table 1
Mixing Calculation Showing Effect of Boron Loading on Mississippi River Quality at Low Flow

7-day 10-year low flow at St. Louis, MO		46500	cfs	Source: ISWS CR 440, 1988 (February)
	$Q_{7,10}$ =	1.1E+11	L/day	
Boron loading rate				
Maximum Boron Concentration in Groundwater (Cmax)		41	mg/L	MW-4
Maximum Hydraulic Conductivity		0.0045	cm/s	MW-7 (Hanson Report)
Hydraulic Gradient		0.001		September 16, 1999 GW contour map
Aquifer Thickness		100	ft	
Length of Ponds + 500 feet (each way) north and south		3,500	ft	
Q = KIA				
K = Max Hydraulic Conductivity		1.5E-04	ft/s	
I = Hydraulic Gradient		0.001		
A = Cross-Sectional Area		350,000	ft^2	
Q (per second)		0.05185	cfs	
Q (per day)		126,860.16	L/day	
Loading Rate (L)		5.2E+06	mg/day	= Cmax * Q
	L =	11.44	lb/day	
Boron concentration increase in Mississippi River at low flow due to loading from Ponds 2 and 3				
	d_B =	4.6E-05	mg/L	= $L/Q_{7,10}$
Boron concentration increase near-shore in Mississippi River at low flow due to loading from Ponds 2 and 3				
Assumes loading distributed within 50 feet of east bank		0.0019	mg/L	relative to a total river width of 2,100 feet
Typical boron laboratory detection limit		0.0038	mg/L	Source: USEPA SW-846 Method 6010c

Conclusion:

The calculated boron concentration increase in the Mississippi River at ***low flow*** due to groundwater loading from Ponds 2 and 3 is below our ability to measure, even if we only consider a small portion of the river. These calculations indicate that the effects of boron loading in groundwater discharge to the Mississippi River are negligible.

Table 2
Mixing Calculation Showing Effect of Arsenic Loading on Mississippi River Quality at Low Flow

7-day 10-year low flow at St. Louis, MO		46500	cfs	Source: ISWS CR 440, 1988 (February)
	$Q_{7,10}$ =	1.1E+11	L/day	
Arsenic loading rate				
Maximum Arsenic Concentration in Groundwater (Cmax)		0.215	mg/L	MW-7
Maximum Hydraulic Conductivity		0.0045	cm/s	MW-7 (Hanson Report)
Hydraulic Gradient		0.001		September 16, 1999 GW contour map
Aquifer Thickness		100	ft	
Length of Ponds + 500 feet (each way) north and south		3,500	ft	
Q = KIA				
K = Max Hydraulic Conductivity		1.5E-04	ft/s	
I = Hydraulic Gradient		0.001		
A = Cross-Sectional Area		350,000	ft^2	
Q (per second)		0.05185	cfs	
Q (per day)		126,860.16	L/day	
Loading Rate (L)		2.7E+04	mg/day	= Cmax * Q
	L =	0.06	lb/day	
Arsenic concentration increase in Mississippi River due to groundwater discharge near Ponds 2 and 3				
	d_B =	2.4E-07	mg/L	= $L/Q_{7,10}$
Arsenic concentration increase near-shore in Mississippi River due to groundwater discharge near Ponds 2 and 3				
Assumes loading distributed within 50 feet of east bank		1.0E-05	mg/L	relative to a total river width of 2,100 feet
Typical arsenic quantitation limit (Atomic Adsorption method)		0.001	mg/L	Source: USEPA SW-846 Method 7010

Conclusion:

The calculated arsenic concentration increase in the Mississippi River at ***low flow*** due to groundwater loading in the vicinity of Ponds 2 and 3 is two orders of magnitude lower than can be reliably qunatified using standard laboratory analytical methods. Note that this calculation is based on the highest (non-outlier) arsenic concentration detected at the site, and ***that available data indicate that the source of arsenic concentrations observed in groundwater is not the Venice ash ponds*** .

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Reddy, D.V., and B. Butul: A Comprehensive Literature Review of Liner Failures and Longevity (1999, 07-12)

A COMPREHENSIVE LITERATURE REVIEW OF LINER FAILURES AND LONGEVITY

Submitted

to

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ABSTRACT

A comprehensive review of landfill liner failures, the causes and consequences, and design methodology to avoid failures are presented.

In Chapter 1 the types of liner are reviewed. The different materials, types of liners, and manufacturing procedure are explained in detail, providing a base for a better understanding of the problems associated with liners. Currently used liners are comprised of composite structures of clay and geosynthetics materials. The commonly used geosynthetics materials are HDPE (High Density Polyethylene), PVC (Polyvinyl Chloride), and PP (Polypropylene); they are produced in the form of geomembranes (impermeable) and geonets (permeable) of different thickness.

Chapter 2 deals with the properties of polymeric geomembranes as well as those of geosynthetic clay liners. The physical, mechanical, hydraulic, and endurance properties are listed and explained, referencing the different standards associated with each properties.

Chapter 3 addresses the different modes of failures and liner degradation.
Creep is the deformation of a material over a prolonged period of time and under constant pressure. This phenomenon is mainly a function of the temperature, load, and time; and is of primary importance since geosynthetics are very sensitive to creep. Under sustained constant loading, the material will elongate and break. This problem can be eliminated by using a resin that is not affected by creep, and by a proper design that limits the high stress in the geomembrane.

Stress cracking is the brittle fracture of a geosynthetic material under significantly lower stress than the material yield strength. The factors influencing this phenomenon are: UV (Ultraviolet) radiation, temperature, temperature gradient, chemical agent, and stress (particularly fatigue). Stress Cracking leads to small cracks and even holes in the geomembrane, that allow leakage through the membrane. This can be prevented by using a UV and chemical resistant resin and by limiting high stress in the liner.

Damage caused by puncture will plastically deform the material up to failure and cause leaks. Static puncture is due to contact of stones on the geosynthetic under high static load (weight of the waste), while dynamic puncture is due to the fall of objects mainly occurring during installation. Static puncture may be eliminated by using protective layers made of geonets and rounded soil particles, as well as stiff and thick geomembranes. Dynamic puncture can be eliminated by considerable care in construction (skilled workmanship is required).

Seams are the weakest points of a liner. Many problems encountered in landfill originate at seam locations. Seams are regions of high stress concentration due to defects in seaming operations and residual stresses. Also, stress cracking and brittle fractures can

deteriorate and even break seams. It is possible to reduce damage considerably at seams by using proper equipment, workmanship, quality construction, and proper inspection.

Shear properties of liners are very important for the stability of the landfill, particularly earthquakes. The materials comprising the liners, their roughness, their stiffness, the normal load; and the temperature are factors influencing interface shear strength.

Aging of geomembranes is also an important problem, since environmental conditions such as temperature, UV, oxidation, and chemical agent tend to deteriorate the liners. The modes of failure are as follows: a) softening and loss of physical properties due to depolymerization and molecular scission, b) stiffening and embrittlement due to loss of plasticizers and additives, c) reduction of mechanical properties and increase of permeability, and d) failure of membrane seams. In the majority of cases there are combinations of these factors, which can cause damage to the liner system.

Chapter 4 deals with the design and construction methods currently used, as well as quality assurance/control criteria required to ensure long term performance of the liners. It is pointed out that a good design taking into account all the problems outlined in this report will yield a theoretically flawless liner. This has to be followed by reasonable “flawless” construction, with quality assurance and control.

Finally, methods for the life prediction of geosynthetics are reviewed in Chapter 5. The four methods are the time-temperature (WLF) superposition, the Arrhenius equation, the rate process method, and the bidirectional shifting method.

It is concluded that with proper design, construction, and inspection, the safe performance life of landfill liners can be considerably increased, with significant cost-benefit ratios.

INTRODUCTION

Landfills continue to be the most predominant method of waste disposal. Due to the public resistance to landfill construction and operation, the Environment Protection Agency (EPA) has established the Resource Conversion and Recovery Act (RCRA) Subtitle D program. The program requires a landfill lining system, which is composed of primary and secondary liners, leakage detection and leakage collection systems, to be used in the construction of new landfills.

The liners are composed of High Density Polyethylene (HDPE), Polyvinylchloride (PVC), and Polypropylene (PP). These materials are used for their high values of chemical resistance, elastic modulus, yield and puncture strength, and weathering resistance.
The primary function of the liner is to create an impermeable barrier, which is the last line of defense in protecting the groundwater. The groundwater is in constant danger of becoming contaminated from leachate, which is liquid that migrates through the landfill, either from precipitation, or already present in the waste.

There are many steps in the construction of the liner, or of the landfill, during which the liner may become damaged. These flaws cause the material to prematurely fail and significantly increase the cost of the project. Quality Assurance and Quality Control are the methods being used to prevent damage during construction and installation. Questions are still being raised about how long the material can perform. Research to predict the service life of the material, with and without installation damage, is of paramount importance. Work on a project of the Principal Investigator, entitled "Life Prediction of HDPE Geomembranes in Solid Waste Landfills", sponsored by Florida Center for Solid and Hazardous Waste Management (FCSHWM), identified the need for an extensive state-of-the art literature review of liner failures and longevity.

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1 Different Technologies of Landfill Liners

This chapter deals with the technologies used in the different types of landfill liners currently used in Municipal Solid Waste Landfills.

1.1 Different Materials

1.1.1 Compacted Clay

Compacted clays find applications as both primary and underlying components of liners in waste containment systems. When properly compacted, clay liners have a permeability of 10-7 cm/s or less due to the small particles, and plastic characteristics of clay. Thus clay is considered a highly effective and economical liner material. (1)

Long-term performance of clay liners is a function of properties, such as low permeability, low diffusivity, ductility, internal and interface shear strengths, chemical compatibility, chemical retardation, minimum of preferential flow paths, and good constructability. Factors such as soil composition, placement and construction conditions, post-construction changes, and chemical compatibility affect these properties.

1.1.2 Modified Soils

When the local soil is not suitable for use as a liner, current practice is to add commercially produced bentonites or other clay minerals in the in-situ soil to lower the permeability. Since bentonite is an expansive material (resulting mainly from its sodium-montmorillonite component), only a small quantity needs to be mixed to improve the soil's permeability.

The efficiency of the modified soil depends on many characteristics such as the form of bentonite used (granular or powdered), mineralogy (percentage of sodium and/or calcium-montmorillonite), the rate of application, the characteristics of the soil (lift thickness, moisture content, and the size, type, and operation of the roller), and the use of good quality control operations (1)

1.1.3 Geomembranes (Synthetic liners)

The recent years have seen a dramatic increase in the utilization of synthetic liners, mainly due to their easy availability and low volume consumption. Geomembranes are manufactured with thicknesses ranging from 1 to 3 mm (30 to 120 mils). Landfill liners generally require geomembranes having a thickness at least equal to 80-mil (1). However, certain states as Florida, allow the use of 60-mil geomembrane when the membrane is made of HDPE material.

To assess the geomembrane's chemical compatibility with the site-specific leachate, laboratory testing is highly recommended before the installation of the membranes in the site.

The main materials used in the United States for the manufacturing of geomembranes are described below.

* Polyethylene (PE):

The most commonly used polyethylene is HDPE (High Density Polyethylene). Effectively, the semicrystalline (40-50%) microstructure of HDPE is responsible for the material's high strength, and excellent chemical resistance to many chemicals. Sealing membranes can also be made of CPE (Chlorinated Polyethylene). CPE powder is obtained by PE chlorination in the wet phase. The properties depend mainly on the quality of the PE and the degree of chlorination; moreover polyester fabric or sheet can improve the structural properties of CPE (2).

* *Polyvinylchloride (PVC):*

PVC is the chain assemblage of the basic raw material vinylchloride (VC), which is a reaction product from ethylene and chlorine or ethylene, air and hydrochloric acid. Many designers choose HDPE for its greater resistance to chemicals, and ignore many of PVC's advantages. Plain PVC geomembranes are quite stiff materials and cannot, therefore, be used for landfills. Loss of plasticizers is such an important problem that the state of Florida does not allow the use of PVC for liner material. However, various studies comparing the chemical resistance of HDPE and PVC have shown that the landfill leachate has virtually no effect on PVC after 16 months (3). Moreover, plasticizers increase the material's flexible characteristics. Therefore Florida should lead some studies to determine whether or not PVC materials are suitable for application as liner materials.

An interesting advantage of PVC is its fabrication into large sheets requiring less field seaming than HDPE membranes. Nevertheless, in the case of fire, highly toxic fumes of hydrochloric acid are formed (2).

* *Polypropylene (PP):*

New materials for liners are as follow: a reactor blended PP, and a fully cross-linked elastomere alloy of PP and EPDM. PP has many properties similar to PE; this similarity is explained by the fact that PP and PE are part of the same polyolefin family. PP crystallinity is generally slightly lower than PE, and even with a high value of crystallinity, stress cracking has little influence on this material. Chemical resistance of PP is less than that for HDPE, but it has better seaming behavior than HDPE: it can easily be seamed by hot air equipment at low ambient temperature (the PP/EPDM alloy has been successfully seamed at a temperature of -9^{o}C in strong wind and snow). PP has lower UV resistance than HDPE, even though thermoplastic alloy has better UV resistance (3).

* *Ethylenecopolymer Bitumen (ECB):*

Landfill engineering uses ECB membranes as sealing materials that have been developed for the roofing industry. ECB is the assembly of raw materials composed of ethylene, butyle acrylate (50-60%), and special bitumen (40-50%). The role of the bitumen material is to soften, give a thermoplastic character, and lightly stabilize the mix (2).

* *Other materials in current use are as follows:*
- Chlorosulfonated polyethylene-reinforced (CSPE-R)
- Ethylene interpolymer alloy-reinforced (EIA-R)
- Linear low-density polyethylene (LLDPE)
- Chlorinated polyethylene-reinforced (CPE-R)
- Fully cross-linked elastomeric alloy (FCEA)
- Polyisobutylene and butyl rubber
- Polychloropene (neoprene)
- Ethyle vinyl acetate (EVA)
- Block copolymers of styrene and butadiene such as SBS rubber
-Ethylene propylene diene monomer (EPDM)

* *Additives:*

Most polymers need certain additives to improve processing as well as end-use properties. For instance additives, such as lead salts and organic derived of Ba, Ca, Cd, Zn, and Sn, are added to PVC to improve the heat and light stability. Lubricating additives, such as stearates or palmitates, are added to the polymer to improve the material's manufacturing. Plastizicers in PVC and HDPE improve membrane flexibility. Moreover, to increase chemical and UV resistance, antioxidants and additives are melted into the polymer (2).

1.2 Types of liners

The different types of architecture used for landfill liners are as follows: single liner (clay or geomembrane), single composite (with or without leak control), double liner, and double composite liner (4).

1.2.1 Single liner

A single liner system includes only one liner, which can be either a natural material (usually clay), *Fig 1a*, or a single geomembrane, *Fig 1b*. This configuration is the simplest, but there is no safety guarantee against the leakage, so a single liner may be used only under completely safe hydrogeological situations. A leachate collection system, termed LCS (soil or geosynthetic drainage material), may be placed above the liner to collect the leachate and thus decrease the risk of leakage.

1.2.2 Single composite

A single composite liner system, *Fig 1c*, includes two or more different low-permeability materials in direct contact with each other. Clayey soil with a geomembrane is the most widely recommended liner.

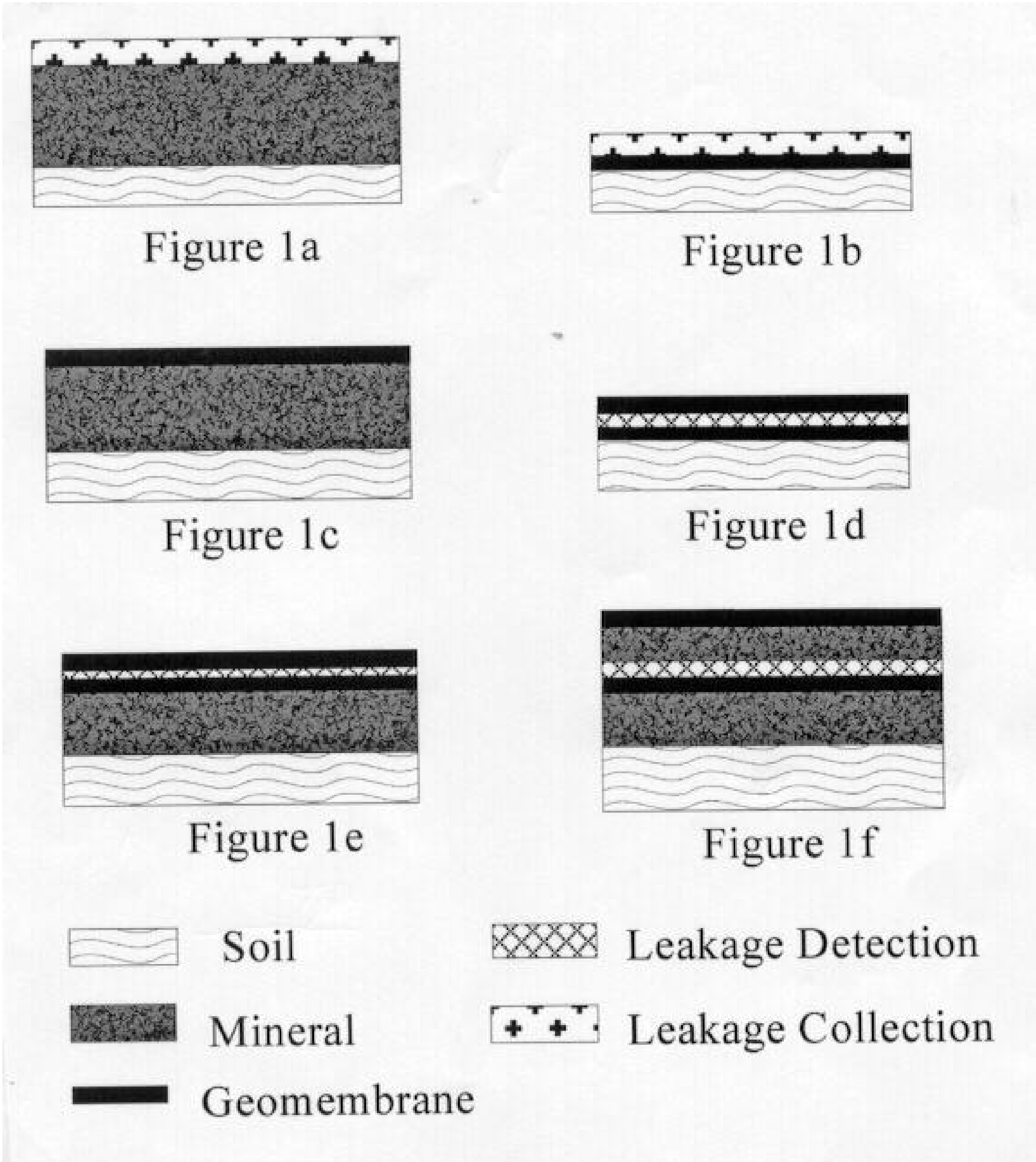

Figure 1: Cross section of different liner systems

Geotextile-bentonite composites are often used as substitutes for mineral liners (liners using stones or rocks as material) for application along slopes, even though many engineers prefer clay.

One of the main advantages of composite liners over single liners is the low amount of leakage through the liner, even in the presence of damage, such as holes in the geomembranes. Controversial points of view are expressed concerning the placement of draining materials between the clay and the geomembrane, also called the leakage detection system (LDS), the role of which is to detect, collect, and remove liquids between the two liners. The presence of a LDS separates the two low-permeability

materials which form two single liners separated by a layer of permeable material; for some engineers this configuration is two single liners separated by a LDS and for other it is still a composite liner. The opinion of the author of this report is that since two different materials are used this configuration forms a composite liner.
Some engineers point out that to maximize the advantages of composite liners, geomembranes should be positioned with direct contact on the top of the mineral liner, while others refute this idea and recommend placing a collecting system between the two components. The latter practice is to cope with the possibility of the geomembrane being pierced; the leachate can be evacuated outside the composite to decrease the possibility of leakage through the clay. It is always possible to place a leachate collecting system above the membrane.

1.2.3 Double liner

A double liner system, *Fig 1d*, is composed of two liners, separated by a drainage layer called the leakage detection system. A collection system may also be placed above the top liner. Double liner systems may include either single or composite liners. Nowadays, regulations in several states require double liner systems for MSW landfills. A clay layer may be placed under a double liner made of membranes as shown in *Fig 1e*.

1.2.4 Double composite liner

Double composite liners are systems made of two composite liners, placed one above the other, *Fig 1f*. They can include a LCS above the top liner and an LDS between the liners. Obviously, the more components in the liner system, the more efficient is the system against leakage.

1.3 Manufacturing considerations

Different technologies are employed to fabricate geomembranes, among those extrusion is used for HDPE, calendaring for PVC, and spraying for urethane. Even though geomembranes are quality products now, some problems may appear, such as creasing of polyethylene membrane due to the manufacturing process causing stress fractures; moreover abrasion process will add damage to the crease (5).

For HDPE materials, the resin is melted and forced through a die forming sheets; three different techniques are used:

- Horizontal cast index extrusion shapes a long strip (25mm width), then the different strips are assembled into a continuous sheet. This technique allows the fabrication of wide sheet, up to 11 meters.
- Horizontal continuous flat extrusion produces a full width from sheet feeding through counter-rotating calenders in a continuous manner (6). Five-meter wide sheets can be used.
- Vertical continuous circular extrusion produces a blown film that is stabilized, sized, and lifted by air both inside and outside the cylinder.

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2 Properties of geomembranes

This chapter reviews geomembrane properties and the test methods used for their assessment. Although there are a number of different types of membranes, the review is restricted to polymeric geomembrane, and geosynthetic clay liners. These properties characterize the material and help the designer to choose among the various geomembranes the most appropriate one for a special application (each landfill is unique). The properties can be classified into different groups: physical, mechanical, and endurance properties.

2.1 Polymeric geomembranes

2.1.1 Physical properties

Physical properties are assessed for the final product (not during manufacturing), and allow the proper identification of the geomembrane.

** Thickness:*

The test method ASTM D 5199 uses an enlarged-area micrometer under a specific pressure (20 kPa) to determine the geomembrane thickness. Today's membranes are 20 mils (0.5 mm) thick or greater, and the current regulation recommends a thickness of at least 30 mils (0.75 mm) for hazardous waste material pond liners.

** Density:*

The density or specific gravity depends on the base material forming the geomembrane. For polymer materials, values may range from 0.85 to 1.5 g/cc, with an ASTM classification requiring a density at least equal to 0.941 g/cc. One method used is ASTM D 792, based on specific gravity. Another and more accurate method, is ASTM D 1505 commonly used for material with specific gravity less than 1.

** Melt flow index:*

Manufacturers use this property to control the polymer uniformity referring to ASTM D 1238. This test is very important for quality control and quality assurance of polyethylene resins and geomembranes.

** Mass per unit area (weight):*

The weight is measured for unit area of a representative specimen (ASTM D 1910).

** Water Vapor Transmission:*

This test is important since it assesses a very critical characteristic of geomembrane: its impermeability. The water vapor transmission test consists of a sealed specimen over an aluminum cup with either water or a desiccant in it, while a controlled relative humidity difference is maintained (ASTM E 96). The required test time varies from 3 to 30 days. From the results of this test, the water vapor transmission, permeance, and permeability are calculated. The results differ depending on the material: for a PVC geomembrane (30 mils of thickness) the water vapor transmission is 1.8 g/m^2-day, and for a HDPE membrane (31 mils of thickness) 0.017 g/m^2-day.

** Solvent vapor transmission:*
In the presence of liquids other than water it is important to consider the concept of permselectivity. The values of vapor transmission through the membrane are most of the time different for the solvent compared to water, due to the molecular size and attraction of the liquid vis-a-vis the polymeric liner material. The test is identical to the water vapor transmission test (ASTM D 96), except that the water is replaced by solvents, which can range from methyl alcohol to chloroform.

** Coating over fabric:*
The assessment of the property is not covered by any ASTM test but can be carried out by an optical method (5).

2.1.2 Mechanical properties
Many tests developed to assess the mechanical properties of polymeric sheet materials can be used to evaluate geomembranes.

** Tensile behavior:*
Tensile tests, covered in ASTM D 638, D 882, D 751, are commonly used to evaluate simple samples for quality control and quality assurance of manufactured sheet materials.
The curve (stress versus strain) shows a pronounced yield point, then the curve goes slightly downward, and finally extends to approximately 1000% strain, when failure occurs. Curves for VLDPE and PVC geomembranes are relatively smooth; the stresses increase gradually until failure at 700% and 450% strain.
Other types of tests can also be carried out: a) using wider specimens (8", 200 mm) to prevent the contraction in the central region giving one-dimensional behavior not conforming to the field configurations (ASTM D 4885), here the width remains uniform; b) using axisymmetric tensile test behavior when the membrane is submitted to out-of-plane stresses (GRI test method GM4).

** Seam behavior:*
The joints between the geomembranes can be weaker than the membranes due to some imperfection in the field seaming. Several tests were developed to evaluate the strength of a seam: typical shear tests are ASTM D 4437, D 3083, and D 751; typical peel tests are ASTM D 4437 and D 413. In the peel test a specimen is taken across the seam and tested in a tensile mode. For shear testing, the specimen is separated by pulling-out, in an in-plane motion, two different points creating shear stress and strain in the seam appear.

* *Tear resistance:*
Different methods can be used to evaluate the tear resistance: ASTM D 2263, D 1004, D 751, D 1424, D 2261, and D 1938. Nevertheless the trapezoidal tear test (D 2263) is often recommended. A notched specimen is tested in a tensile machine. The tear resistance value corresponds to the maximum load. For certain membranes such as thin, non-reinforced geomembranes, the tear resistance is low, from 4 to 30 lb (18 to 130 N). Low values are problematic, especially during geomembrane handling and installation since the membrane can be pierced or damaged by sharpen objects. However, this problem is overcome when the thickness increases. The values of tear resistance for scrim-reinforced geomembranes are significantly higher, and can fit the range of 20 to 100 lb. (90 to 450 N).

* *Impact resistance:*
This property is important, since during installation the geomembrane may be damaged by falling objects that may propagate tears and consequent leaks. The test methods used are ASTM D 1709, D 3029, D 1822, D 746, D 3998, and D 1424. These tests are carried out by a free-falling dart, a falling weight or pendulum impact; all impact resistance varies greatly depending of the thickness and type of geomembrane tested.

* *Puncture resistance:*
Stones, sticks, or other debris can cause punctures to geomembranes during installation as well as during the membrane's service life. These punctures create points of tearing or leakage. The test method, ASTM D5494, consists of a geomembrane clamped over a cylindrical mold that is compressed. A rod is pushed into the geomembrane to cause puncture. The value at the breaking point is called the puncture resistance. Puncture resistance ranges from 10 to 100 lb. (45 to 450 N) for thin, non-reinforced geomembranes, and can go up to 50 to 500 lb. (220 to 2200 N) for reinforced ones. The values for puncture resistance, like other properties such as impact or tear resistance, are functions of the geomembrane thickness. The GRI test method, GM3, also addresses membrane puncture resistance.

* *Geomembrane friction:*
Soil-to-membrane friction is a critical parameter since numerous side slope failures have occurred. The ASTM D5321 test method consists of a split shear box with the geomembrane/soil interface. The friction angles of soil/geomembrane interfaces are always less than those for soil/soil ones. Smoother, harder geomembranes have the lowest values, while the rougher, softer geomembranes have higher friction values.

* *Geomembrane anchorage:*
In some liners, the geomembrane is sandwiched between two materials and is stressed by an external force, possibly creating membrane failure. This phenomenon can be modeled in the laboratory by sandwiching the membrane between suitably anchored channels back-to-back. The channels are compressed with a hydraulic jack, and the exposed geomembrane end is pulled by grips in a tension machine (GRI test method GM2).

* *Stress-cracking:*
ASTM D1693 can be used to test polyethylene materials: a notch is introduced in small specimens, which are then bent into a U shape, placed within the flanges of a channel holder with the notches at the bottom, and immersed in a surface wetting agent at an elevated temperature. No external loading is applied. The test records the proportion of the total number of failures in a specific time.
A more efficient test method is ASTM D5397, placing dumbbell-shaped specimens with a notch under constant tensile load in a surface wetting agent at an elevated temperature.
A ductile-to-brittle behavior is observed while tensile testing specimens at different percentages of their yield stress. The transition time varies from 10 to 5000 hours depending on the material tested. The current recommendation for HDPE is 100 hours.

Other properties may be evaluated, such as the modulus of elasticity (ASTM D882), the hardness (ASTM D2240), and ply adhesion (ASTM D413) (5).

2.1.3 Endurance properties
* *Ultraviolet:*
Ultraviolet light can cause chain reactions and bond breaking of polymeric material due to the penetration of short wavelength energy. Accelerated tests can be carried out in the laboratory, ASTM G26 and G53, but it may be more efficient and accurate to carry out outdoor tests as described in ASTM D1453 and D4364. Nevertheless, CSPE-R and HDPE geomembranes are able to withstand UV up to 20 years thanks to additives. Other geomembranes must be buried in soil.

* *Radioactive degradation:*
Radioactivity, higher than 10^6 and 10^7 rads, causes polymer degradation due to chain scission. Thus geomembranes must not be placed in high-level radioactive waste, but can be used to contain low-level radioactive waste.

* *Biological degradation:*
Soil contains a tremendous number of living organisms, such as small animals, which burrow through the membrane, fungi (yeast, molds, and mushroom), and bacteria. ASTM G21 deals with the resistance of plastics to fungi, while G22 deals with the resistance of plastics to bacteria. The main concern here is not the polymeric degradation, but the fouling and clogging of the drainage system.

* *Chemical degradation:*
Chemical resistance is a very important and critical parameter since the geomembrane is in direct contact with the waste most of the time. To insure proper resistance, it is recommended to assess its behavior with the leachate or waste, the membrane will contain. The testing should be as similar (leachate, temperature) as possible to the exposure in the landfill. From test methods, EPA 9090 and ASTM D 5322, the response curves should be plotted indicating the percent change in the measured property from the original versus the duration of incubation.

* *Thermal degradation:*
Polymeric geomembranes are sensitive to changes in both warm and cold temperatures, each causing its own effects. ASTM D 794 is used to assess the consequences of hot temperature on polymeric geomembranes. Cold temperatures have less critical effects than warm ones, nevertheless the membrane's flexibility decreases and seams are more difficult to make. ASTM D 2102 and D 2259 characterize the contractions of the membrane, while D 1042 and D 1204 characterize the expansion and changes of dimensions.
Appendix VII gives the coefficients of liner thermal expansion.

2.2 Geosynthetic clay liners (GCLs)

GCLs are composite liners comprising a layer of clay under a geomembrane sheet.

2.2.1 Physical properties

* *Clay type:*
The composition of the clay can be determined by X-ray diffraction, which is an accurate but expensive method. An easier method is the American Petroleum Institute (API) methylene blue analysis.

* *Thickness:*
The determination of GCL's thickness can be problematic for certain materials. However, ASTM D1777 can be used but with maximum care.

* *Mass per unit area:*
ASTM D3776 allows the determination of a composite GCL's mass per unit area. Another method is to assess the overall mass per unit area of the complete GCL roll, which is mainly used by manufacturers for quality control check, even though the results will not be as accurate as the D3776 method since the roll weight exceeds 3000 lb.

* *Moisture content:*
Moisture content is measured by the ASTM D4643 test method and can be defined as the water content divided by the oven-dry weight of the specimen, expressed as a percentage. Bentonite clay is a very hydrophilic material, and its moisture content can be as high as 20% in humid areas.

2.2.2 Hydraulic properties

* *Hydration:*

The hydrating property of bentonite clay varies depending on the nature of the hydrating liquid, and on the applied normal stress. The assessment of this property is important since it provides the low-permeability characteristic to a CGL liner system.

* *Free swell:*
This test assesses the amount of swelling of the bentonite under zero normal stress. Two tests methods are used: a) NF-XVII from the United States Pharmacological Society which consists of a cylinder filled with water (100 ml) and bentonite (2 g). After 24 hours, the volume occupied by the clay is determined; b) ASTM D 35.04: The clay is placed in a mold, then a stress of 14 lb/ft^2 is applied on the test specimen immersed in water, and deflections are measured for 24 hours

* *Permeability:*
The test method ASTM D 35.04 evaluates the permeability (or hydraulic conductivity) of GCL with the help of a permeameter under field-simulated conditions. The values of the permeability range between $6x10^{-9}$ to $3x10^{-10}$ cm/sec.

<u>2.2.3 Mechanical Properties</u>
* *Tensile strength:*
Three different kinds of tensile strengths of importance need to be evaluated: Wide-width tensile behavior, confined wide-width tensile behavior, and axisymmetric tensile behavior. The tensile behavior of CGL is almost similar to the tensile behavior of the geomembrane since clay property is low. Moreover, the test should be done with dry clay. The wide-width tensile behavior is determined with the test method ASTM D4595. The second test is similar to the first one, except for the confined environment. The axisymmetric tensile behavior is a very important characteristic of CGL, but unfortunately no tests have been developed to assess this property.

* *Direct shear behavior:*
The test is similar to that for polymeric geomembranes; the specimen is tested in a shear box where constant strain is applied.

* *Puncture resistance:*
Different tests can assess the puncture resistance of CGL: ASTM D 3787, FTM 101C-M2065, and ASTM D 5494. They use either a puncturing or pyramidal probe. One interesting property of bentonite is its capacity to self-cure after puncture, which is unfortunately not the case for polymeric material.

Endurance tests can be carried out to determine the longevity of CGL. These tests are similar to the ones used for polymeric material; obviously the results are not the same.

<u>2.3 Example of geomembrane properties</u>

The properties of two different geomembranes are listed in Table 1. Obviously, the properties vary as a function of the thickness.

The first geomembrane is UltraFlex manufactured by the SLT Corporation, the second one is a smooth HDPE geomembrane manufactured by the Poly-Flex Corporation.

Table 1: Mechanical Properties of Different Geomembranes

	SLT mil		Poly-Flex	
Thickness	60 mil	80 mil	60 mil	80 mil
Density (g/cc)	0.931	0.931	0.95	0.95
Melt Flow Index (g/10 min.)	≤ 1	≤ 1	0.2	0.2
Carbon Black Content	2.5 %	2.5 %	2.5 %	2.5 %
Tensile Strength at Break (ppi)	300	400	285	380
Elongation at Break (psi)	1000	1000	900	900
Tear Resistance (lbs)	45	60	50	66
Puncture Resistance (lbs)	90	120	96	128
Low Temperature Brittleness (^oF)	< 120	< 120	< 112	< 112
Environmental Stress Crack (hrs)	> 5000	> 5000	> 2000	> 2000
Dimensional Stability	± 1	± 1	± 0.5	± 0.5

The following tables list some properties of different geotextile materials. Table 2 provides water vapor transmission values, Table 3 lists tensile strength values of membrane sheets and seams, Table 4 presents the tensile behavior properties values of HDPE, VLDPE, PVC, and CSPE-R membranes, Table 5 shows the impact resistance, Table 6 lists the interface friction angles of different geotextiles with different types of soil, Table 7 lists the angles of friction of geotextile/geomembrane 33 erfaces, and Table 8 lists the coefficients of linear expansion for different polymeric materials.

Table 2: Water Vapor Transmission Values (2)

Geomembrane Type	Thickness		WVT Results	
	Mil	mm	g/m^2-day	perm-cm
PVC	11	0.28	4.4	1.2×10^{-2}
	20	0.52	2.9	1.4×10^{-2}
	30	0.76	1.8	1.3×10^{-2}
CPE	21	0.53	0.64	0.32×10^{-2}
	31	0.79	0.32	0.24×10^{-2}
	38	0.97	0.56	0.51×10^{-2}
CSPE	35	0.89	0.44	0.84×10^{-2}
EPDM	20	0.51	0.27	0.13×10^{-2}
	48	1.23	0.31	0.37×10^{-2}
HDPE	31	0.8	0.017	0.013×10^{-2}
	96	2.44	0.006	0.014×10^{-2}

Table 3: Values for Geomembranes Tensile Test on Sheets and Shear Test on Seams (1)

Type of test	HDPE	VLDPE	PVC	CSPE-R	EIA-R
Tensile test on sheet					
ASTM test method	D638	D638	D882	D751	D751
Specimen shape	Dumbbell	Dumbbell	Strip	Grab	Grab
Specimen width (in.)	0.25	0.25	1	4 (1 grab)	4 (1 grab)
Specimen length (in.)	4.5	4.5	6	6	6
Gege length (in.)	1.3	1.3	2	3	3

Strain rate (ipm) 20 20 20 12 12

Table 4: Tensile Behavior Properties of 60-mil HDPE, 40-mil VLDPE, 30-mil PVC, and 36-mil CSPE-R (1)

a) Index tension tests:

Test property	HDPE	VLDPE	PVC	CSPE-R
Maximum stress (MPa)	19	8	21	55
Corresponding strain (%)	17	500	480	19
Modulus (MPa)	330	76	31	330
Ultimate stress (MPa)	14	8	21	6
Corresponding strain (%)	500	500	480	110

b) Wide-width tension tests:

Test property	HDPE	VLDPE	PVC	CSPE-R
Maximum stress (MPa)	16	8	14	31
Corresponding strain (%)	15	400	210	23
Modulus (MPa)	450	69	20	300
Ultimate stress (MPa)	11	8	14	3
Corresponding strain (%)	400	400	210	79

c) Axisymmetric tension tests:

Test property	HDPE	VLDPE	PVC	CSPE-R
Maximum stress (MPa)	23	10	15	31
Corresponding strain (%)	12	75	100	13
Modulus (MPa)	720	170	100	350
Ultimate stress (MPa)	23	10	15	31
Corresponding strain (%)	25	75	100	13

Table 5: Impact Resistance of Different Geomembranes (1)

	Point Geometry Angle				
Geomembrane	**15 deg.**	**30 deg.**	**45 deg.**	**60 deg.**	**90 deg.**
PVC (20 mil)	4.8	6.6	11	> 15.6	> 15.6
PVC (30 mil)	6.8	10	13.5	> 15.6	> 15.6
HDPE (40 mil) reinforced	5.6	6.9	8.3	8.3	6.4
CSPE (36 mil) reinforced	9	9.4	10.3	14.2	> 15.6

Table 6: Friction Values and Efficiencies for Soil to Geomembrane Interfaces (3)

Geomembrane	Soil Type		
	Concrete Sand ($\phi = 30^o$)	**Ottawa Sand ($\phi = 28^o$)**	**Micha Schist Sand ($\phi = 26^o$)**
EPDM-R	24^o (0.77)	20^o (0.68)	24^o (0.91)
PVC *rough*	27^o (0.88)	-	25^o (0.96)
PVC *smooth*	25^o (0.81)	-	21^o (0.79)
CSPE-R	25^o (0.81)	21^o (0.72)	23^o (0.87)
HDPE	18^o (0.56)	18^o (0.61)	17^o (0.63)

Table 7: Friction Values and Efficiencies of Geotextile/Geomembrane Interfaces (3)

	Geomembrane				
Geotextile	EPDM-R	PVC *rough*	PVC *smooth*	CSPE-R	HDPE
Nonwoven, needle punched	23^o	23^o	21^o	15^o	8^o
Nonwoven, heat bond	18^o	20^o	18^o	21^o	11^o
Woven, monofilament	17^o	11^o	10^o	9^o	6^o
Woven, slit film	21^o	28^o	24^o	13^o	10^o

Table 8: Coefficients of Linear Thermal Expansion for Different Polymeric Materials (1).

Polymer type	Thermal linear expansivity x 10^{-5}	
	per 1^oF	per 1^oC
Polyethylene		
High density	6-7	11-13
Medium density	8-9	14-16
Low density	6-7	10-12
Very low density	8-14	15-25
Polypropylene	3-5	5-9
PVC		
Unplasticized	3-6	5-10
35% plasticizer	4-14	7-25
Polystyrene	2-4	3-7
Polyester	3-5	9-9

2.4 References

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3 Liner Failure and Prediction

The failure modes can be divided into two categories: leaking and liner destruction (1):

* Leaking is the liner's failure to ensure the containment of waste. Leachate or even waste leak from the containment to the in-situ soil, through the liner through holes or the loss of material permeability.

* The liner destruction mainly corresponds to a loss of mechanical properties or extensive membrane movements caused by phenomena such as creep, membrane uplift by excessive wind, puncture, etc.

The phenomena can be coupled; for instance puncture creates a hole that causes a leak followed by tear propagation.

3.1 Creep

3.1.1 Definition

The physical phenomenon occurring in most material, and particularly in plastics, termed creep is the deformation of the material over a prolonged period of time under constant pressure (1). Creep is a material, load, temperature, and time-dependent phenomenon. It is associated with all the mechanical deformations: tensile, compression, torsion, and flexure (2). However, tensile and compressive creeps are the only deformations that matter for landfill liners since geomembranes are flexible materials.

The tensile creep test is carried out by applying in-plane stress while the compressive creep test is realized by applying normal loading. Creep and creep-rupture data must be taken into consideration for the determination of the creep modulus and strength of the material for long-term behavior (3).
The creep test measures the dimensional changes of a specimen submitted to a constant load during a certain period of time, while the creep rupture test measures the time taken for rupture to occur under constant load. (2).
Creep behavior is commonly assessed at constant times and temperatures, and is shown in the graph (see Fig 2): either strain versus time (or log time) or strain rate versus time.

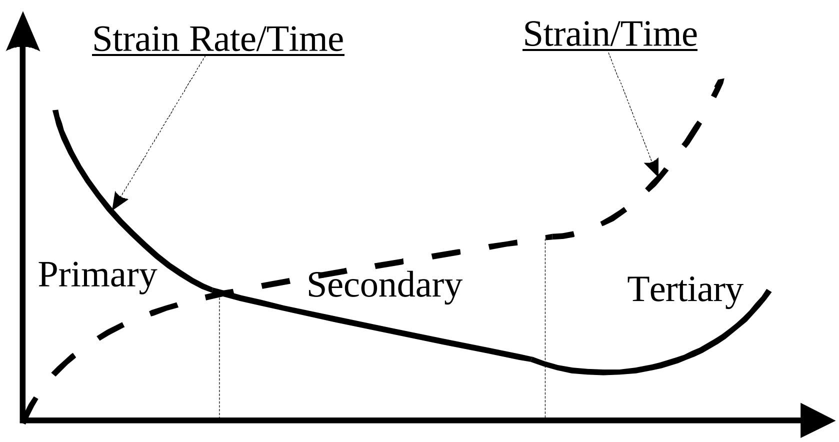

Figure 2: Typical creep curves (3)

3.1.2 Different phases of creep response

The creep behavior of a constant polymeric material can be divided into three phases called primary, secondary, and tertiary creep. During the primary phase the strain increases but the strain rate decreases, in the secondary phase (also called steady state) both the strain and strain rate are constant, and the tertiary phase is characterized by a rapid increase of strain and strain rate leading to the specimen's rupture.

For polymeric materials, tertiary creep is the dominating phase for polyethylene and polypropylene, while in geosynthetics made of polyester, primary creep is the dominating phase, thus some materials do not show strain and strain rate increases before rupture.

Long-term performance is a function of polymer type, grade, manufacturing techniques (since they influence the orientation and length of molecules), and the percent of crystallinity. Macrostructure affects creep behavior, since debonded fibers can straighten and thus increase creep strains, postponing the creep-rupture limit. Even though several studies show that temperature has little influence on creep behavior, time-temperature superposition principles are used to estimate the long-term properties of polymeric materials. Moreover, for HDPE, increasing the molecular weight can reduce the temperature influence (4). However, the effect of load is many times greater than the effect of temperature (3).

Torsion and flexural creep behavior pose no problems for flexible geomembranes that emphasizes the importance of tensile and compressive creep testing.

3.1.3 Tensile creep behavior

Cazzuffi et al. (3) evaluated the tensile creep behavior of high-strength geosynthetics, using the CEN European Method in order to compare the European and American methods. Twelve specimens were placed in a load frame, and tested at a constant temperature and humidity (controlled air-conditioned room). HDPE extruded geogrids, PET woven geogrids, and PP/PET woven/nonwoven composite geotextile were trimmed to conform to the CEN Standard (European Standard), and tensile creep tests were performed. Comparing the CEN and ASTM methods, no major differences in the procedures were observed, although parameters such as specimen sizes and loading time differed slightly.

The test temperature was 20^{o}C and the humidity 65%; three different loads were applied, 20%, 30%, and 50% of the wide-width tensile strength. Strain versus time and strain rate versus time graphs were plotted for each load and material. The testing time extended to 10000 min. Only one specimen posed a problem: the HDPE extruded geogrid approached failure for a load equal to 50% of the wide-width tensile strength; other specimens remained acceptable for this small period of time.

3.1.4 Multi-axial tensile creep

Merry and Bray (5) tested geomembranes for multi-axial tensile creep. Specimens were made of extruded HDPE produced by two different manufacturers. The objective of this study was to evaluate the stress-dependent creep of HDPE geomembranes at different

temperatures ranging from 2°C to 53°C. Specimens were exposed to a constant stress ranging from 2 MPa to 15 MPa for a period of 36 hours.
The test results proved that when the temperature increases, the response softens significantly. When loaded to the same stress level, a geomembrane exposed to a higher temperature will fail sooner than a geomembrane exposed to a cooler temperature.
This test contradicts the common thought that creep behavior is poorly affected by temperature, and implies that other studies should address exposing specimens to longer time periods. An interesting conclusion of this test is that the behavior of membranes tested in a multi-axial mode can be modeled by an adaptation of the Singh-Mitchell (9) creep model, originally developed for soil.

3.1.5 Creep rupture envelope

While characterizing the creep behavior of a material, it is interesting to evaluate the creep rupture envelope (2), which is the curve connecting the rupture points of several tensile creep-rupture test curves, Fig. 3. The creep-rupture tests are carried out for different temperatures and loads. The envelope curves are of primary importance for designing with geomembranes.

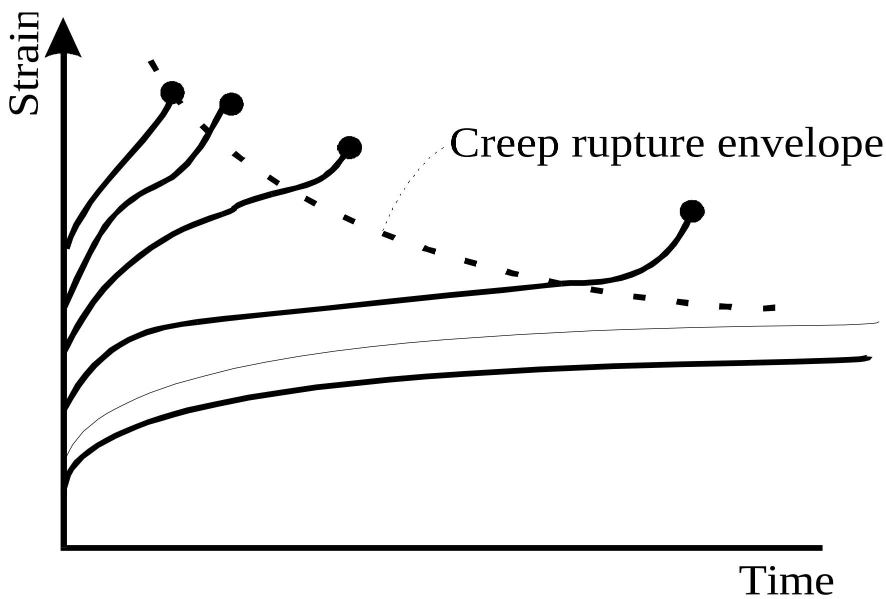

Figure 3: Creep Rupture Envelope (2)

3.1.6 Compressive creep

Beside tensile creep behavior, the compressive creep behavior should be evaluated. Effectively a landfill liner is submitted to a constant vertical load during a long period of time, causing geometric deformations and eventual damage leading to the liner's failure.

Montanelli and Rimoldi (6) evaluated the effect of long term hydraulic flow capacity of compressive and intrusion phenomena. One aspect of this test was the assessment of the compressive creep behavior of two drainage geocomposites (Tenax TNT 300 presenting a thickness of 7 mm, and Cleymax GCL 500 SP presenting a thickness of 5.2 mm). The specimens (100x100 mm) were placed between two rigid steel plates and loaded with specific pressures equal of 100 kPa and 200 kPa.

The test was performed for 10,000 hours and as expected a decrease in thickness was observed but no failures were recorded. The thickness decrease ranged from 3 to 6 percent of the original thickness.

Reddy and Daniel (7) evaluated the effects of compressive creep on landfill liners by testing the compressive creep behavior of a HDPE geonet. In the first part of this study specimens of different thickness (160, 220, and 300 mil) were tested in untreated and treated (by an agent inhibiting the development of excessive biological growth) leachate at a constant pressure of 110 psi. The percent strain, in the untreated leachate, ranged from 3.8% (160 mil) to 5.8% (220 mil). Values for the treated leachate were significantly lower than those for the untreated one, which implies that the more contaminated the leachate, the larger are the compressive creep effects. Nevertheless, no failures were observed for the time period of 120 days.

On the sides of a landfill, the liner is not only submitted to compression stress but also to shear stress due to the side slope. Some studies analyzing the effects of shear stress on the membranes have been realized. Cazzuffi (8) presented the procedures for combined normal and shear compressive creep testing. Similar to regular compressive creep testing, the specimens must be tested at a constant temperature of 20^{o}C, and humidity of 65%; their shapes can either be rectangular or circular. The test is carried out in a compressive machine, the apparatus is composed of a fixed base plate and a top plate free in the vertical and horizontal directions. The inclination of the membrane should be adjustable. The test is conducted like a regular compressive test: the change in thickness is measured for a prescribed period of time, at least for 1,000 hours.

Fig. 4 presents typical compressive creep curves under three different pressures.

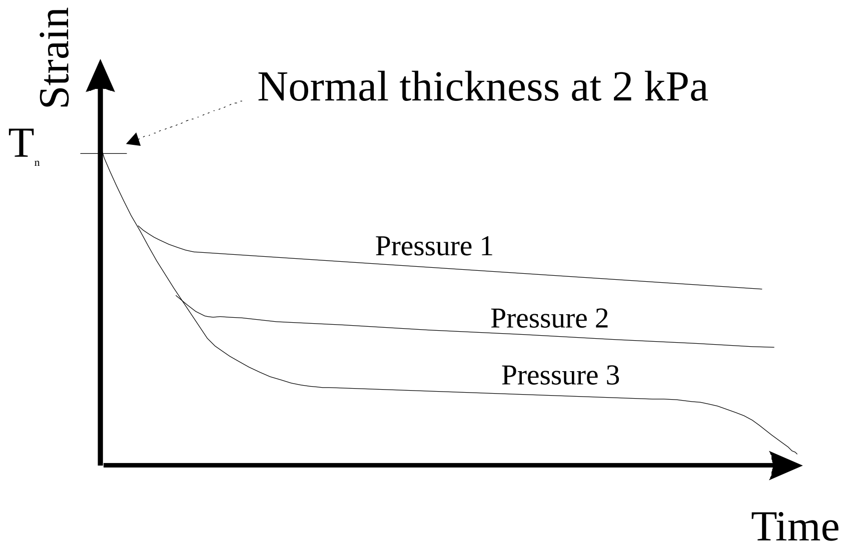

Figure 4: Typical compressive creep curves (8)

Methods are available to predict the life of a geomembrane based on creep failure. These methods are discussed in detail in the Chapter 5, devoted to life prediction of geomembranes.

3.1.7 References

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3.2 Stress Cracking

3.2.1 Definition

Stress cracking (SC) is the brittle fracture (internal or external) of thermoplastic material under sustained tensile stress at a significantly lower stress than the material yield strength (1). Environmental stress cracking is the stress cracking of materials subjected to environmental conditions such as weather or chemical agents.

Many failures due to SC reported are restricted to uncovered liquid impoundment liner or liner caps; but no failures in landfill bottom liner have been presented (2). Even if no evidence was found to show that SC occurs in the covered liner, it is important to assess this phenomenon since it occurs in the uncovered liner, therefore chances are that it also occurs in the buried one. It may be only a question of time before buried liners damaged by SC will be reported.

SC not only occurs in polyethylene material but also in plain carbon steel, several stainless steels, metallic alloys, PET, and in plasticized and unplasticized PVC.

3.2.2 Different types of failure

Two different modes of SC may occur: rapid crack propagation (RCP) or slow crack growth (SCG). As the name indicates, RCP is associated with very high velocities (over 300 m/s), and may spread over hundred of meters in length. Failures of this type, also called shattering failures, occur in geomembranes exposed to extremely cold weather with temperatures lower than –20^{o}C. The triggering is some kind of dynamic or impact type of failure (3).

SCG is associated with velocities less than 0.1 m/s and propagates at a specific (possibly varying) rate during the membrane service life. The rate of propagation is a function of the polymer material, applied stress, and temperature. This mode is really problematic since failures can appear with stresses as low as 20% of the material yield stress.
In a rapid crack failure, the rupture occurs in a brittle manner (rupture abrupt, without plastic deformation). In a slow crack failure, the geomembranes may fail either in a totally ductile (important plastic deformation) or totally brittle manner, or may start with a ductile behavior and change to a brittle mode. This depends mainly on the stress applied.

Figure 5: Different faces of the specimen. Left: Ductile, Center: Brittle, Right: Quasi Brittle

Fig. 5 presents the three different types of failure: ductile fractures usually occur at high temperatures with low load application velocity, while brittle fractures occur at low temperatures under high velocity loading.

3.2.3 Mechanism of Stress Cracking

A crack failure can be divided into three different phases: first a craze (a non-opening defect) appears at the notch, then it progresses to an open crack, and finally the crack propagates through the geomembrane thickness creating the failure (Fig. 6).

As soon as a crack is initiated, it is extremely difficult to predict the propagation rate, since it depends on a multitude of factors.

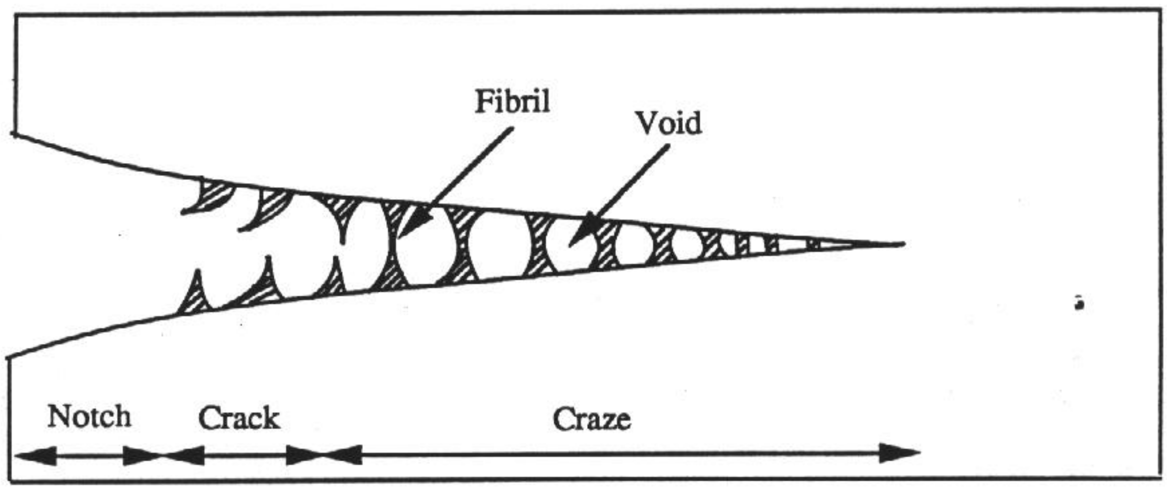


Figure 6: Crack and craze formation in HDPE geomembranes (3)

The crack propagates perpendicularly to the stress orientation through the membrane thickness due to the periodical rupture of the fibril. The rate of slow crack growth can be mathematically modeled by the following equation:

$$K = q\left(\frac{da}{dt}\right)^{p} \quad \text{[3.2.1]}$$

Where:

K: Fracture Toughness (Mpa/$m^{0.5}$)

da/dt: Crack Growth Rate (m/s)

p: Constant Dimensionless (ranging from 0.5 to 0.125 for PE Materials)

q: Constant with Dimensions of [(Mpa/$m^{0.5}$) $(m/s)^{-p}$]

Table 9: Fracture Toughness (K) Values of Different Polymers (4)

Materials	Fracture Toughness (Mpa-m$^{1/2}$)
Polystyrene (PS)	0.7-1.1
Polycarbonate	2.2
Polyvinyl Chloride (PVC)	2.0-4.0
Polypropylene (PP)	3.0-4.5
Polyethylene (PE)	1.0-6.0
Polyamide (PA)	2.5-3.0
Polyesther (PET)	5

3.2.4 Microscopic aspects of SC

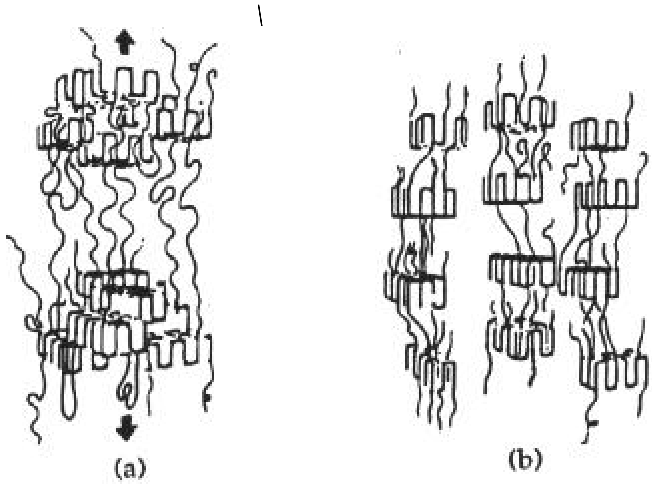
Polymers are composed of crystalline and amorphous regions. The crystalline region is made of long parallel molecule chains forming lamella, which form a spherulitic geometry. Other molecule chains, comprised of tie molecules crossing and joining the lamella without specific orientation, form the amorphous part of the polymer (5).

The tie molecules bind the lamellas and so provide the strength, when their numbers decrease the strength reduces (6). Their role is primordial since they tie or bond the crystalline region into a coherent structure unit, thus forcing ductile behavior rather than brittle behavior (3). The molecular arrangement affects the SC behavior of the material. The SC resistance will decrease with the increase in material density and crystallinity, since when the density increases the amount of amorphous material decreases, and consequently the number of tie molecules.

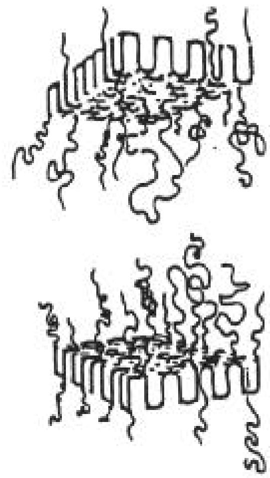
The co-monome content tends to affect the entanglement of the tie molecules and the loose loops, it also tends to reduce the polyethylene crystallinity, thereby increasing the SC resistance. Nevertheless, molecular weight does not necessarily increase the SC resistance, since an increase of crystallinity does not always imply an increase of density.

The molecular mechanisms causing SC are chain scission, bond breaking, cross linking, or extraction of various components.

(a) Initial steps in the deformation of polyethylene



(b) Steps in the ductile deformation of polyethylene



(c) Final step in the slow crack growth of polyethylene

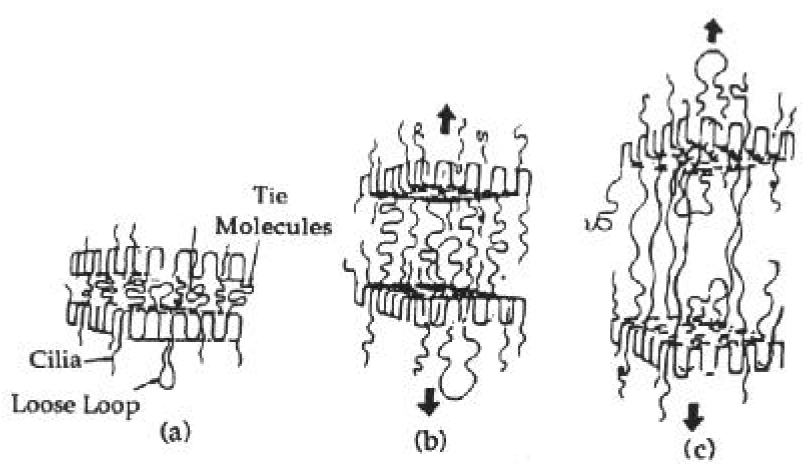


Figure 7: Conceptualization of ductile and brittle failure mechanisms in semi-crystalline polymer materials, after Lustigier and Rosenberg (4).

Fig. 7 shows the different steps for different modes of rupture at a molecular level. Fig. 7a presents the effect of a small deformation, Fig. 7b presents a ductile failure where the crystalline region is pulled apart in a cold drawing mode (plastic deformation of fractured face material, occurring parallel to the applied force), and Fig. 7c presents a brittle failure where the tie molecules are separated in an abrupt mode, while the crystalline region remains intact (3).

As an HDPE liner ages, the amount of crystallinity increases; the number of tie molecules decrease, thus decreasing the SC resistance of the membrane (7).

Even if the SC properties of a polyethylene membrane decrease when the amount of crystallinity and density increase, some medium density polyethylenes are more susceptible to stress cracking than HDPE.

The polyethylene microstructure characteristics and the manufacturing process are the primary influence in the behavior of the geomembrane vis-à-vis SC. Therefore, some geomembranes are better than others, and some seam geometries act better with a specific resins: the problem is to determine the optimum best performance combination of resin and seam geometry (8).

3.2.5 Reasons for SC

To initiate, a crack needs two triggers: a stress and a geometrical imperfection creating a stress concentration point. SC phenomenon is mainly linked to overstressed liners due to restrained thermal contraction during low temperature cycles (8). The stress may be initiated by contained fluid or landfill waste, subgrade settlement, thermal contraction due to geomembrane's shrinkage at low temperatures, or the manufacturing process. A polymer may present ductile behavior and withstand a particular SC agent in an unstressed state, but may fail in a brittle way while in a stressed state, even with low stress values (5). Crazes can be developed by membrane exposure to stress. These crazes are porous regions that absorb chemical fluids, which accelerate the relaxation of the polymer's yield point at the tip of the craze. Crazes may grow into cracks and lead to brittle fracture. The study of the stresses in a liner slope (8) shows that the highest thermal contraction stresses are on the top of the slope, where the material is clamped to the ground and stress relaxation is prevented. In contrast, at the center of the slope the material is free to relax.

The stress concentration factors can be three or more. Stress concentration points are created by surface scratches, extrusion die lines, grinding gouges, seaming machine gouges, re-entrant angles at the edges and on the surfaces of seams, water vapor voids within seams, lack of bonding at seam interfaces, and carbon black agglomerates (8). However, it appears that in most cases the stress concentration point is located at a seam. The problems appearing at seams are due to natural discontinuities of the overlap configurations used to seam geomembranes, and also possibly due to overheating of fusion seams and /or excessive grinding associated with extrusion flat or fillet seams (3).
Failures can also occur along folds or at surfaces. Especially, when different thermal contraction stresses occur on the inside or outside of the fold, the situation is aggravated by unfolding of the membrane during cold weather. Surface cracking can occur due to single bending of a panel exposed to solar radiation. For an uncovered geomembrane, special care must be taken to ensure that the material contains sufficient carbon black or that it is UV treated.

Residual stresses are created by the manufacturing and installation processes, particularly in high crystalline polymers; HDPE is a very sensitive material for the occurrence of residual stresses (9).

In order to determine the residual stress values, Koerner et al. (3) attempted to extrapolate the 'hole method' used in metals and composites to HDPE geomembranes.
This method tends to quantify the residual stress in a material by drilling a hole in the center of a rosette strain gage (see Fig. 8). The rosette is placed on the surface of the material, the indicator is set at zero. After the hole has been drilled the material releases its

residual stress, leading to an ovalization of the hole due to the strain relaxation. At this stage, the material changes from a stressed to an unstressed state; this change in strain is measured by the rosette gives the residual stress.

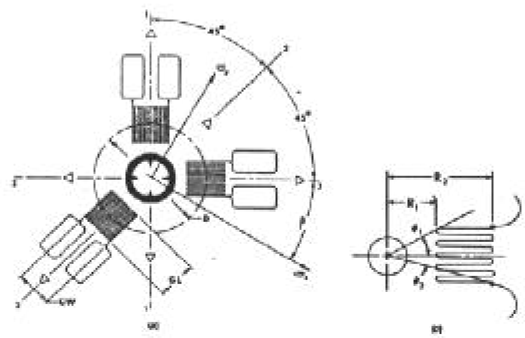


Figure 8: Strain gage rosette for hole drilling method (9)

The results of this first study show that HDPE membranes can have residual stresses as high as 10% of their yield stress. This method has been explained in detail by Lord et al. (9), along with the results on sheet and seam tests.

3.2.6 Different factors affecting the SC behavior of geomembranes

Several field investigations indicate that ultra-violet radiation is an important cause of stress cracking. While exposed to solar radiation, fine parallel cracks appear on the membrane's surface. UV provokes the loss of plasticizer, particularly in PVC material, stiffening the membrane, and enhancing its brittle behavior.

Temperature is also an important factor in the SC of geomembranes. Elevated temperatures promote the oxidation of stabilizer added to the HDPE to retard the liner's breakdown, also reducing its properties (7), while cold temperature causes brittle behavior, and shattering.

The temperature gradient plays an important role since a rapid change in temperature provokes thermal stresses in the material. During winter it is possible that the temperature can change from -20^{o}C at night to 80^{o}C in the day (8), which implies a gradient of 100^{o}C; in this case the amount of material compensation should be at least 2.5m.

Temperature influences the SC behavior by reducing the time of failure. Thus, by combining factors such as temperature, chemical agents, and stress it is possible to accelerate the failure of membranes in a very short time.

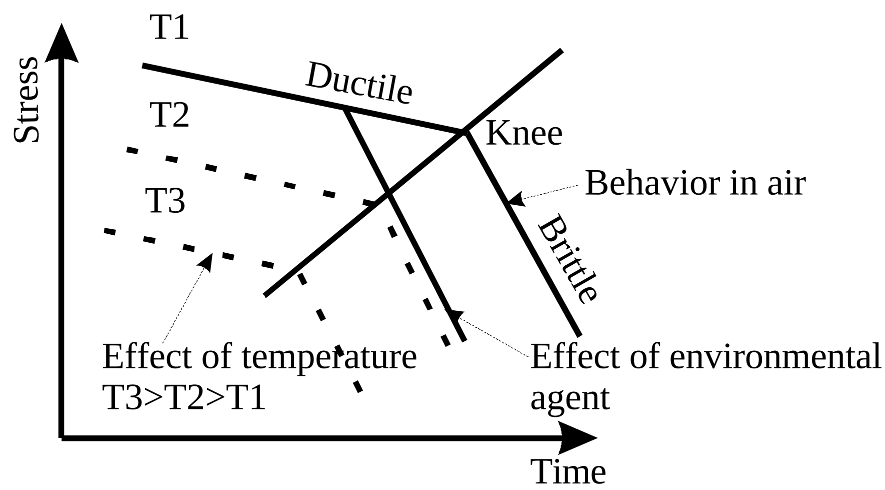


Figure 9: Effect of different factor on stress cracking behavior (5)

Fig. 9 shows the effects of different factors on stress cracking, the effect of temperature is obvious in this figure.
The most common chemical agent to accelerate SC of polyethylene is Igepal CO-630, which is a nonionic surfactant featuring a cloud point (temperature at which turbidity appears) of 52-56^{o}C. The assessment of polymer time to failure with accelerated testing using chemical agents, such as Igepal at a temperature different from the cloud point are not accurate, or provide suspect data since a change of agent concentration will affect the time to failure (5).

Cyclic stress (fatigue) induces faster SC than constant stress (6), which implies that during the design of a liner special care must be taken to account for cyclic loading. However, fatigue may be used for accelerated testing. Unfortunately, no standard test has been developed as yet.

3.2.7 Repair of crack

In stainless steel, repairing a crack by welding can aggravate the crack growth due to the chosen repair process. This may also happen in HDPE geomembranes due to repair of a notch by welding (10).

The repairing of a crack cannot be effected by simply placing a bead of extruded material over the crack zone to close the opening, since more heat in an already stressed region may cause other cracks or increase the rate of propagation of existing crack.

3.2.8 Study of Geogrids

Jailloux and Anderson (1) tested the SC behavior of HDPE geogrids. Two types of specimens were evaluated at different stress values. Specimen Type 1 had a notch in the rib, while the Type 2 specimen had a notch in the transition zone. The notch depth was 30% of the geogrid thickness. The specimens were immersed in an 1% Igepal solution at temperatures equal to 50^{o}C, 65^{o}C, and 80^{o}C. The results of this test showed that the stress rupture properties were affected by temperature, and that the rib part of the geogrid is much stronger than the transition zone. The rupture for Type 1 was by brittle cracking, while Type 2 showed no evidence of brittle cracking. Moreover, plastic deformations occurred primarily due to creep and to cold drawing of the material from the adjacent node material (1). The temperature decreased the time to failure. The extrapolation from the resulting curve must be interpreted with caution since the curve is composed of 2 lines forming a knee. However, if the extrapolation is done only with the first part, the result will be extremely incorrect.

3.2.9 Field investigation

Koerner et al. (3) conducted a study to determine the occurrence of HDPE geomembranes SC in the field. Fifteen sites were analyzed and the reasons of failure determined. It appears that the ruptures at the seams are mostly associated with two extrusion types of seam, which are flat and fillet. Some failures were reported to occur in membranes in time periods as short as 3 months. The locations of failures were always in the exposed runout length or along the side of a slope; for the cases where cracks were in the bottom, the cracks initiated during construction. The causes of the stresses were mostly thermal, and the causes of crack initiation poorly constructed seams.

3.2.10 Brittle cracking

One particular type of stress cracking in geomembrane is the one associated with shattering failure, occurring mainly in polyethylene materials during cold weather with temperatures ranging from 5^{o}C to –30^{o}C. Many failures of this type have been reported on side slopes of uncovered liners.

Brittle cracks may vary from simple cracks (a few centimeter long) to sunburst cracks. Sunburst cracks are multi-branched shattering patterns covering areas reaching up to 70 x 15 meters (11). For all the reported failures, cracks initiated at the seams or spot tack welds, which implies that the seaming technique is the main cause for this problem, even though a small single crack is necessary to generate the shattering crack.

Peggs (11) presented the results of tests conducted to understand the shattering cracking phenomenon. The study of fracture faces with a microscope showed that the faces are very smooth showing no plastic deformation, and featuring chevron patterns pointing to the propagation point. The propagation points were found to be at seams where geometrical notch stress concentration points were located. It was also found that many propagation points were located at the intersections of seams and points reseamed with a fillet bead.

Moreover, it is clear that excessive thermal energy input increases the possibility of brittle SC at seams; incorrect seams may reduce the SC resistance of geomembrane up to 50%.

The crack growth rates were evaluated and different values found for different materials, implying that the different polyethylenes do not have the same mechanical durability (11).

The thermal expansion factors were also assessed to understand the thermal SC caused by the cold weather. The curves are comprised of two parts: one below 50^{o}C with a coefficient approximately equal to 1.2 x 10^{-4} $^{o}C^{-1}$ and the other above 50^{o}C featuring a

coefficient of 7 x 10^{-4} $^{o}C^{-1}$. Uniaxial tensile testing showed that the yield stress increases from 20.7 Mpa, with an elongation of 12%, to 35 Mpa, at 25^{o}C, and an elongation of 6%, at temperature of –30^{o}C. The break point stress also increases from 29 Mpa (850% elongation) to 35.2 Mpa (422% elongation), indicating that during cold weather the geomembrane possesses better properties with respects to stress but will break at lower elongations. This study showed that a stress (50% or less of the yield strength) must exist in the material to initiate the SC phenomenon. During seaming procedures, special care must be taken to prevent notches in the seams, particularly damage by overheating.
A non-penetrating crack can be repaired without affecting the geomembrane, nevertheless while repairing wide shattering cracks, a compensation panel must be placed in the liner system to stabilize the effect of the temperature.

3.2.11 Review of the Stress Cracking Evaluation Test
The first test used the test standard ASTM D 1693 (12) “Bent Strip Test”. A surface notched (20% of the thickness) rectangular specimen is bent in a 180^{o} arc and placed within the flanges of a small metal channel. Ten specimens are usually tested simultaneously in a surfactant agent and at an elevated temperature. The times to failure are monitored.

Although this test was used for many years, it was not included in material specifications for HDPE geomembranes (13). Effectively, this test is not aggressive enough toward modern resins since polyethylene can relax the applied stress, canceling the desirable stressing effects. This implies that whatever stress is applied, the material will relax and the stress will drop to nearly zero. Moreover, it takes an extremely long time to perform, more than 1,500 hours.

ASTM D 5397 (14) “Notched Constant Tensile Load Test, NCTL” is a much more severe test since the specimens cannot relax while under constant load. A dumbbell shaped specimen is notched, placed in a surfactant agent at a specific temperature, and constant stress is applied by a dead weight. The applied stress varies from 20% to 65% of the yield stress. Ten different stress values must be applied to test one specific material; moreover, to ensure the quality of the measure, three specimens must be tested for one applied stress, which means that thirty specimens must be tested to evaluate one material. The time to rupture is monitored and used to generate an applied stress versus failure time curve. Each different stress provides one point, which means that the curve is drawn by joining the ten different points.

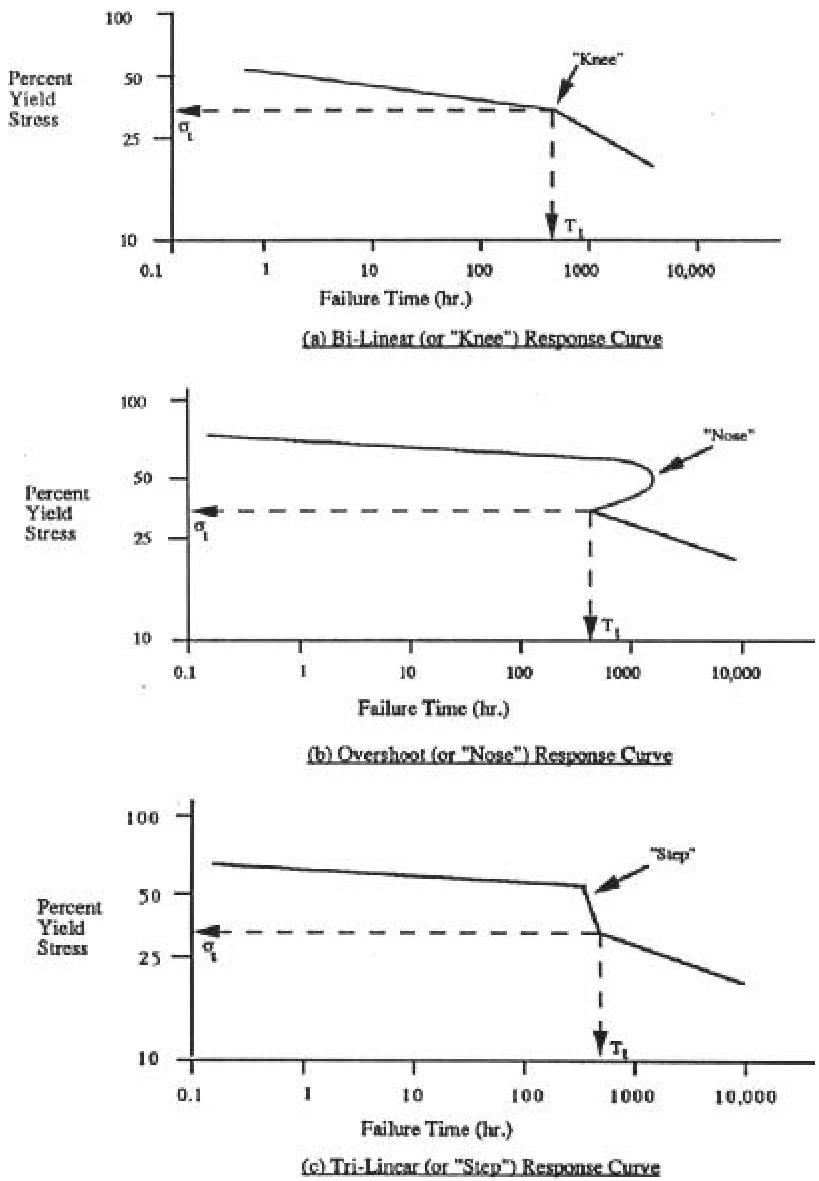


Figure 10: Behavior of HDPE Material in a NCTL Test (3)

Fig. 10 presents the different types of response curves for different HDPE materials. At least two distinct regions can be identified: for high stress level, the specimens respond in a ductile manner, while in the second region (lower stress level) they fail in a brittle manner. Depending upon the applied stress, a specimen can fail in a totally ductile or totally brittle manner. The transition time appears to be at 35% of the yield stress.

The problems associated with this test is that the time required sometimes over 1000 hours, for a sizable number of specimens. Moreover, if the statistical averages are not reasonable, some of the data points must be obtained by re-testing (3).

In order to modify the previous test, the "Single Point Notched Constant Load Test, SP-NCLT" (ASTM D 5397 Appendix) was developed. In this test only one notched specimen is tested at a constant stress equal to 30% of the yield stress (point slightly lower than the transition point). The minimum time a material must withstand is 200 hours. In order to obtain statistical correct values, five tests must be carried out. This test has proven to be the best tool (13). Since its results correlate with the field performance, it can be used with confidence.

However, some disadvantages have been encountered. This test cannot be performed on textured geomembranes since it is difficult to create an accurate notch on the rough surface of the material. Moreover, scattered results among different laboratories were found, increasing the difficulty to evaluate the SC of a geomembrane (13).

There are two reasons for the scattered results. Using an average 30% of the yield stress does not ensure accurate results since a yield stress for a specific material may vary from one roll to another, therefore the applied stress may range from 27.5 to 32.5 percent instead of the specific 30%. Another cause of scattered results comes from the notch; even if the razor blade is replaced every 20 notches, as specified in the ASTM standard, the size of the notch may vary from the first to the last notch. Nevertheless, a good method to prevent scattered results is to do five tests instead of one, and validate geomembranes for more than the 200 hours specified in the ASTM standard.

Some procedures have also been developed to test the SC behavior of seams. An adaptation of the SP-NCLT to seams, the "Seam Constant Tensile Load, SCLT", evaluates the quality of geomembrane seams. Therefore, comparisons between the seam test results and sheet test results can provide information on the effectiveness of the seaming technique. A notch is introduced in a seamed dumbbell specimen (see Fig. 11). The test conditions are similar to those for the SP-NCLT tests.

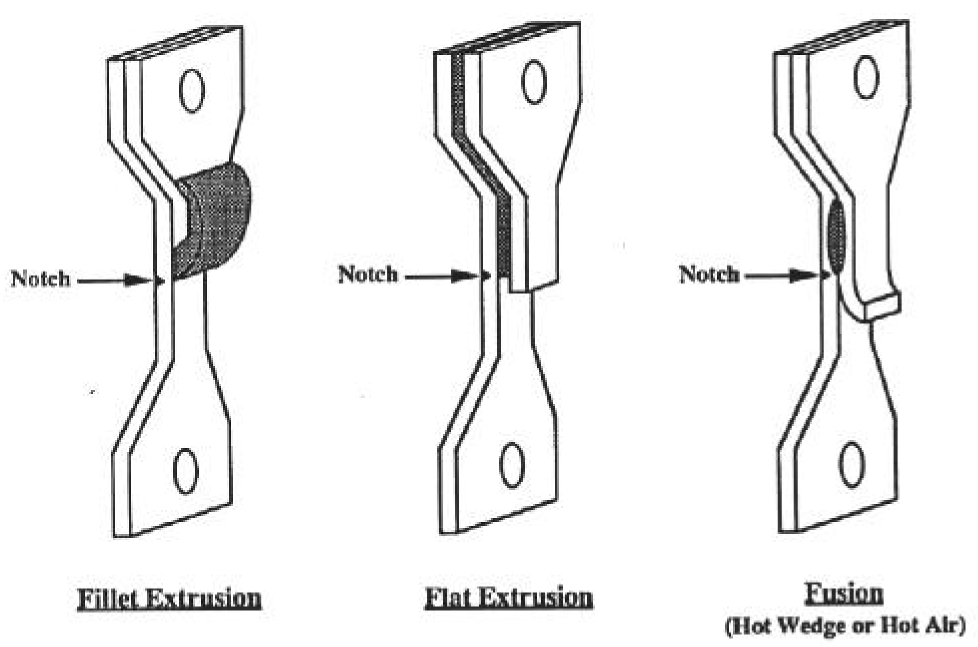


Figure 11: Seam test SCTL specimens (3)

3.2.12 How to prevent SC

It is of paramount importance to ensure that the membrane is installed with sufficient slackness and compensation for applications in cold weather. This creates an error margin, which guarantees non-failure in SC testing. HDPE compensation panels can be inserted allowing the elimination of the thermal stress. Uncovered geomembranes should feature a minimum slackness of 1% when exposed to UV; they must be covered by an insulating panel (10). Special care during seaming is required to minimize the risks of imperfections in the seams, which are stress concentration points that may lead to propagation. A properly selected resin and additive package together with proper manufacturing of the sheet, will ensure a stress crack resistant material (3).

3.2.13 Method of prediction

A method to predict the life of HDPE geomembranes based on SC has been developed by Kanninen (15), and is explained in the chapter devoted to life prediction.

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3.3 Puncture/Installation Damage

3.3.1 Introduction

Installation damage is caused during the construction and installation of the liner; and decreases the strength of the liner. Puncture of the geomembrane or the geotextile is the most common and the worst type of damage to the liner.

One effect of puncture is the alteration of the liner's durability and impermeability. This is of serious concern, as after landfilling it is impossible to determine the state of the membrane, i.e. the puncture phenomena cannot be assessed. The designer cannot use test data to predict the geomembrane behavior.

During their life (installation included), landfill liners are submitted to short term as well as long-term puncture forces. Short-term forces occur during the installation of the drainage gravel, while long-term forces are caused by overburden loads of the waste (pressures of the order of 10,000 to 20,000 lb/ft^3).

The puncture phenomenon can either be static or dynamic. Dynamic puncture is due to the fall of objects as stones, gravels or tools, and occurs mainly during installation. It is a function of the object weight and the fall height. It is a short-term effect. Static puncture is due to the contact of a stone or gravel with the geomembrane under static normal stress. It can either be a short-term (traffic) or long-term (fall of upper layer) phenomenon. Bursting, a sort of static puncture, occurs when static pressure pushes the geomembrane into a gap formed between two aggregates caused by local differential settlement.

Geotextiles are used with geomembranes because of their complementary properties. Geomembranes are impermeable and sensitive to puncture, while geotextiles are permeable and puncture resistant. Hence, to counter the problem of puncture sensitivity of geomembranes, it is common to install a geotextile layer over a geomembrane. Geotextiles possess different advantages when used with geomembranes: they provide a good puncture resistance layer as well as abrasion resistance, they also help welding by providing a clean surface (1).

3.3.2 Methods of prediction

The Solvay group developed a method (2) to ensuring no denting of the geomembrane, and, therefore, no change in durability, by determining the stress at failure and the admissible stress of the geomembrane.

The stress at failure is defined as the maximum static stress that can be applied without causing leakage. The geomembrane is tested with a hydraulic puncture pressure of 1,300 kPa, and the stress at failure is defined as follows:

$$\sigma_r = 1000 / (D_s \text{ x } D_c) \text{ x } [160\ T_g - 0.12 + (1000\ T_g - 0.3\ M^{1,8}] \ldots\ldots\ldots..[3.3.1]$$

where
σ_r: stress at failure (Pa)
D_s: maximum diameter of crushed gravel in supporting layer (m)
D_c: maximal diameter of crushed gravel in protective layer (m)
T_g: thickness of the geomembrane (m)
M: total surface mass of both geotextiles above and under the geomembrane (kg/m^2)
These variables are presented in Fig. 12.

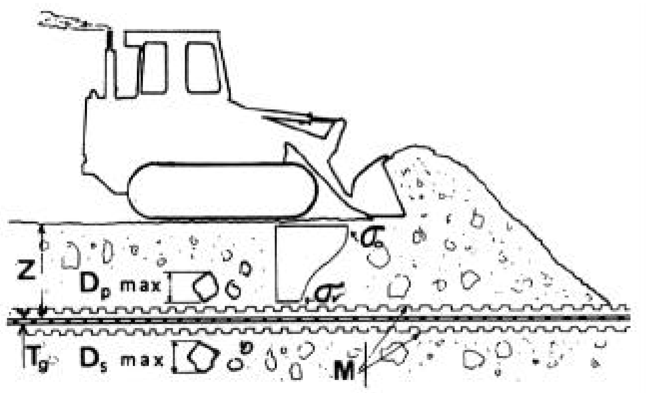


Figure 12: Mechanical puncture parameters (2)

From the stress at failure it is possible to determine the admissible stress, defined as the maximum stress for which no puncture marks will appear on the geomembrane. Using field experiments, the Solvay group determined that the admissible stress is approximately one-tenth the stress at failure. By using the Boussinesq model, the stress due to vehicular traffic at the geomembrane level can be determined with the plots in Fig.13.

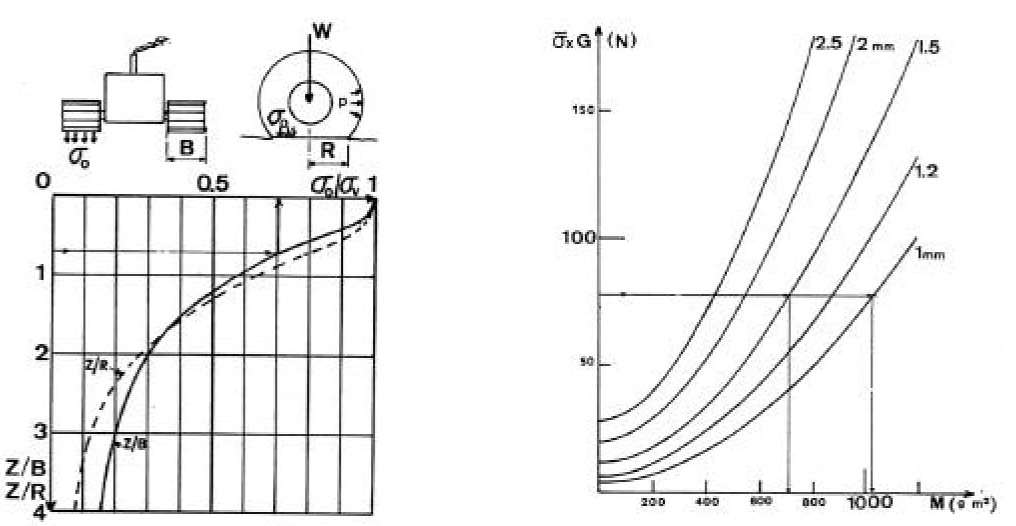
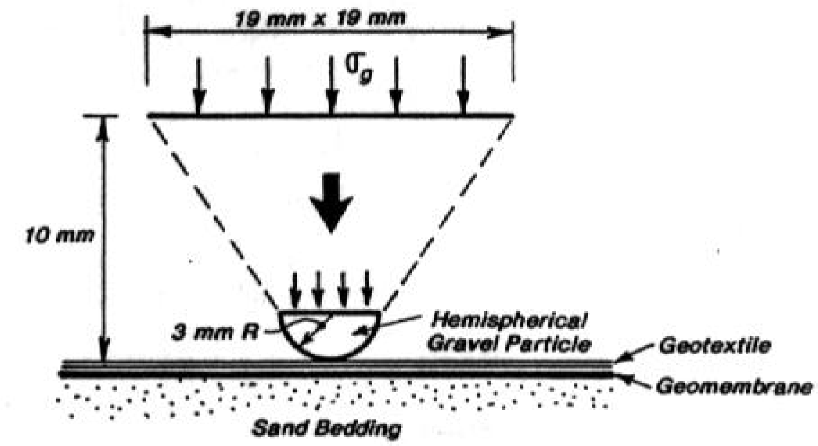


Figure 13: Graph providing the stress at the geomembrane level (left) and its thickness (right) (2)

Using this method it is possible to determine the state of the geomembrane and the thickness of the protecting liner. This method has been validated by many work site observations and can, therefore, be considered efficient.

Wong and Wijewickreme (3) developed a computer analysis method by using the FLAC (Fast Lagrangian Analysis of Continua) program to model the action of gravel on a geomembrane, Fig. 14. Several assumptions were made since the reality is extremely



complex.

Figure 14: Model of a gravel puncturing a geomembrane (3)

A hemispherical gravel particle was modeled, applying stress on the geomembrane, with the geomembrane placed over a sand bedding. A Mohr-Coulomb yield criterion was used to determine the "failure" of the geomembrane. An axisymmetric mesh was used as well as a postprocessor for determining the results. The results were close to the field data proving the efficiency of the program.

Giroud et al. (4) carried out a theoretical analysis of geomembrane puncture and established a relationship between the puncture by a probe, and by a uniform stone layer subjected to liquid pressure. The relationships between the geomembrane resistance to puncture by stone, under different conditions, was also established.

The first part of this study formulated an equation for theoretical puncture resistance of a geomembrane by a probe, based on the assumption that the contact area between the geomembrane and the object can be represented by a circle.
The equation was as follows:

$$F_p = \pi\, d_p\, \sigma_{peak}\, t_{GM}\, Z_{\varepsilon\ peak} \qquad [3.3.2]$$

where F_p is the puncture resistance, d_p is the diameter of the probe, t_{GM} is the thickness of the geomembrane, σ_{peak} is the geomembrane stress at peak, and $Z_{\varepsilon\ peak}$ is the peak value of Z.

This equation was validated by comparing the theoretical results (from Equ. 3) with the test results based on NSF specifications for puncture resistance, tensile stress, and strain at yield of HDPE geomembranes. However, this equation can only be used for material yielding or rupturing at strains not greater than 57 %, since Z_ε exists only in the range of 0 to 57 %. HDPE is one of the materials that allow prediction, since it yields at a strain of 10-15%.

In the second part of this study, the authors established a relationship between the puncture resistance of a geomembrane in a probe test and the resistance to puncture of the geomembrane (laid on a layer of stone) subjected to pressure applied by a liquid.

For the case of a stone, the equation becomes:

$$F_{ps} = \pi\, d_{cs}\, \sigma_{peak}\, t_{GM}\, Z_{\varepsilon\ peak} \qquad [3.3.3]$$

where F_{ps} is the force exerted by a stone on the geomembrane, and d_{cs} is the diameter of the equivalent circular contact area between the stone and the geomembrane.

If the geomembrane is free to elongate, the probe and stone will have the same values of σ_{peak} and ε_{peak} causing puncture failure. But when the geomembrane is in contact with a solid material as a soil, in contact to stones it is not free to elongate. To counter this problem, the pressure is applied by a liquid, which allows it to elongate.

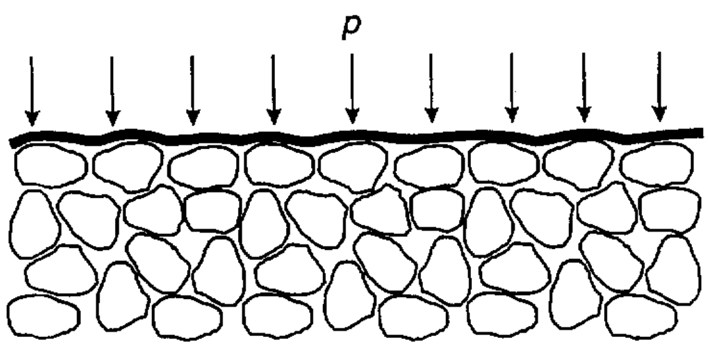


Figure 15: Configuration of a pressurized geomembrane placed on a uniform layer of stone (4)

The puncture force in this configuration is:

$$F_s = p\, A_{avg} - p\, \pi\, d^2_{cs}/4 \qquad [3.3.4]$$

with p the pressure applied by the liquid, and A_{avg} the average surface area of the geomembrane associated with the stone.

$A_{avg} = \lambda\, d_s$ in the general case, with λ ranging from 0.87 to 1.

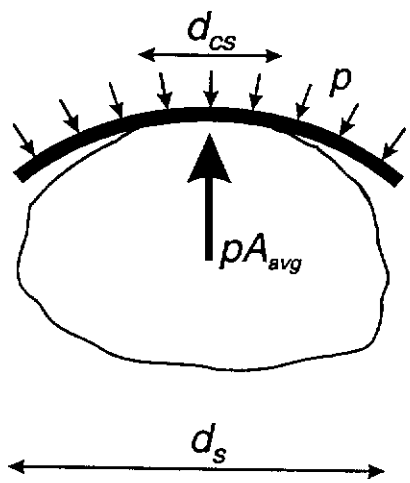


Figure 16: Stone contact on a geomembrane (4)

Since $d_s >> d_{cs}$ the equation becomes:

$$F_s = \lambda\, d_s^2\, p_p \qquad [3.3.5]$$

with p_p being the pressure of the liquid.

For the case of round stone, Fig. 16, the puncture resistance is increased since the contact pressure is decreased due to the increased surface contact. But it is possible that the geomembrane will fail by bursting between the stones instead of failing by puncture. The authors established relations for geomembrane resistance to puncture by stone under different conditions. The relation that can be used for the design of field applications has to be based on laboratory probe puncture tests. This study also proved that the geomembrane puncture phenomenon is a function of the diameter of the contact area between the geomembrane and the puncturing object, the membrane thickness, and the tensile properties of the material.

3.3.3 Laboratory tests

Motan et al. (5) assessed the damage caused by overburden pressure (10,000 to 20,000 lb/ft^3) on geomembranes. The first stage of the study was to expose the geomembrane (with or without geotextile) to gravel in a pressurized chamber, Fig. 17, pressures being set at 10,000, 15,000, and 17,000 lb/ft^3. The second stage was multi-axial testing (according to the test method GRI-GM4). The air pressure was gradually increased, with monitoring of the central deflection of the geomembrane (only the specimens that did not suffer puncture during the first step were tested in the multi-axial chamber).

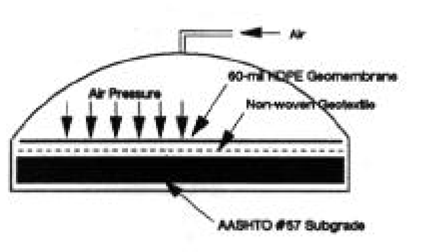


Figure 17: Setting of the pressure chamber used during the first part of this project (5)

Three configurations were studied to protect a smooth 60 mil HDPE geomembrane: a) a continuous-filament, polyester, non-woven, needle-punched geotextile, b) a continuous-filament, polypropylene, non-woven, needle-punched geotextile; and c) a staple, polypropylene, non-woven, needle-punched geotextile. The gravel (AASHTO #57) was chosen because of its angularity to induce damage.

To get important data, three different configurations were tested in the multi-axial test chamber: a) virgin specimens not exposed to pressure, b) specimens exposed to pressure but without geotextile protection, and c) specimens exposed to pressure with geotextile protection.

The results showed that for unprotected geomembranes, specimens failed during pressurization at 10,000 lb/ft^3. An interesting result is that when the geomembrane does not puncture during the first stage of the test (pressurization), it will yield the same results as a virgin geomembrane that is multi-axial tested. But it was not possible to classify the different geotextiles, since they showed the same protection properties. The breaking strains appear to decrease with the increase of pressure, and increase with the increase of the geotextile weight. Different failure modes occurred: loss of pressure, pinholes, large-scaled splits or tears.

Two test methods are commonly used to assess puncture properties: ASTM D5494 and GRI-GM3. Beside these methods, the Austrian standard ONORM S 2076 presents two interesting test methods to assess the long and short-term puncture effects on liners. The first test consists of a pressure plate to simulate the long-term effect, while a pyramid puncture test simulates the short-term effect. Werner and Puhringer (6) used these two test methods to assess needle-punched PP continuous filament non-woven and needle-punched HDPE staple fiber non-woven geotextiles.
The pressure plate apparatus is composed of a plate embedded with steel balls to simulate gravel as well as obtaining an even distribution of defects. A plate is set in contact with the protecting geotextile, which is on the top of the geomembrane. Below the geomembrane, a soft metal sheet is placed (see Fig. 18), which will be deformed by balls; then laser scanning is used to evaluate the deformations (see Fig. 19). Two different temperatures are used to simulate the temperature inside the landfill; also, two loads are used: 589 kN/m^3 and 1104 kN/m^3, which simulate waste heights of 50 and 90m respectively.

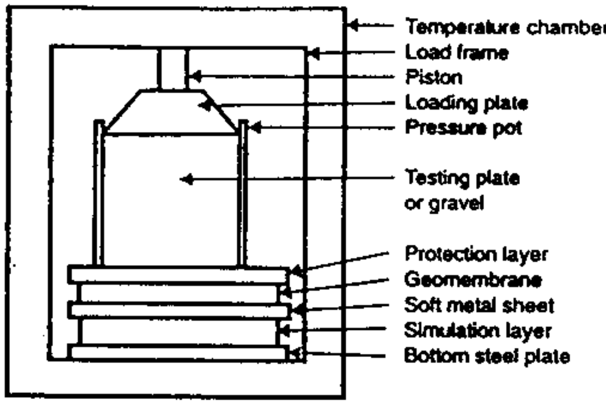


Figure 18: Pressure plate apparatus (6)

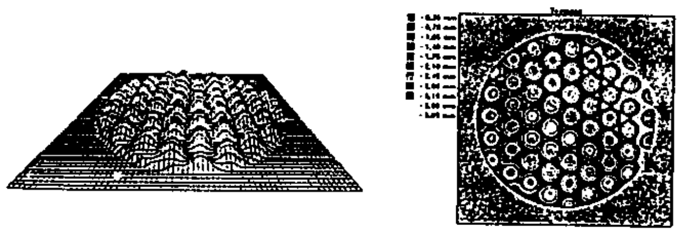


Figure 19: Profile of the sheet plate by laser scanning (6)

The pyramid test consists of a pyramid-ended rod pressing against the tested sample An electrical current between the rod and the base plate indicates when the perforation occurs (see Fig. 20).

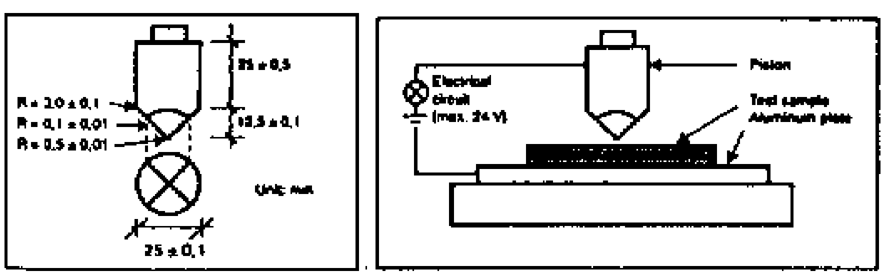


Figure 20: Pyramid piston apparatus (6)

The results of these tests showed that for both configurations the PP continuous filament non-woven geotextile has superior puncture resistance compared to the HDPE staple fiber non-woven geotextile.

It was also shown that the parameter-influencing punctures are as follows: overburden load, geomembrane type, geotextile type and mechanical properties, temperature, type and size of drainage gravel, and the evaluation method. The conventional scanning method used for the evaluation of the soft steel sheet deformation leads to misleading results since local deformation peaks are not detected. This problem emphasizes the efficiency of the laser scanning method.

Artieres and Delmas (7) presented different tests for the determination of liner puncture resistance on several liner materials. These tests were intended to characterize the behavior of the test specimens while exposed to dynamic and static puncture.

The puncture resistance system of a liner consists of a non-woven needle-punched geotextile protecting the geomembrane from the gravel of the drainage system. An efficient method to test material against puncture is to conduct larger scale performance tests that exactly reproduce the liner-layered structure. However, these tests are expensive, long, and cannot be repeated as wanted. To counter these problems, index tests have been developed which are inexpensive, rapid, and repeatable. Performance tests require the reproduction of the liner condition (same material, same scale), while for index tests some parameters are arbitrary fixed (usually the shape of the loading piston and the type of support) to facilitate laboratory tests and repeatability.

For dynamic testing, the stiffness of the matrix is an important parameter, which conditions the specimen deformations. A flexible geomembrane will have a lower puncture resistance than a stiffer product, even when a geomembrane protection layer is used. Protection against dynamic puncture has been shown to be very efficient, especially when using the combination of upper and lower geotextile protection layers (with good bearing capacity but small surface hardness). For static puncture, it has been shown that stiffer geomembranes possess better resistance than flexible ones. Moreover, the resistance is almost a linear function of the material thickness, indicating that thicker the geomembrane, more the resistance. Tests of geomembranes protected with geotextiles show that the resistance of the assembly is approximately equal to the sum of the puncture resistance of the different components calculated independently.

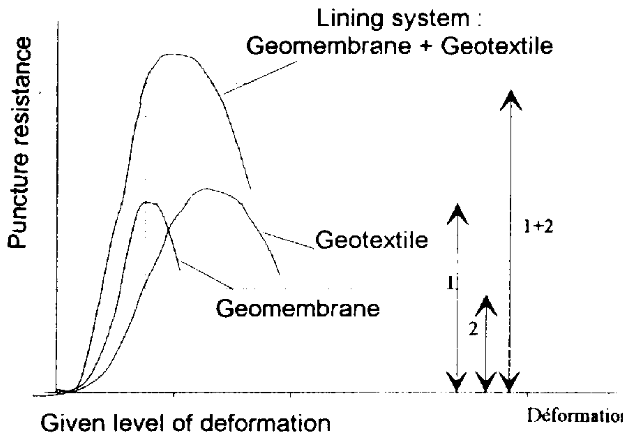


Figure 21: Puncture resistance summation of two different components of a liner (7)

Therefore, the designer can calculate the puncture resistance of a liner system by simply adding the puncture resistance of the different components (see Fig. 21). The index tests results are quite close to the field results, thus proving their effectiveness for preliminary design; the final design can be based on the analysis of the simulated real condition (7).

3.3.4 Full-scale tests

Wong and Wijewickreme (3) assessed the survivability of 40 mil HDPE and 30 mil VLDPE geomembranes submitted to puncture stress during installation with stress induced by vehicular traffic. This study modeled a cap preventing leakage. To protect the geomembrane a thick non-woven needle-punched geotextile blanket was placed above it.

A 300 mm thick layer of gravel was placed above the geotextile blanket that is placed above the geomembrane, which is installed above a bedding. For each geomembrane (30 mil VLDPE and 40 mil HDPE), three different bedding conditions were used: 1/3 of compacted sand and gravel, 1/3 with loose sand, and 1/3 with compacted sand. For each configuration, the blanket covered only 2/3 of the geomembrane surface to assess the geotextile efficiency. The loading consisted of a 51,477 lb truck which passed over the soil at 5 km/h. to simulate construction conditions; the truck stopped and started many times. After the application of stress, the geomembranes were exhumed and the density of the soil measured at different locations

The number of holes and deformations on the two geomembranes were determined, and then analyzed to evaluate the different parameters of the puncture effects. For sand bedding with a blanket, it was found that in both cases the geomembranes were capable of withstanding the load. It was also shown that disturbances in the sand due to footprints made during installation were not detrimental to the geomembrane survivability.

For the sand and gravel bedding with a blanket, the results showed the presence of many holes and pressure points, indicating that in these conditions this type of bedding is inappropriate and should not be used. Moreover, results from other studies confirmed the same observations. In this configuration the gravel acts as a hard point, while the sand acts as a matrix compressing the gravel against the geomembrane, thus deteriorating it.

At locations where the geotextile did not cover the geomembranes, results showed that more holes and pressure points appeared, proving the efficiency and the necessity of the geotextile. The two geomembranes yielded the same results when well protected, but when gravel was used in the bedding, HDPE showed its superiority. Therefore, the 40mil HDPE is more adequate than the 30 mils VLDPE geomembrane in such conditions. It was proved that the most critical mode of loading is the stop/start action of the truck, which increases puncture stress at the geomembrane level, even with a geotextile blanket that decreases the puncture stress.

Darilek et al. (8) paper presented the effects of the installation of protection soil over a geomembrane during the construction of a landfill. This study is very interesting since liners are sensitive to the emplacement of a protection soil cover or gravel damaging the liner. The liner was composed of a 900 mm layer of compacted clay, 2mm HDPE geomembrane, 300 mm of gravel, a 2 mm HDPE geomembrane, a layer of geogrid and geotextile, another 300 mm of gravel, another geotextile, and finally a 300 mm layer of sandy clay.

To assess the damage caused by the installation of the gravel, an electrical leak location survey (composed of 12 leak locations) was carried out before and after the emplacement of the gravel on each geomembrane. The role of the gravel is to serve as a drainage medium to evacuate hypothetical leaks above the primary liner, and for a leak location system above the secondary liner.
The electrical leak detection system is based on the insulation properties of the liner materials and the conductivity of the water, thus when a leak exists the electrical current goes through the liner carried by the water conductivity. This method is accurate to locate leaks even as small as pinholes.
After the geomembrane is installed, an electrical leak survey is used to assess the leak in the geomembrane before the gravel installation. Several leaks were detected, most of them in the extrusion welds, but the largest ones were due to punctures and slits in the liner panels. These leaks were related to improper seaming and installation of the geomembrane.
Before the installation of the gravel, a test was carried out to assess the deterioration caused by a bulldozer on the geomembrane. This test took place outside the landfill with a geomembrane layer, covered by a thin layer (2.5”) of gravel. A bulldozer drove over it and executed sharp pivot turns. No leaks were detected even though some marks appeared on the liner. However, it was indicated that a minimum layer of 12” of gravel should separate the geomembrane from the bulldozer.
Special care was used to place the gravel: a sacrificial sheet of liner was placed on the side slope to create an access ramp, a geofabric, plywood sheeting, and timber were also used to protect the geomembrane from installation damage. First, the slope was covered by gravel, and then two bulldozers scraped the gravel in the central section of the landfill by monitoring the minimum 12” of gravel layer. When the gravel was installed, one bulldozer

passed by the ramps, then the excessive amount of gravel in the ramp was taken out; finally, the last bulldozer was towed out on plywood in neutral gear.
After installation of the gravel nine leaks were detected electrically. These flaws, created during gravel installation, varied from pinhole size to 64 mm gage. Moreover, it was noticed that a concentration of these leaks happened to be near the emplacement of the temporary ramp. No leaks were detected on the primary liner; this is due to the utilization of geogrid and geofabric to protect the geomembrane, thus preventing damage. The study proved the efficiency and necessity of a protective layer, especially when heavy bulldozers are used to set the gravel. The efficiency of the electrical leak detection system was also proved. Finally, the quality and conscientiousness of the installation team was shown to be an important factor in the elimination of installation damage.

Reddy et al. (9) used various field testing procedures to evaluate the efficiency of different protective cover soils. Two kinds of gravel were used (fine and medium), with the same geomembrane (a 60 mil HDPE). The geotextile was a non-woven needle-punched polypropylene; two bulldozers (one light CAT D4 and one large CAT D7) were placed on the gravel. Before installation the geomembrane was inspected to detect hypothetical flaws. Then the entire liner was constructed in accordance with the real configurations. The construction procedure was identical to the real one (especially for the bulldozer work).

First, the different soils were tested before and after the construction of the liner, it was found that there were no significant differences between the “before” and “after” indicating that the properties of the soil were not modified by the liner construction.
Then, to assess the effect of the construction on the geomembrane, different tests were performed on the geomembrane before and after construction. The water vapor transmission test (ASTM E 96) was used for permeability evaluation of the geomembranes. The larger the transmission values, the more the damage. The results showed no significant change between the virgin and the exhumed geomembranes for the different configurations, indicating that the geomembrane is marginally affected by the construction of the liner for the range of studied configurations.

Multiaxial tension tests (ASTM D 5617) were also carried out. It was shown that the average geomembrane tensile stresses from field specimens were approximately equal to the values for a virgin geomembrane.
Exhumed Geomembranes used without geotextiles showed slightly higher tensile stresses than the virgin geomembrane. The geomembrane with the geotextile showed a slightly lower tensile stress than the virgin geomembrane. However, the results of elongation at failure showed significant differences from one protection configuration to another. The elongation at failure decreased with increase of the soil particle size and use of a heavy bulldozer, but in the case of a protected geomembrane, the specimen elongation, at burst, increased significantly to a value larger than that for a virgin geomembrane, thus proving the efficiency of the protecting geotextile.

The last series of tests consisted of wide strip tensile testing (ASTM D 4885). It was shown that the geomembrane's yield stress under the different configurations is almost equal to that of the virgin specimen. Moreover, the specimen yield stress and strain were not affected by the configuration.
However, all the geomembranes failed at a lower value than the virgin geomembrane, with smaller difference for the protected geomembrane. It was also noticed that all unprotected geomembranes suffered scratches and dents, but no tears or holes were found. Finally, it was concluded that the use of a geotextile greatly increases the protection of the geomembrane.

Koerner et al. (10) assessed the installation damage of different geosynthetics products under two different backfills. The first backfill was made of angular, poorly graded gravel, while the second was composed of poorly graded sand. Six different geotextiles and one geogrid comprised the materials tested. Their properties were determined before and after installation. For each of the two sites, the specimens were placed and installed as part of the regular construction. After installation, the specimens were exhumed and tested. The results showed that the geosynthetics placed over the angular backfill suffered severe damage while those placed over the sand were not so affected.

The geogrid in the first case was less damaged than the other geosynthetics, while in the second case no visual damage was found on the geogrid. The heaviest geotextiles were the least affected in the first case, in the second case no holes were found on the geotextiles.

These results prove the influence of the backfill effects on the installation survivability of the geosynthetic products. The authors also defined a factor-of-safety expressed as the inverse of the percent strength remaining in the wide-width test (ASTM D 4595). These factors ranged from 1.4 for the geogrid to 4.3 for the thinnest geotextile.

Geotextiles can suffer damage during the different stages of their lives, but it is during the compaction that they are exposed to the maximum damage.

Billing et al. (11) assessed the installation damage of different materials (polypropylene P1, polypropylene P2, polyester, polyester strip, and polyethylene grid) for three different backfills (a well-graded crushed limestone, a uniformly graded quarzitic sand, and a silty sandy clay). The damage was caused by compaction of aggregate layers over the geosynthetics. Then, visual inspection and mechanical tests provided information on the behavior of the different materials versus the backfill type. The visual inspection indicated the damage caused by the aggregate. The rib is the most sensitive part of the geogrid, also different types of damage were seen on the geotextiles. The mechanical tests showed reduction in tensile strength for different materials, ranging from 7% for the polypropylene P1 to 36% for the polypropylene P2. Creep tests showed no change in the creep rate, even though the damage caused a reduction in the initial strain. This study agreed with expected behavior, and reinforced the findings of other studies, proving that the more angular the backfill, the more the damage.

3.3.5 Parameters influencing puncture resistance and installation damages

The different parameters that affect the puncture resistance of landfill liners are as follows:

- diameter of the contact area between the geomembrane and the puncturing object
- thickness and tensile properties of the geomembrane
- angularity and size of backfill particle
- weight and type of construction and compaction equipment
- type of material comprising the liner (weight, thickness and mechanical properties)
- overburden weight of waste
- quality and conscientiousness of the workers

3.3.6 Design and construction of the protecting layer

To protect the geomembrane liner, the protective liner should meet the following specifications:

- prevent the geomembrane damaging due to drainage installation and waste placement
- prevent the geomembrane from tearing, bursting, and puncture impact
- serve as a drainage system for the landfill leachate
- withstand landfill construction (i.e. waste placement, closure) without deformation.

In the United States, several problems exist concerning the protecting layer, as mentioned by Reddy et al. (9) and explained below:

- the type of soil that can be used is not explicitly defined, hence local material tends to be used, even if the properties do not match the specifications
- no specific rationale has been defined to determine the effective thickness of the protective liner
- no construction procedures exist

Ruetten et al. (12) presented a method for the designing of liner protective soil cover by using geotextile and soil layers.

A step by step explanation of the design is provided below:

- Identification of foundation conditions and physical properties of the geomembrane/geotextile, which comprise the liner.
- Determination of the availability of the material in a local region; the cost is an important factor during this phase. The drainage material may consist of either a single material, or composition of several materials or a geotextile layer.
- Determination of the material physical properties (grain size distribution, permeability, soundness, and shear strength), as well as chemical compatibility to the leachate.
- Determination of the possibility of waste migration to the granular material voids. The nature of the waste must be estimated.
- Analysis of constructibility and puncture resistance. A protection layer should be placed over the geomembrane to limit point pressure, support construction equipment, and limit rutting. To ensure and verify the proper design, a field trial is advised. During this trial, pressure is applied by the action of a bulldozer, then tests such as multi-axial burst, help to determine the geomembrane survivability. Based on the results of these tests, material must either be discarded or protected by a protective layer.
- Determination of the side slope stability of the protective cover.

The different materials that can be used in protective covers are as follows: geotextile, gravel, composite layer of different gravel, sand-filled geotextile, gravel-filled geotextile, geosynthetic clay liner, and concrete-filled geotextile.

The sequential steps for the installation of a protecting cover are listed here for the case of only one impermeable geomembrane:

- geomembrane liner is placed over compacted clay
- geotextile is placed over the geomembrane
- protecting cover soil is dumped on the geotextile; bulldozers spread the soil over the entire surface for a specific thickness.

The placement of the geomembrane liner should be effected between 40^{o}F to 104^{o}F. It should not be placed during precipitation, excessive moisture, or excessive wind.

The placement of the geomembrane should be done as follow (13):

- each panel should be rolled out and installed in such a way that all the seams run down the slope on the perimeter berms (perpendicular to top of slope)
- the geomembrane rolls should be placed using the correct spreader and rolling bars with cloth slings
- each panel should be inspected for damage or defect before seaming, defected panels should be automatically replaced
- the geomembrane sheet must not be dragged over the rough soil sub-bases
- the geomembrane should be anchored according to the manufacturer's recommendations
- workers should not smoke, wear damaging shoes, or act in a manner that can damage the material
- edge of the geomembrane should be loaded to prevent uplift due to wind
- no debris, tools, or unexpected objects should be kept on the geomembrane, the geomembrane should be neat in appearance
- vehicular traffic should not be permitted across the liner
- a scrap geomembrane sheet should be placed under each equipment necessary for the liner construction to prevent damaging the liner
- equipment should not remain on the liner overnight

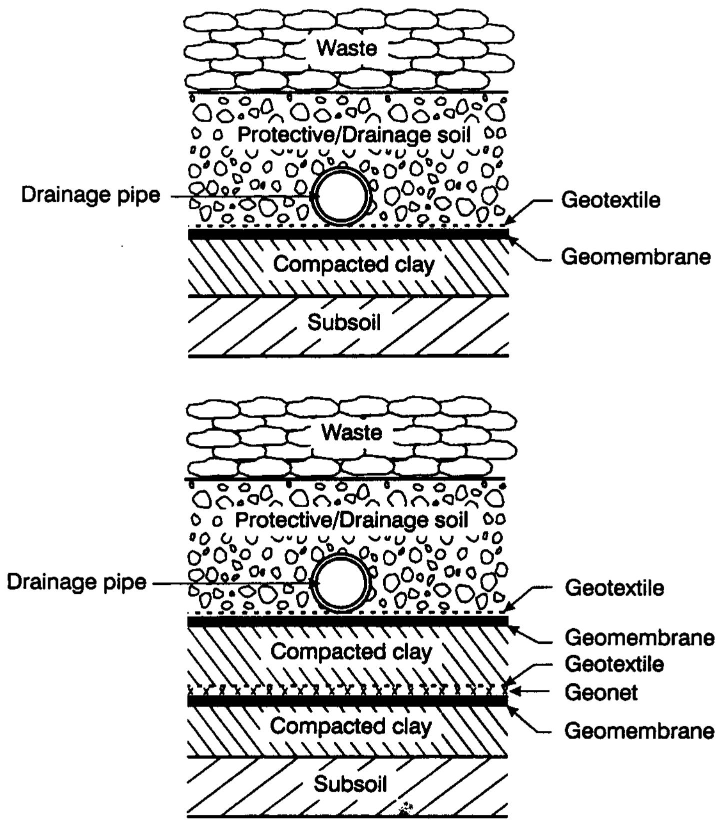


Figure 22: Cross section of single composite and double composite liners (9)

Fig. 22 presents the cross sections of typical single and double composite liners.
During these steps, special care must be taken not to damage the geomembrane, especially due to the heavy equipment used to place the protecting cover soil. To minimize risks of damage, machines must not be driven directly over the geotextile, and a minimum thickness of the soil must always be maintained between the geotextile and the wheels.

Large aggregates are used as backfill material (14) to prevent clogging of the drainage system, which occurs when fine aggregates are used. However, the large aggregates increase damage to the geotextile and geomembrane used in the liner system.

3.3.7 Values of tests results

In his literature review, Allen (15) listed the survivability levels of different liner conditions (see Tables 10 and 13), he also gathered results from previous studies concerning installation damage on material properties (see Table 12) and indicated factors of safety (see Table 11).

Table 10: Survivability Levels for Slope and Wall Application (15)

Type of Compaction equipment	Backfill Characteristics	Initial Lift thickness (cm)		
		< 15	15 to 30	> 30
Tracked equipment	Fine to coarse, sub-rounded silty sand	Low	Low	Low
	Well-graded sub-rounded to sub-angular sandy gravel (75 mm minus)	Moderate	Low	Low
	Poorly graded angular gravel (75 mm minus)	Very High	High	Moderate
Full size steel roller or rubber tired equipment	Fine to coarse, sub-rounded silty sand	Moderate	Low	Low
	Well-graded sub-rounded to sub-angular sandy gravel (75 mm minus)	High	Moderate	Low
	Poorly graded angular gravel (75 mm minus)	Not Recommended	Very High	High

Table 11: Partial Factors of Safety to Account for Installation Damage (15)

Geosynthetic Polymer	Geosynthetic Type	Geosynthetic weight (g/m^2)	Range of Safety Factor	
			High Survivability	Low Survivability
PP and HDPE	Nonwoven	< 270 > 270	2.0 1.8	1.15 1.05
	Woven	< 270 > 270	2.5 1.4	1.2 1.1
	Grid	All weights	1.4	1.0
	Nonwoven	< 270 >270	3.2 1.8	1.25 1.1
	Woven	< 270 > 270	? 2.2	? 1.4
	Grid	All weights	?	?

Table 12: Effect of Installation Damage on Strength, Strain, and Modulus (15)

Study	Geosynthetic Type	Undamaged strength (Kn/m)	After Installation		
			Strength retained	Failure strain retained	5 % Secant modulus Retained
Allen (18)	PE geogrid PE geogrid PP slit film woven PP stitch/bond woven PP stitch bond/woven PETP multifil. woven	76.4 94.2 31.0 62.0 92.3 186.3	73 % 68 % 60 % 77 % 88 % 60 %	70 % 63 % 64 % 83 % 75 % 61 %	95 % 102 % 97 % 101 % 122 % 115 %
Watts and Brady (19)	PP woven PP woven PETP woven PE geogrid	190.0 46.1 187.9 53.9	64 % 46 % 35 % 87 %	67 % 55 % 50 % 75 %	No change
Troost and Ploeg (20)	PETP multifil. Woven PETP multifil. Woven PETP multifil. Woven coated PETP geogrid	150.0 400.0 600.0 55.0	46 % 65 % 75 % 82 %	Not reported	85 % 90 % 94 % 103 %
Viezee et al. (21)	PETP multi. yarn	77.8	81 %	77 %	100 %
Elias (22)	PETP nonwoven needle PETP nonwoven needle PETP nonwoven needle	48 17.7 9.8	54 % 21 % 25 %	Not reported	67 % 33 % 33 %

	PP slit film woven PP woven monofil.	33.6 48.5	20 % 34 %		37 % 61 %
Leclerq et al. (1990)	PETP nonwoven needle	13.1	77 %	71 %	Not reported
	PETP nonwoven needle	41.9	92 %	75 %	
	PETP nonwoven needle w/PETP grid	28.4	80 %	72 %	
	PETP nonwoven bonded	5.3	95 %	84 %	
	PETP nonwoven bonded	12.4	92 %	85 %	
	PETP nonwoven bonded	17.7	88 %	87 %	
	PETP multifil. Woven	115.2	70 %	82 %	
	PETP multifil. Woven	158.7	65 %	83 %	
	PP slit film woven	21.4	87 %	101 %	
	PP slit film woven	37.8	88 %	81 %	
	PP slit film woven	40.8	85 %	90 %	
	PP slit film woven	96.3	91 %	99 %	
	PP monfil. woven	55.0	78 %	78 %	

Table 13: Survivability Level for Separation and Embankment Application (15)

Subgrade preparation conditions:	Low ground-pressure equipment (< 27 kPa), 15-30 cm initial lift	Medium ground-pressure equipment (>27 kPa, <55kPa), 15-30 cm initial lift	High ground-pressure equipment (> 55 kPa), 15-30 cm initial lift
Subgrade is smooth and level	Low	Moderate	High
Subgrade has been cleared of large obstacles	Moderate	High	Very High
Minimal site preparation is provided	High	Very High	Not Recommended
Type of cover Material		Medium ground pressure equipment (> 27 kPa, < 55 kPa), 30 cm initial lift	High ground pressure equipment (> 55 kPa), 30 cm initial lift
Fine sand to 2” minus gravel, rounded to subangular	N/A	Low	Moderate
Coarse angular aggregate with diameter up to one-half lift thickness, may be angular	N/A	Moderate	High
Some to most aggregate with diameter greater than one-half lift thickness, angular and sharp-edged, few fines	N/A	High	Very High

3.3.8 Conclusions

1) Through these studies it clearly appears that the use of a protecting layer (a single geotextile or a heterogeneous layer composed of layers of different materials), will significantly decrease the damage to the geomembrane during the construction of the liner, as well as during its service life.

2) Stiffer geomembranes possess better puncture resistance than flexible ones.

3) To obtain an approximate estimate of a liner system made up of liners of different materials, the puncture resistance of the different components should be added.

4) Most damage occurs during the compaction of the gravel, especially during the stop-and-start process of the heavy equipment.

5) The creep properties of geomembranes and geotextiles are not affected by installation damage.

6) The angularity and size of the backfill is of paramount importance for the puncture resistance of the layer, the more angular the backfill, the more the damage. However, if using round stone, the designer should be aware of the bursting possibility.

7) Thick and heavyweight geotextiles will provide a lot more protection than thin lightweight geotextiles.

8) The scanning method used by Werner and Puhringer (6), as well as the electrical leak detection system used by Darilek et al. (8) are efficient and accurate.

9) The different failure modes associated with puncture and installation damages are marks, pinholes, large-scale splits, and tears.

10) Guglielmetti et al. (16) evaluated the installation and construction survivability of geomembranes used for landfill caps, and showed that truck loading caused more damage than low-ground pressure bulldozers.

11) The damage induced by construction affects the breaking strength properties, but not the yield properties (17), as yield properties are mostly functions of the resin densities, while the breaking strength properties are mostly functions of the flaws present in the materials.

3.3.9 References

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3.4 Seams

The purpose of seaming is to join the different geomembranes forming the liner to prevent leaks between sheets. Seaming consists of joining geomembrane sheets by reorganizing the surface of the polymer structure in a specific manner. The sheets are bonded either by chemical or thermal process; for certain processes such as extrusion seaming, an addition material is required (1).
Theoretically, the properties of the sheets and the seams should be identical with no loss of tensile strength. However, differences between the seam and the sheet properties have been noticed for almost every type of seam. These differences are due to stress concentrations resulting from seam geometry. The seam characteristics are functions of the seaming technique, seam geometry, geomembrane resin and residual stress in the seams.

3.4.1 Different seaming technologies

Currently, seven different techniques are used (1), they are categorized either as thermal or chemical processes. The seven techniques, presented in Fig. 23, are thermal extrusion: fillet and flat, thermal fusion: hot wedge and hot air, chemically fused: chemical and bodied chemical, and chemical adhesive.

- *Thermal extrusion (welding):*

This technique is only applicable to polyethylene material. A ribbon of molten polymer is extruded over the edge of, or in between, the two surfaces to bond. The hot extrudate brings the two sheets to the melting temperature, then the sheets join together while cooling. When the extrudate is placed over the leading edge of the seam, the technique is called extrusion fillet, and when the extrudate is placed between the two sheets, it is called extrusion flat. Extrusion fillet is the only technique allowing the seaming of polyethylene patches and seaming in poorly accessible areas such as sump bottoms and around pipes. Temperature is a very important factor in order to obtain a proper seam. Effectively, too much melting weakens the geomembranes, while too little results in an inadequate flow across the seam interface, and in poor seam strength. Pressure, seaming rate, and geomembrane resin are also very important factors.

To prepare sheets for extrusion fillet seams, it is necessary to grind the upper sheet to a 45^{o} bevel, when the sheet is greater than 60 mil thick. While grinding, special care must be taken to insure that grinding is done in the direction perpendicular to the seam thus reducing the possibility of initiating cracks. Excessive grinding has been recognized as an important cause of geometry default causing stress cracking. The purpose of grinding is to remove the oxide layer and waxes from the surfaces and to roughen the sheets. The grinding depth should range from no less than 5% to no more than 10% of the sheet thickness. To avoid the recurrence of surface oxide, the grinding should be done less than 10 minutes before the seaming. After seaming, it is important to verify that no puckering (sign of excessive temperature or too slow rate of seaming) appears, and that the grinding marks do not exceed 0.25” beyond the extrudate.

- *Thermal fusion:*

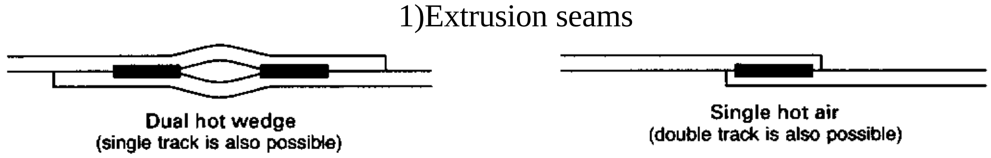
The techniques using thermal fusion involve the melting of a portion of the mating surfaces. The hot wedge or hot shoe method uses an electrical heater resistance, featuring a wedge shape, which moves between the sheets, thus seaming the two geomembranes. As the surfaces melt, shear flow occurs across the upper and lower surfaces of the wedge. A roller to form the final seam applies the pressure needed to create a strong bond. This technique allows the creation of either single uniform width or dual seams. A dual seam is constituted of two parallel seams with a uniform unbonded space between them. This space can be extremely useful to assess the seam quality; leaks can be detected by pressing this space. No grinding or brushing must be used, the sheets must not be tacked since the wedge moves between them.

The hot air method uses a heater, a blower, and a temperature controller, to blow hot air between the two sheets to melt the opposing surfaces. After the hot air is introduced, pressure bonds the surface. This technique allows the creation of single or dual seams. This method is used for a pre-seaming process, tacking the surfaces before the final seaming. For the extrusion welding, temperature, pressure, seaming rate, and material are of primary importance to create a proper fusion seam.

- *Chemical fusion:*

Chemical fusion is induced by applying a liquid chemical agent between the sheets. Then after a few seconds, pressure is applied bonding the two surfaces. Too much chemical will weaken the sheets, while too little will yield a poor seam. Bodied chemical fusion seams are identical to the chemical fusion seams with the exception that a small percentage, ranging from 1 to 100 %, of the geomembrane resin is dissolved and added to the chemical agent, thus increasing the working time as well as causing an increase of viscosity for slope work, preventing runoff of the chemical. The chemical adhesive process consists of applying a dissolved bonding agent, different from the geomembrane material, to both the mating surfaces; then a roller applies pressure to bond the assembly. Two distinct approaches exist: the solvent adhesive and the contact adhesive methods.

1)Extrusion seams



2) Fusion seams

3) Chemical solvent seams

4) Chemical adhesive seams

Figure 23: Different techniques of seaming (16)

For each of the previous techniques, a minimum and maximum overlap of the sheet is required, which may vary from 3 to 6 inches after seaming. Prior to seaming, the overlapped surfaces must be clean (no scratches or flaws) and free of moisture. No seams must be made during rainy, snowy, frozen soil or hot temperature conditions. The sheet temperature during seaming must be above 40^{o}F and below 104^{o}F.
Table 14 presents the compatibility between seaming techniques and resins. It can be seen that certain techniques cannot be used with any type of resins, i.e. HDPE cannot be seamed using solvent fusion or adhesive techniques.

Table 14: Compatibility Between Seam Techniques and Resins (17)

Type of Seaming Method	Type of Geomembrane							
	HDPE	VLDPE	PVC	CSPE-R	EIA-R	LLDPE	PP	FCEA
Extrusion (fillet and flat)	A	A	N/A	N/A	N/A	A	A	N/A
Thermal fusion (hot wedge and hot air)	A	A	A	A	A	A	A	A
Solvent fusion (solvent and bodied solvent)	N/A	N/A	A	A	A	N/A	N/A	A
Adhesive (solvent and contact)	N/A	N/A	A	A	A	N/A	N/A	A

A=Available, N/A=Non-available

The hot wedge fusion seam method features more advantages since, unlike other techniques, it can be used to seam all thermoplastic geomembranes. Moreover the wedge temperature, nip roller pressure, and the seam's speed are adjustable, implying that depending on the seaming condition (weather, sheet temperature, time of the day, etc.) the operator has the possibility to adjust these features to obtain and maintain proper and identical seams. The different techniques have been described by Landreth (1).

The surfaces to be bonded must be clean; grinding can be used to clean-up the sheet, but special care must be taken since excessive grinding will create grind marks reducing the sheet thickness and possibly initiating cracks. In order to ease the fabrication of seams, surface preheating is recommended especially in cold weather. Hot air can be used to preheat the sheet to a temperature ranging from 90 to 110^{o} C.

3.4.2 Tests of double track fusion seams and effect of wedge geometry and roller pressure

Thomas et al. (2) evaluated ten double track fusion seams made with two different types of wedges and drive wheels, and five different resins. Peel separation and strength, shear elongation at break and strength, optical microscopy, impact resistance, and stress cracking resistance were the tests performed. Peel and shear testing provided pass or fail information, while impact and stress cracking tests enabled the classification of geomembranes according to their seams quality.

Impact resistance testing was done by following the draft Canadian standard method CAN/CGSB 148.1-113 (modification of ASTM D 1709). A specific weight is dropped from a known height causing fracture of the specimen. The energy to cause rupture is determined by the height and weight, before testing the specimen, which has been frozen for 21 hours at -40^{o}F. The stress cracking test is a regular NCTL test (see stress cracking chapter). Different geometries had different impact properties implying that the resin and welding processes affect the seam response at cold temperature.

No seams showed failure from the peel and shear tests. It appears, from the microscopic photographs, that the shapes of the welding zone are controlled by the shapes of the wedge and drive wheels, and are different for each type.

The stress cracking test showed that breaks were initiated at some types of crack initiation sites (corroborating the results of the chapter concerning stress cracking). The sites are at the edge of the seam near the root of the squeeze-out bead. The results of the stress-cracking tests were extremely scattered, distinguishing the good from poor stress cracking-resistant geomembranes; moreover, they showed the effects of resin and wedge geometry. First, for the same wedge geometry, the results varied from 3 to 283, proving the importance of the use of a proper resin; then for the same resin, values varied from 283 to more than 3300, identifying the importance of the wedge geometry. All the seams used with the second wedge were at least three times more resistant.

It was concluded from the different tests that the peel and shear tests are not suitable for seam evaluation, since the stress-cracking phenomenon is not considered. Wedge and roller geometries affect the quality of fusion seams. Impact and stress cracking tests are very useful to assess seam behavior.

3.4.3 Peel and shear tests

A liner is composed of different sheets (bonded together by seams) forming an entire system. In order to obtain a proper system (no leaks or failures), every single seam should transfer tensile forces without shearing and peeling. The peeling phenomenon has often been described as non-existent in liners, however, Peggs (3) proved that it may appear at edges of wrinkles, which often align along the more rigid seams due to different causes. Peeling occurs when a geomembrane is dragged on a soil subgrade, or when soil is spread against the seam overlap (3). It also occurs when shear stresses occur as the seam rotates to align the two geomembranes (4).

The main seam tests are for peel, Fig. 24b, and shear strengths, Fig. 24a, however the elongations should also be evaluated. The reason of this is that the failure may occur outside the seam (FTB) due to improper welding either by excessive grinding or by overheating (3).

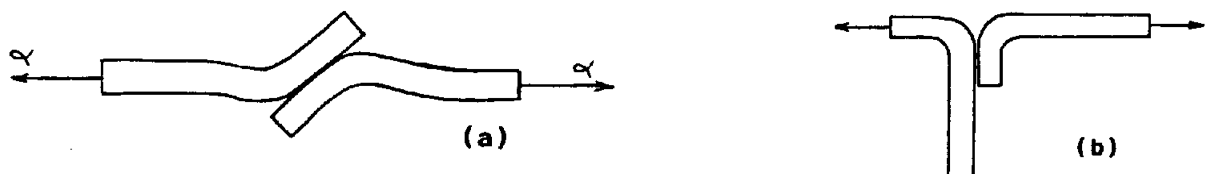


Figure 24: Shear (a) and peel (b) tests (4)

Overheating increases the probability of stress cracking adjacent to the membrane due to consumption of the protective antioxidant, and increase of oxidation and crystallinity. Overheating may cause stress concentration notch geometries.

While opening in a peel mode, crazes may occur in an incorrectly bonded geomembrane reducing the stress cracking resistance (up to 70%). In the shear strength test, failure ruptures will always occur in the adjacent sheet and not in the seam (3), since the seam bond is a lot stronger than the sheet (1000 ppi versus 2000 ppi). Therefore, it is not possible to get information on the seam strength.

If the seam is over-ground, it will fail with a low strength value and a low elongation value, while if overheated, failure will occur with a high strength and low elongation. Thus, only a low elongation identifies both conditions (3). This implies that only the shear elongation test should be used, or at least taken into consideration. Shear elongation should exceed 100% of the distance between the edge of the seam and the nearer grip.

The problem during the shear strength test also occurs in the peel strength; the rupture will always occur in the sheet since the bond is stronger, therefore, no information on the seam is obtained. The peel separation test is the most effective since it provides information on the minimum required criterion for bond strength (no separation), and the effect of welding on the adjacent geomembrane (no loss of ductility) (3). Therefore, while evaluating a geomembrane, only the peel test is sufficient to provide the required information.

For geomembranes made of materials different from HDPE, the peel resistance is about 1 to 3 kN/m, while for tensile strength the resistance is about 4 to 70 kN/m, and shear resistance is about 80% to 90% of the tensile value. This implies that the seam is the weakest point for the geomembrane. However, for HDPE geomembranes, resistance to peel and shear is at least equal to the tensile value of the sheet, implying that the rupture will more probably occur in the sheet than in the seam.

Heavily reinforced geomembranes are more weakened by peel than unreinforced geomembranes (4); and to prevent this, the seam width should be greater for heavily reinforced geomembranes than for light reinforced one.

Carlson et al. (11) presented the results of more than 74,000 HDPE geomembrane seam tests. The seaming techniques used to bond the sheets were extrusion fillet, extrusion lap, single-track hot wedge, and double-track hot wedge. The common seam tests; shear and peel were used to assess the seam properties, and the notched stress rupture tests to evaluate the effects of seaming on geomembrane sheet properties. During peeling, crazes appeared at the unbonded surfaces; crazes are the precursors of cracks. Therefore, it is very important to consider peel while designing the liner. The peel test is extremely useful since it is the only means to evaluate the uniformity of adhesion between geomembranes.

The shear strength test does not provide information on the seam itself, since barely no seam failure occurs for HDPE material, but it provides the elongation in and adjacent to the seam. If the elongations in the seam and in the sheet are almost identical, the seam area has not been altered. Different values of elongation imply an alteration of the seam area, probably due to incorrect seaming procedures.

3.4.4 Impact resistance test

An interesting test procedure has been developed and described by Rollin et al. (5), to evaluate the impact properties of seams, which mainly depend on the sheet thickness and quality of the seam. This Canadian procedure is a modification of ASTM D 3029: “Standard Test Methods for Impact Resistance of Rigid Plastic Sheeting or Parts by Means of Tip (falling weight)”. The impact resistance test provides information on the seam’s brittleness, a predominant factor in the long term behavior of HDPE lined facilities (6).

Prior to doing impact testing, the authors first determined the two moduli characterizing a HDPE geomembrane: modulus of elasticity and secant modulus at different locations near the seams, by trimming and testing dumb-bell specimens which provided these values for the adjacent sheet. It was concluded that both moduli were higher near the seams enhancing the sheet rigidity. However, the results did not allow the identification of brittle seams. Thus, this test is not sensitive enough to evaluate brittle seams.

The impact test apparatus consists of a vertical steel pipe, a seam specimen holder, and a metallic mass. The weight of the mass and falling distance provide the impact energy. As defined by Rollin et al. (7), the impact resistance is the average energy, $W_{50,}$ necessary to fail 50% of the tested specimens.

Two methods can be used: the Probit and the Bruceton Straircase methods. The first method consists of the grouping into many sets, an equal number of specimens (20 to 40) selected at random locations from the seam, and testing each set at a specific different energy level.

The Bruceton Straircase method consists of determining W_{50} (average rupture energy) of a randomly chosen specimen by increasing the mass of the falling weight. This procedure was used by the author to test more than 700 specimens. The seams were made by two different welding techniques: hot air (single and double seams) and wedge double seams. All seams were made at the same temperature: 23^{o} C for the sheets and 400^{o} C for air and wedge. However, in order to assess the effect of incorrect manufacturing (overheating, incorrect pressure), different welding speeds were used. Two other sets were made with high roller pressure (high pressures are expected to cause brittle seams).

Seams made with low speed had low impact energy, which was expected since low seam speed implies overheating, leading to poor performance. The seams made with high pressure also had lower impact energy, implying that high applied pressure causes brittle seams. A microscopic analysis showed that rupture is always initiated along the edge of the seams in the top sheet. The results proved that a highly brittle seam would break with low energy.

Hot air-produced seams were tested at different temperatures ranging from –10^{o} C to 21^{o} C; the seams become more brittle with a decrease of temperature, however, for temperatures higher than 10^{o} C, the seam behavior was constant.

The thickness plays an important role since a 80 mils thick sample requires approximately two times more energy to fail than a 60 mils thick sample (95 Joules against 47 J). However, the rupture level is the same for single or double seams, proving that both types behave in an identical manner. The different results from the testing proved the importance of correct equipment calibrations, like welding speed, temperature, and roller pressure, and also the effects of sheet thickness.

The notched stress rupture test was used for seamed and unseamed sheets, to enable the comparison of the different values. The test procedure was identical to the test procedure used for the NTCL test (test described in the stress cracking chapter), except that the specimen was seamed, see Fig. 25.

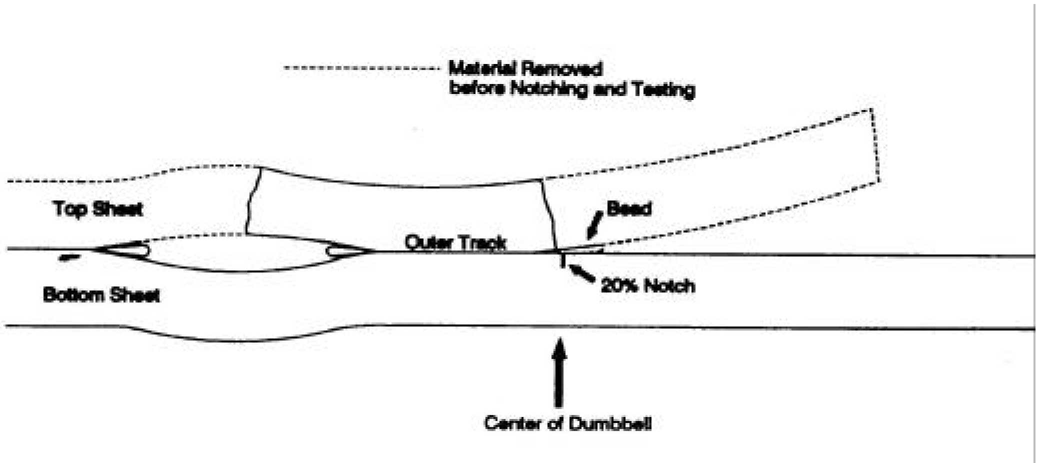


Figure 25: Notch location on a double track fusion seams for a notched stress rupture test (11)

The results of these tests did not show consistent differences between specimens with and without seams. This is probably due to the special care taken by the manufacturer to seam the sheets. Nevertheless, it was impossible to determine if the non-seam effect was due to the improper test method, or if there were really no differences. However, this test proved that HDPE seams could be used without altering the sheet properties, when processed with care. The rate of crack growth may be multiplied by two for the specimens; this is due to the differences in the resin and seaming techniques. It appears that single-track extrusion lap seams were the most susceptible to failure, while the double track fusion seam had the lower rate of failure.

3.4.5 Effect of temperature and freeze-thaw cycles

The effects of freeze-thaw cycles on geomembranes seams were evaluated by Lafleur (8), The results of his study showed no reduction in the seam shear strength. Comer et al. (9) also carried out freeze-thaw cycle experiments on geomembranes and seams. Different resins (PVC, HDPE, VLDPE, etc…) were seamed with different seaming techniques such as chemical, hot wedge, fillet extrusion, and dielectric. The study was divided into three parts in order to assess the effect of freeze-thaw cycling, cold temperature, tensile strains, and temperature-induced cyclic stress on the geomembranes.

In the first part, specimens were submitted to freeze-thaw cycles at -20^o C for approximately 16 hours and tested at room temperature (20^o C). In the second part, the specimens were cycled the same way but tested at a temperature of -20^o C. In the third part, specimens were strained to 25% of their yield or break strength during the freeze-thaw cycling, and then tested at 20^o C. To assess seam behavior, the 25mm strips were tested in the peel and shear modes.

The results of parts one and two showed that the 1.5mm HDPE-T seams, CSPE-R chemical seams, and EIA chemical seams showed strength increases of 10%, 35%, and 15%, respectively in the shear mode. Neither the peel mode nor the shear mode failures were encountered. In part 3, only the CSPE-R chemical seams showed an increase in strength. An explanation for this is the seam's aging. Seams failed during peel tests due to

ply delamination (between the membrane ply and the scrim), however, these failures were not attributed to freeze-thaw but to poorly fabricated seams.
It was shown that freeze-thaw cycles have no real influence on the seam behavior, only a few (3 or 4) specimens were affected. Colder temperatures had more effects since the shear and peel test values were higher at –20^{o} C than at room temperature. Finally, the tensile straining seems to have had no significant effects, this could be due to the stress relaxation in the materials. This study was restricted to 50 cycles, which is a small number. Therefore, other tests must be carried out with freeze-thaw cycles of 200 and more to get definitive findings.

Hsuan et al. (18) assessed the effects of freeze-thaw cycling on 321 combinations of seams made with five different techniques: chemical, hot wedge, fillet extrusion, hot air, and dielectric seams.
The freeze-thaw cycling was carried out with temperature oscillation ranging from –20^{o} C to +30^{o}C. Three sets of specimens were used: first unconstrained specimens were submitted to 200 cycles, then tested at +20^{o} C, a similar second set was cycled the same way but tested at –20^{o} C, while for the third test the specimens were constrained and submitted to 500 cycles and then tested at +20^{o}C. The results of the shear and peel tests showed no significant changes between the different temperature tests. Also, the values were not affected by freeze-thaw cycles.

3.4.6 Residual stresses in geomembrane sheets and seams

Lord et al. (10) evaluated the residual stresses in geomembrane sheets, in and near the seams by the hole drilling method. Dual hot wedge, extrusion fillet, extrusion flat, and hot air seams were tested, the residual stresses were assessed at different locations: in the air channel for the dual seam, in the seam tracks, and at difference distances from the seam (12, 37, 62, 100mm). Values were monitored just after the hole was drilled as well as 30 min. later. Stresses were all compressive, except in the air channel where tensile stresses were applied. Values near the seam and in the sheet were approximately equal, which was particularly strange. The stress magnitude was approximately 10% of the sheet’s tensile strength. After 30 min., the values decreased slightly due to the stress relaxation on the material. This test only allows the assessment of the surface residual stress (up to 0.75 mm deep), but does not provide information on the stress in the material’s core.

3.4.7 Strain concentrations adjacent to the seams

Giroud et al. (12) carried out a complete study on the analysis of strain concentrations next to the geomembrane seams, compared different seaming techniques, and provided recommendations to minimize the strain concentration. To enable this study several assumptions had to be made; therefore, the geomembrane was only subjected to tension (in a direction perpendicular to the longitudinal direction of the seam). The geomembranes were homogeneous (reinforced geomembranes are not included) and the seams were free to translate and rotate.
Three different seaming techniques were studied: fusion seams (single and double), extrusion lap seams, and extrusion fillet seams. When a geomembrane is submitted to tensile strains due to the applied force, thermal contraction, or shrinkage, strain

concentrations occur adjacent to the seams. At the unstressed seam location, the two sheets are in different planes, but when tensile forces are applied they tend to align in the same plane; this alignment is only possible if the seam rotates (see Fig. 26).

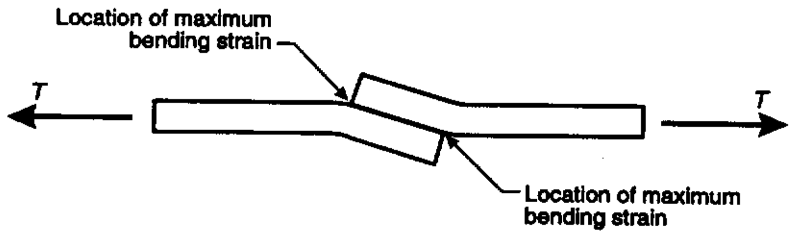


Figure 26: Sheet alignment due to tensile forces (12)

When the seam rotates, bending strains occur in the vicinity of the seam. The bending strains add to the already present tensile strains, and are amplified by the strain concentration factors. The maximum values of bending strain occur at the connection between the geomembrane and the seam. It was shown that for small angles, about 1 to 5^o, the bending strain ranges from 0.75 to 1.5 times the tensile strain in the geomembrane, with a stress concentration approximately equal to 2.

This study proved that bending strains are higher in the lower sheet for the extrusion. This explains why failures often occur in the lower geomembranes for extrusion fillet seams, Fig. 28, but no reasons have yet been found to explain why it occurs in the case of the other techniques.

However, an explanation was found for cold weather, where thermal strains are not uniformly distributed throughout the geomembrane thickness. The thermal strains cause bending which causes strains that are always greater next to the seam at the upper surface of the lower geomembrane, Fig 27.

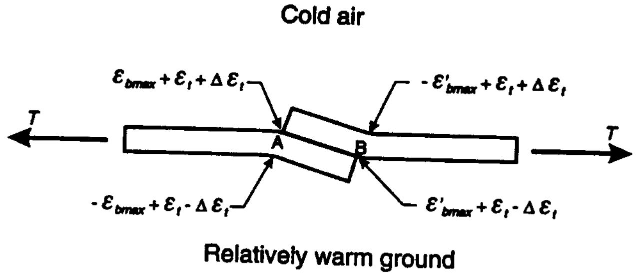


Figure 27: Strains in an air exposed geomembrane (12)

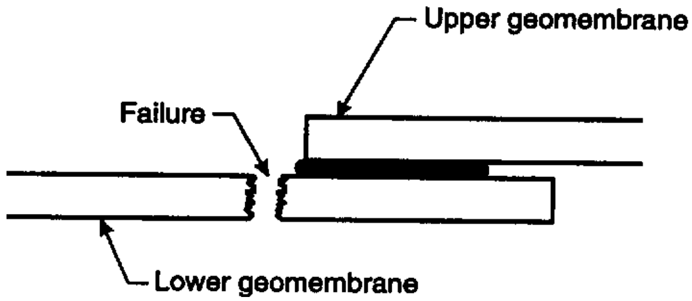


Figure 28: Failure occurs in the lower sheet (12)

Fusion seams cause low maximum bending values; for a 1 mm geomembrane seamed by fusion or extrusion fillet seams, the relation between bending strains and applied tensile strains is linear, unlike other configurations.

The thicker the geomembrane, the greater the bending strains. However, for wide seams thickness has poor influence on the bending strains. Bending strains are functions of the seam width. Therefore to minimize them, a 1 mm thick geomembrane should be used, with at least 40 mm fusion seams, 50 mm extrusion lap seams, and 25 mm extrusion fillets.

3.4.8 Stress cracking in the seams

Peggs et al. (13) assessed the different phenomena of stress cracking in polyethylene geomembranes sheets and seams, providing the field experience for real data.

It was found that many features may initiate cracks, such as extrusion die lines, grinding gouges, seaming machine gouges, re-entrant angles at the edges and on the surfaces of seams, water vapor voids within seams, or lack of bonding at seam interfaces. In the majority of cases involving extruded lap or fillet seams, cracks occurred along the edges of seams, even though they were observed to occur within the extruded bead, on the top and underside of the seams, and slightly removed from the edge of the seam.
Identical cracks may also occur in the fusion welded seams, but failures along the edge are less frequent. However, when this happens, cracks lengths are greater for fusion seams than for extrudate ones.
Cracks along the edges of extrudate fillets seams invariably occur in the bottom of the two geomembranes panel (confirming Giroud et al. (12) finding), this is due to the larger mass of extrudate located on this side of the seam and the higher energy input.

In other types of cracking, the initiating point can be located at other parts of the seams, such as the seam’s surface or within the body of the seam, and not only on the lower sheet. This is especially true for cracking within the extruded fillets, hot air extrudate seams, and extrudate lap seams.

Overheating is an important cause of cracking in seams, cracks have been reported on the edges of a regular seam as well as at the seam's intersections, where the input thermal energy is greater than in the adjacent area causing stress concentration cracks.

3.4.9 Brittle fracture in seams

Peggs and Carlson (14) have studied brittle fracture in polyethylene seams emphasizing field results. They found that brittle cracks occurred along the edges of fused seams even in geomembranes considered acceptable by visually inspections and by peel/shear tests. For all the cases studied, failures appeared on the side of the seam of the overlapped geomembrane.

Seaming consists of melting the surfaces to rearrange their microstructure to form one piece. But problems will appear if the seam is overheated, if it cools rapidly or asymmetrically due to wind, if the melt indices of the parent material and the extrudate do not match, or if it is not heated uniformly.

Crazes that are the precursors of cracks have been seen to occur at the edges of hot wedge seams, at the edges of the top sheet in extrudate filet seams, and at the edges of the extrudate bead in extrudate lap seams. For extrudate fillet seams, cracks often occur at the edges of the top sheet, due to crazes initiated in the weld deposit.

Residual stresses often appear in seams due to asymmetrical processing (temperature or pressure not uniform over the seam's width). This phenomenon may cause crazes to initiate, as it was found in hot wedge seams, where residual stresses at the root of the extruded bead initiated crazes, which propagated through the sheet and seam. They also occured in extrudate fillet seams, where crazes were initiated by residual stresses at the intersection of the edges of the top sheet, the bottom sheet, and the extrudate bead. It was concluded that most of the brittle cracks that occurred in geomembranes were due to unexpected stresses acting at geometrical stress concentration points created by mechanical damage or seams overheating.

3.4.10 Seam inspection

Seams must be inspected by different means, such as shear and peel tests, visual inspection, microscopic analysis (cross section must be assessed during classification tests), and non-destructive testing (such as vacuum box and hot air pressure).

Richardson and Koerner (17) presented the different non-destructive seams tests. They are summarized in Table 15. The costs are those in 1987, date of publication.

Table 15: Nondestructive Geomembrane Seam Testing (17)

Test method	Cost of equipment	Speed of tests	Cost of tests	Type of result	Recording method	Operatror Dependency
Air Lance	$200	Fast	Nil	Yes-no	Manual	Very high
Mechanical point stress	Nil	Fast	Nil	Yes-no	Manual	Very high
Dual seam (positive presure)	$200	Fast	Moderate	Yes-no	Manual	Low
Vacuum chamber (negative pressure)	$1000	Slow		Yes-no	Manual	High
Electric sparking	$1000	Fast	Nil	Yes-no	Manual	Low
Electric wire	$500	Fast	Nil	Yes-no	Manual	High
Electric field	$20,000	Slow	High	Yes-no	Manual and automatic	Low
Ultrasonic pulse echo	$5000	Moderate	High	Yes-no	Automatic	Moderate
Ultrasonic impedance	$7000	Moderate	High	Qualitative	Automatic	Unknown
Ultrasonic shadow	$5000	Moderate	High	Qualitative	Automatic	Moderate

3.4.11 Difficulties associated with seaming and the mode of failure

Defective seams must be repaired by placing capstrips (15) over flaws. Regrinding and re-welding are highly inadvisable, since they increase the possibility of stress cracking. Seaming must not be used at locations where testing is difficult due to the geometry, corner for instance. For these cases, factory-formed corners, or dumps must be placed.

The reasons why field seaming is difficult have been listed by Koerner (16) as follows:

- Horizontal (sloped) preparation surfaces
- Non-uniform preparation surfaces
- Nonconforming sheets to the subsurface (air pocket)
- Slippery liners made of low-friction materials
- Wind-blown dirt or bentonite in the area to be seamed
- Moisture and dampness in the subgrade beneath the seam
- Frost in the subgrade beneath the seam
- Moisture on the upper surface of the geomembrane
- Penetrations, connections, and appurtenances
- Wind fluttering the sheets out of position
- Ambient temperature variations during seaming

- Uncomfortably high (and sometimes low) temperatures for careful working
- Expansion and/or contraction of sheets during seaming

Efforts must be made to increase the role of nondestructive testing, in particular the ultrasonic shadow method. Nondestructive methods assess both the quality and the continuity of the seams.

Table 16 and 17 present the different modes of failure of dual wedge-weld seams and extrusion fillet-wedge seams, respectively.

Table 16: Different Possibilities of Failure for Dual Wedge-Weld Seams (19)

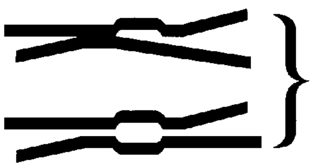
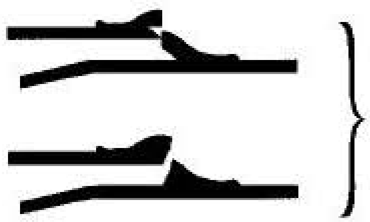
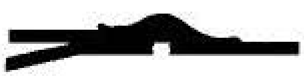
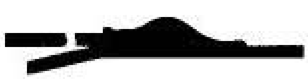
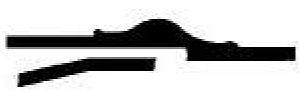
Type of Break	Code	Break Description	Classification
	AD	Adhesion Failure. Complete separation on one or both sides of the air channel.	Non-FTB
	BRK	Break in Sheeting.	FTB
	SE-1	Break at outer edge of seam. Break can be either top or bottom sheet.	FTB
	SE-2	Break at inner edge of seam.	FTB
	AD-BRK	Break in first seam after some adhesion failure. Break can be either top or bottom sheet.	FTB

Table 17: Different Possibilities of Failure in an Extrusion Fillet-Wedge Seam (19)

Type of Break	Code	Break Description	Classification
	AD-1	Failure in adhesion. Specimens may also delaminate under the bead and break through the thin extruded material in the outer area.	Non-FTB
	AD-2	Failure in adhesion.	Non-FTB
	AD-WLD	Break through the fillet. Such breaks range from those that start at the edge of the top sheet to those that run through the fillet after some adhesion failure between the fillet and the bottom sheet.	FTB
	SE-1	Break at seam edge. Specimens may break anywhere from bead/outer area edge to the outer area/buffed area edge. (Applicable to shear only.)	FTB
	SE-2	Break at seam edge. Specimens may break anywhere from bead/outer area edge to the outer area/buffed area edge.	FTB
	SE-3	Break at seam edge. (Applicable to peel only.)	FTB
	BRK-1	Break in sheeting. A "B" in parenthesis after the code means the specimen broke in the buffed area. (Applicable to shear only.)	FTB
	BRK-2	Break in sheeting. A "B" in parenthesis after the code means the specimen broke in the buffed area.	FTB
	AD-BRK	Break in sheeting after some adhesion failure between the fillet and the bottom sheet. (Applicable to peel only.)	FTB
	HT	Break at the edge of the hot tack for specimens which could not be delaminated in the hot tack. (Applicable to shear tests only.)	FTB

3.4.12 References

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3.5 Seismic Response and Interface Strength

3.5.1 Introduction

The seismic response of a landfill may be important for the survivability of the installation. Different studies were carried out to present the possible damage that may be induced by an earthquake, to help designers and constructors to protect the landfill against this threat. The response of a landfill to seismic forces is closely linked to both the slope stability and the interface shear strength between the liner and the soil. Therefore, many tests were performed to assess the shear behavior of different interfaces under different types of excitation.

The landfill should be designed with the following regulations: US Code of Federal Regulation of Environment (1), which states that a landfill located within the seismic impact zone should be designed for a level of acceleration associated with 10% chance of exceedance in 250 years. USGS (2), published a map of the US indicating the different levels of acceleration to be considered for each region of the country.

Studies of different failures due to seismic excitation show that problems appear in the majority of the cases at the interfaces between the different components of a composite liner, since these interfaces are characterized by a very low shear strength (3).

Singh and Sun (3) investigated the response of clay liners to seismic excitations and outlined guidelines to be taken in consideration while designing a composite clay/geomembrane liner. One of the main conclusions of this paper is that the sliding surface (featuring a noncircular shape) will most probably pass through the clay-geomembrane interface, because of the low shear strength of the interface. This is further decreased by the presence of water, which accumulates in the vicinity of the interface (3).

To assess the shear behavior of interfaces different tests are available, some involve static loads, while others feature oscillating excitations.

3.5.2 Monotonic tests

Pasqualini et al. (4) carried out direct shear tests on different interfaces to determine their interface shear strength. The interfaces tested were LDPE geomembrane/geotextile, HDPE geomembrane/geotextile, LDPE geomembrane/geonet, geotextile/geonet, and LDPE geomembrane/compacted clay.

This study enabled the following important findings:

- Temperature has an important influence on the shear behavior of the geomembrane/geotextile interface; it was proved that at 30^{o}C the interface possesses better shear resistance than at 26^{o}C.
- The shear resistance of smooth geomembrane/clay interfaces is clearly affected by the wetting of the compacted clay.
- The geonet penetrates the geotextile, which increases the shear resistance of this interface; moreover water has very little influence on this configuration.

- In contradistinction to the geonet/geotextile interface, wet conditions decrease the shear resistance at most other interfaces.
- It is advisable to carry out tests leading to relatively large displacements in order to obtain correct values.

Vaid and Rinne (5) assessed the coefficients of interface friction between the geomembrane and sand by using a ring shear apparatus. The ring shear test (Fig. 29) is more convenient than a regular direct shear test, since it allows the determination of the true normal load on the plane of shear, thus providing a better definition of the peak interface friction, as well as the residual interface friction.

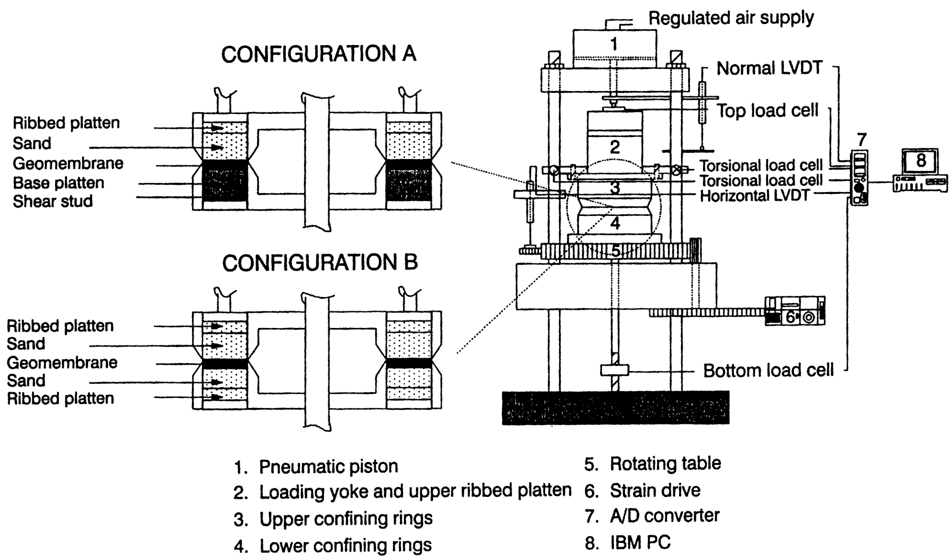


Figure 29: Ring shear test apparatus (5)

Two different sands were used, they had the same gradation but not the same grain shape, the Ottawa C-109 sand was comprised of round particles with a grain size equal to 0.4 mm, while the Target 20-30 sand is compressed of angular shapes with a grain size of 0.55 mm. The constant values of friction (ϕ_{cv} = 29^o for the Ottawa sand and ϕ_{cv} = 33^o for Target sand) are better values for friction than $\phi_{peak,}$ since they are constant and independent of the packing density, gradation, and normal stress.

PVC and HDPE geomembranes were tested. The PVC geomembrane was medium stiff, with one side rough and the other one smooth; for this study the geomembrane thicknesses were 20 and 30 mil. The HDPE geomembrane was stiff and hard, the smooth specimens were 20 and 100 mil thick, while the rough specimens were only 100 mil thick.

This study established the influence of the materials, their textures, the angularity of the sand, and the normal stress on the behavior of the geomembrane/sand interface.

The peak interface friction was found to be a function of the smooth HDPE resistance to shearing. The rough HDPE and the smooth PVC geomembranes had friction angles equal to the constant volume friction angle of the sand. The best configuration to obtain maximum shear strength is a rough geomembrane with Ottawa sand. The waviness component of roughness is not an influencing parameter for the interface friction. Smooth geomembranes present scraping grooves after testing, which is not the case for rough materials. The roughness of geomembranes is unaffected by the testing.

Table 18, from Vaid and Rinne (5), summarizes the results of different studies that provide friction angles for different types of soil and geomembrane.

Table 18: Summary of Tests Results (5)

Soil Type	Geomembrane Type				Type of Test	Reference
	HDPE		PVC			
	δ, δ_p (°)	σ' (kPa)	δ (°)	σ' (kPa)		
Concrete Sand Ottawa Sand	24 20	15-100 15-100	25[1] 27[2]	15-100 15-100	Direct Shear	Martin et al. (6)
Concrete Sand Ottawa Sand	27 19	Up to 100	26	Up to 100	Direct Shear	Williams and Houlihan (7)
Sand	20-25	120	30-34[3]	120	Direct Shear	Akber et al. (8)
Sand		100-400	42		Direct Shear	Lam and Tape (9)
Concrete Sand Ottawa Sand	18-22,24-28 15, 18	50-400 50			Ring Shear	Negussey et al. (10)
Ottawa sand	21, 19	200			Direct shear	Saxena and Wong (11)
Sand			27-31	5-50	Direct shear	Weiss and Batereau (12)
Ottawa Sand	19	3-70	30	3-70	Direct shear	O'Rourke et al. (13)
Ottawa Sand			24.1	10-27	Direct Shear	Lauwers (14)

Where:

δ: friction angle (degree)
δ_p: peak friction angle (degree)
σ': normal stress (kPa)
[1]smooth
[2]rough

[3]PVC –2 = 17mm (67 mils) thick
[4]PVC-4 = 0.76mm (30mils) thick

Cazzuffi et al. (15) presented a European pre-standard method to assess the shear behavior of an inclined interface. The apparatus is quite similar to a regular shear box used for direct shear testing, but instead of being horizontal, it is inclined at a certain angle, Fig. 30.

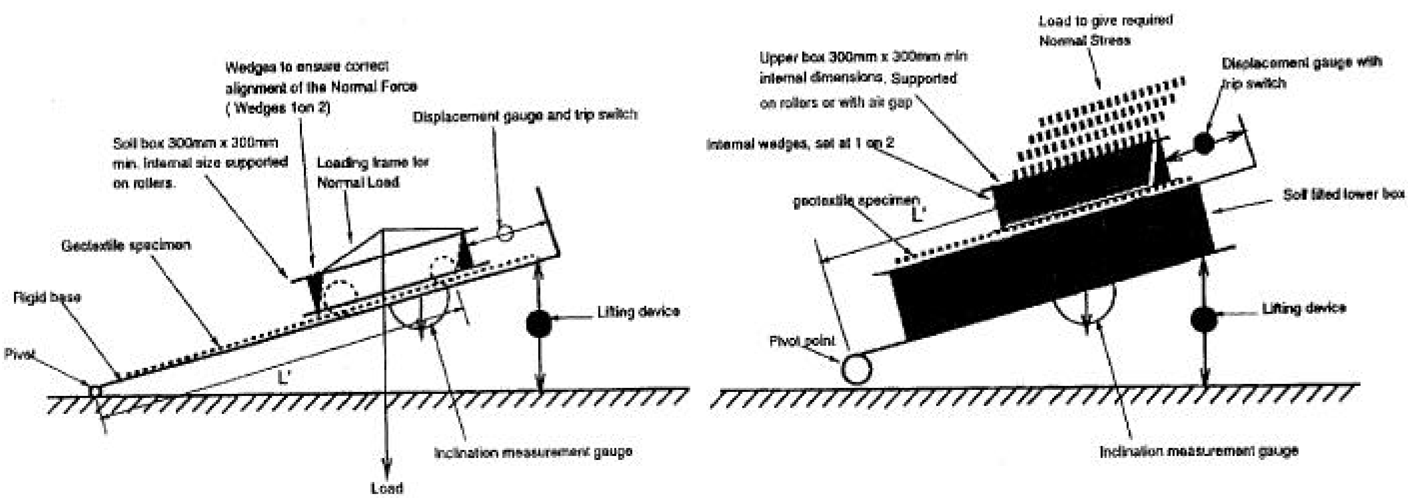


Figure 30: Inclined friction test apparatus (15)

This paper describes exhaustively the apparatus and the test procedures that allow the determination of the angle of friction and the shear strength. Only preliminary results are available (see Table 19), and even if some problems need to be resolved, it is thought that this test method would be an efficient tool in the characterization of the interface shear properties.

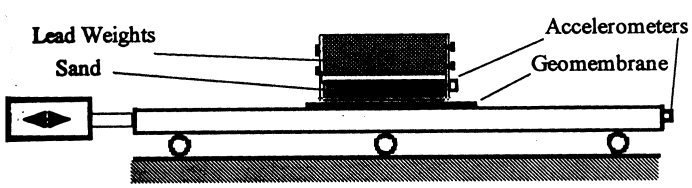
Table 19: Results of Inclined Friction Tests (15).

Geosynthetic	Support	Cover soil	Friction angle: ϕ_{gp} (^{o})
PET woven geotextile	Rigid plate	Sand	30.9
PET nonwoven needle-punched geotextile	Rigid plate	Sand	32.5
		Gravel	40.1
PVC geomembrane	Rigid plate	Sand	29.3
PET woven geogrid	Sand	Sand	30.1
	Rigid plate (with 2 layers PE film)	Sand	40.9
	Rigid plate	Gravel	41.9
HDPE extruded mon-oriented geogrid	Rigid plate	Sand	32.4
		Gravel	37.0
	Rigid plate (with 2 layers PE film)	Sand	29.7
		Gravel	39.9

3.5.3 Seismic Response/dynamic shear tests

Yegian et al. (16) presented the results of tests to evaluate the dynamic response of geomembrane/geotextile and geomembrane/soil interfaces excited by seismic excitation.

For both interfaces, the materials were placed on a shaking table (see Fig. 31) and the accelerations and displacements (slip) of the lead blocks weights (12.4 kPa) and the table were recorded.



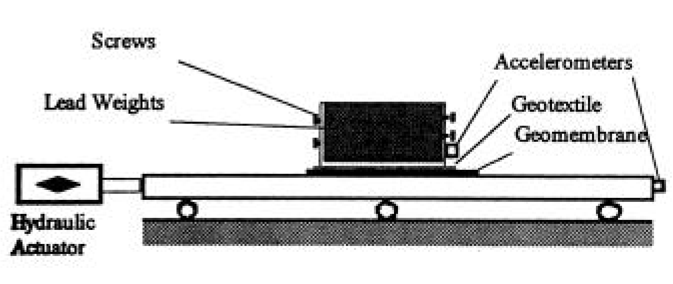


Figure 31: Test apparatus for dynamic shear properties (16)

The different materials used for the tests were a nonwoven, continuous filament, needle punched geotextile (Polyfelt TS 700), a smooth 60 mil HDPE geomembrane, and Ottawa sand.

The peak acceleration of the block a_b is function of the dynamic interface friction angle ϕ_d, and the gravity g, and is defined as:

$$a_b = g \tan \phi_d \quad \text{[3.5.1]}$$

For the first part of this study the excitations were steady state harmonic.
For the geomembrane/geotextile interface, it was shown that for accelerations less than 0.2g the table and the block move together, which indicated no relative displacement (slip), but for higher accelerations slip of 0.75" occurred.
Since the threshold limit between the slip and the no slip occurs at 0.2 g, it is possible to determine ϕ_d as follows:

$$\phi_d = \text{cotan}\,(a_b/g) = 11.3^{o} \quad \text{[3.5.2]}$$

Only a limited shear stress can be transmitted through the interface; the value of the maximum shear stress is given by:

$$\tau = \sigma \tan \phi_d \quad \text{[3.5.3]}$$

where σ = normal stress and ϕ_d = dynamic interface friction angle, are both known.

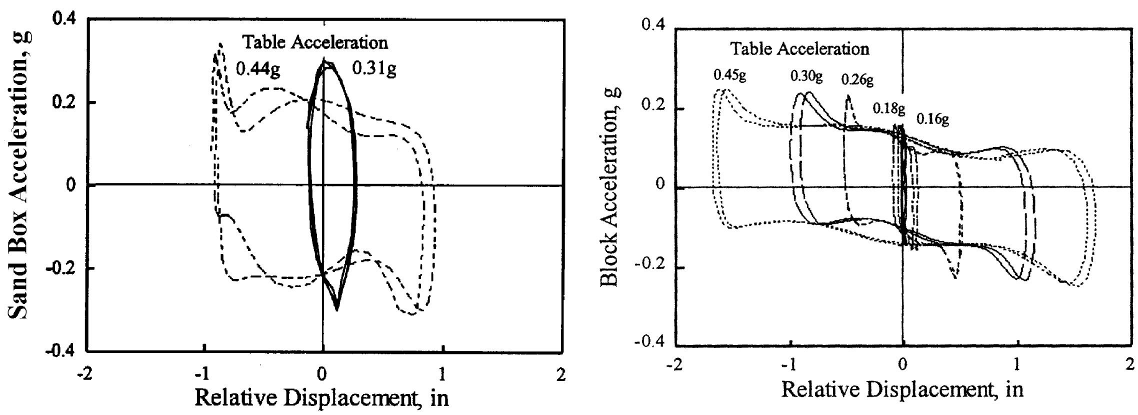


Figure 32: Dynamic response of geomembrane/sand interface (left) and geomembrane/geotextile interface (right) (16)

From Fig. 32, it is possible to determine the dynamic stiffness and damping characteristics of the interface, as well as the interface shear force. The stick-slip phenomenon occurs when the table motions are reversed. The dynamic interface shear property is non-linear. For the geomembrane/sand interface, slip occurred at a level of acceleration equal to 0.3g corresponding to $\phi_d = 16.7^o$.

The sand/geomembrane interface is able to transmit more shear stress between the two components than the geotextile/geomembrane interface, this explains why the slips were smaller in this case.

In the second part of this study, the dynamic response of the sand/geomembrane interface submitted to earthquake excitations was investigated. The excitations of the table were set to reproduce the earthquake in Spitak, Armenia in 1988, during which the maximum recorded acceleration was 0.4g. The response is more complex in the case of earthquake excitations than for steady state harmonic excitations. It was observed that the yield acceleration is not constant and is difficult to define. For a peak acceleration of 0.4g, the maximum slip was 1.2", while the permanent slip was 0.4", and the acceleration of the block 0.3g.

These tests showed that the stick-slip phenomenon occurs during the inversion of the table motion, which temporarily increases the shear force. Because of the complexity of the response under earthquake excitation, designers should be careful not to extrapolate results from the steady state harmonic excitations to earthquake application. The geotextile acts as a base isolator since the level of acceleration pulses of the ground motion is reduced by it and the wave energy is absorbed by the interface due to slip (17).

During, slip the different layers of the liner, including the geomembrane, may sustain plastic deformation, or tearing with consequent decrease of the impermeable properties of the liner. One of the main causes associated with landfill failure due to seismic excitation is very low shear strength of the liner composed of different layers of geosynthetics, especially when a smooth geomembrane is utilized (18).

De and Zimmie (19) tested four different interfaces: geotextile/smooth geomembrane, smooth geomembrane/smooth geomembrane, smooth geomembrane/geonet (longitudinal), and smooth geomembrane/geonet (transverse).

First, the different interfaces were tested by monotonic and cyclic (frequency of 0.25 Hz) direct shear tests. Shear stress versus displacement curves were almost linear under monotonic loading, up to a maximum point (peak). Past this point, the curves dropped, even though some showed a residual stress larger than the peak value. An interesting finding was that the geonet transverse and longitudinal interfaces exhibit the same behavior indicating that orientation is not a factor in the shear strength at interface. Two sizes of specimens were tested and only small differences were noticed.
Under cyclic loading, the shear stresses tend to decrease with time. The ratio of the values of initial and terminal shear stresses is defined as the coefficient of dynamic friction for the studied cycle. The final stress is either larger or smaller than the initial value depending on the nature of the interface; moreover, the difference between initial and terminal values is a function of the normal stress applied. The decrease of shear stress associated with cyclic tests is explained by the wearing of the contact surfaces, which reduces the surface roughness (19).

The second part of this study addressed shake table tests, which allow the determination of the dynamic friction angle and therefore, the shear force. Small as well as large values of acceleration were used for the table excitation. In order to provide a high level of acceleration, up to 40 g, a 100 g-ton geotechnical centrifuge was used. For both small and large levels of acceleration, the dynamic friction angles were found to be similar, approximately 12.5^{o}, implying that slip occurs at the same level of excitation (0.2g) for each interface. Moreover, results of the direct shear tests corresponded to the results found by the shake table.

3.5.4 Influence of material roughness

Dove et al. (20) assessed the relationship between the geomembrane roughness and the interface shear strength for geomembrane/soil interfaces using a newly developed optical technique OPM (Optical Profile Microscopy), which characterizes the roughness of a geomembrane.

The surface roughness parameter is defined as follows (se Fig. 33):

R_s = As/Ao, see Fig. 33…………………………..……..[3.5.4]

But in practice, the stereology relation is defined as follows:

$R_s = \overline{R_L \Psi}$ ………………………………………..[3.5.5]

With Rl is the profile roughness parameter, and ψ the profile structure factor.

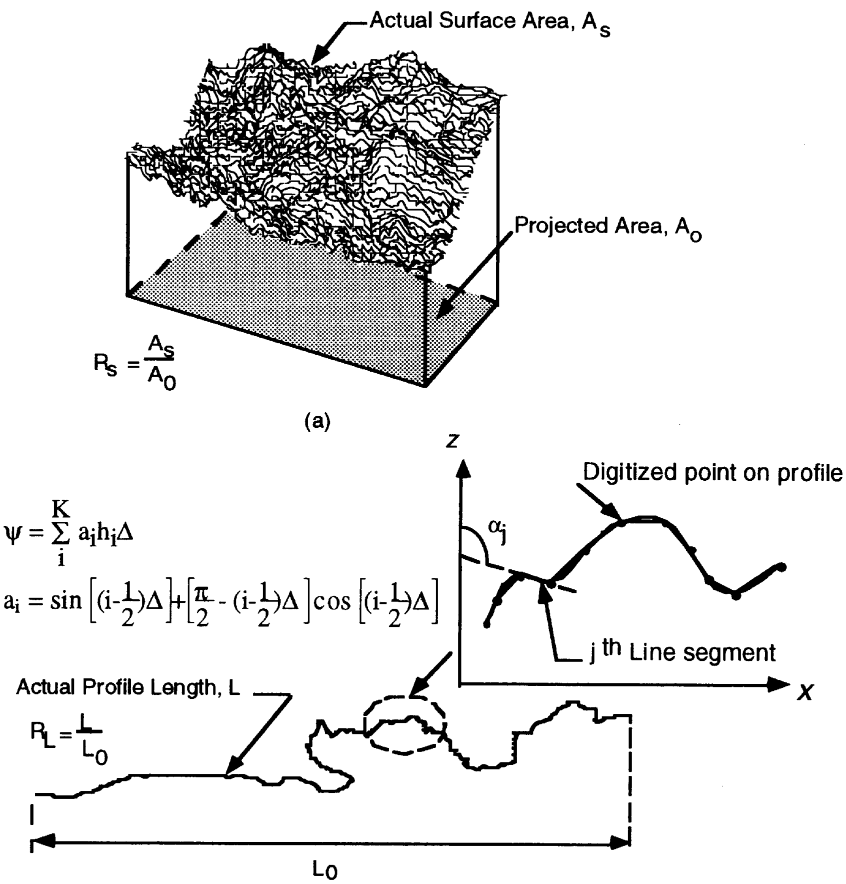


Figure 33: Definition of roughness parameter by Dove and Frost (21).

In this study, one smooth and three textured HDPE geomembranes were tested over two standard Ottawa sands, and a upper drain material from a landfill (the three soils possessed approximately the same properties).

Before testing, the shear strengths of the different interfaces in round and square direct shear boxes, and the geomembrane roughnesses were assessed with the OPM technique.
These tests confirmed that roughness is a very important parameter in the shear resistance of the geomembrane/sand interface. The shear strength increases with an increase of the roughness up to a limit value of R_s approximately equal to 1.4; then beyond this value, the shear strength is less affected by the geomembrane roughness. Thus, to optimize the design of a liner, it is important to use a geomembrane possessing a roughness parameter equal to 1.4.

3.5.5 A theoretical evaluation of interface stability

Giroud et al. (22) developed a theoretical method to assess the stability of geosynthetics/soil interfaces on slopes. The slope instability of landfills is due to excess weight and low shear strength of the interfaces. Different methods of determining the factor of safety equation for slope liners have been presented by Giroud and Ah-Line (23), Martin and Koerner (24), Giroud and Beech (25), and Koerner and Hwu (26). All these methods are based on limit equilibrium making them simple to use (expression of the slope stability through a factor of safety), and their applicability has been proven through many years of utilization. But special care must be taken while evaluating a multi-layered liner, since the ultimate shear strength for each layer is not required at the same instant.

Different assumptions and calculations lead to equations defining the factor of safety.

For the case of uniform thickness:

$$FS = \frac{\tan\delta}{\tan\beta} + \frac{a}{\gamma t \sin\beta} + \frac{t}{h}\frac{\sin\phi}{\sin(2\beta)\cos(\beta+\phi)} + \frac{c}{\gamma h}\frac{\cos\phi}{\sin\beta\cos(\beta+\phi)} + \frac{T}{\gamma h t} \quad \text{.....[3.5.6]}$$

and for non-uniform thickness:

$$FS = \frac{\tan\delta}{\tan\beta} + \frac{a}{\gamma t_{avg}\sin\beta} + \frac{t_B^2}{h t_{avg}}\frac{\sin\phi}{\sin(2\beta)\cos(\beta+\phi)} + \frac{c}{\gamma h}\frac{t_B}{t_{avg}}\frac{\cos\phi}{\sin\beta\cos(\beta+\phi)} + \frac{T}{\gamma h t_{avg}} \quad \text{..........[3.5.7]}$$

with
FS: factor of safety
δ: interface friction angle along the slip surface (^{o})
β: slope angle (^{o})
a: interface adhesion along the slip surface (Pa)
γ: unit weight of the soil (N/m^3)
t: thickness of the soil layer for the case of a layer of uniform thickness (m)
h: height of the slope
ϕ: internal friction angle of the soil component of the layered system (^{o})
c: cohesion of the soil component of the layered system (Pa)
T: tension in the geosynthetics above the slip surface (N/m)
t_a: thickness of the soil layer at the point A defined in Fig. 34

t_B: thickness of the soil layer at the point B defined in Fig. 34

t_{avg}: average thickness of the soil layer defined as $t_{avg} = \frac{t_a + t_b}{2}$ in the case of a tapered soil layer.

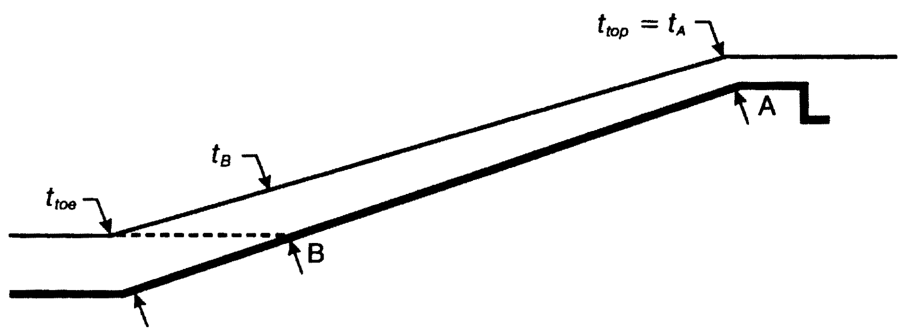


Figure 34: Definition of t_A, t_B, and t_{toe}. (22)

Design examples were presented for the method developed by Giroud et al. (22) to prove its efficiency. The method is very exhaustive, simpler than the previous ones, and features an accuracy totally acceptable. An important advantage is that equations defining the factor of safety are sums of five terms, which are the independent parameters, influencing the factor of safety (see Table 20).

Table 20: Explanation of Terms in the Factor of Safety by Giroud et al. (22)

Slope	Infinite Slope		Additional terms of finite slope		
Mechanism	Interface Shear		Toe buttressing		Geosynthetic
Parameter	Interface Friction	Interface Adhesion	Soil internal friction	Soil cohesion	Geosynthetic tension
Symbol	δ	a	φ	c	T
General equation	$\frac{\tan\delta}{\tan\beta} + \frac{a}{\gamma t \sin\beta} + \frac{t}{h}\frac{\sin\phi}{\sin(2\beta)\cos(\beta+\phi)} + \frac{c}{\gamma h}\frac{\cos\phi}{\sin\beta\cos(\beta+\phi)} + \frac{T}{\gamma h t}$				
φ (+)	↔	↔	(+)	(+)	↔
β (+)	(-)	(-)	(-)	(-)	↔
h (+)	↔	↔	(-)	(-)	(-)
γ (+)	↔	(-)	↔	(-)	(-)
t (+)	↔	(-)	(+)	↔	(-)

(+) corresponds to increase
(-) corresponds to decrease

This accounts for the factor of safety contribution to the interface friction angle, the interface adhesion, the internal friction angle, the cohesion of the soil component located above the slip surface, and the tensile strength of the geosynthetic located above the slip surface. Unfortunately, due to the assumptions made, this method cannot be used in cases where the slopes are submerged or if water is flowing along them.

3.5.6 Conclusions

It appears that the shear properties of liner interfaces are of paramount importance to prevent earthquake damage as well as to ensure a proper stability of the landfill. The materials composing the liner, their roughness, their stiffness, the normal load, as well as the temperature are factors influencing the interface shear strength.

However, review of the materials literature indicated that only very few articles present damage caused to geomembranes/geotextiles materials by slips and shear stresses due to seismic and steady-state harmonic excitation. Even if the slips are of small order, it should be interesting to evaluate their effects on the properties and durability of geotextile liners. Since it is possible that a landfill can survive an earthquake without collapsing, the liner may suffer excessive deformations or tears, which will allow leakage, or reduce the liner durability. This damage will be aggravated as other earthquakes occur.

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3.6 Effect of Natural Parameters on Geosynthetic Aging

3.6.1 Introduction

Many investigations have addressed the aging of geosynthetics and geomembranes, since aging is one of the most important concerns for materials used for landfill liners. The environments in and around landfills are usually aggressive towards geosynthetics, i.e.: temperature, UV, oxidation, and chemical agents that deteriorate the liner. This chapter is restricted to the aging problem in landfill environments.

Haxo et al. (1) studied the factors in the durability of polymeric membrane liners and classified the different modes of failure of a membrane as follows: a) softening and loss of physical properties due to depolymerization and molecular scission, b) stiffening and embrittlement due to loss of plasticizers and additives, c) reduction of mechanical properties and increase of permeability, d) failure of membrane seams.

3.6.2 Conditions at the liner level

Landereth (2) summarized the conditions encountered in a landfill: temperature between 40 to 70^{o}F, constant flow of leachate, no light, aerobic or anaerobic conditions, bacteria, acidity, gas, etc. In a hazardous waste landfill, microbes will be more active if the waste does not kill them, also less gas will be produced.

Typical chemicals found in a landfill environment are listed in Table 21:

Table 21: Typical Chemicals in a Landfill Environment

a) Typical Chemical in Landfill Gas (18):

Typical constituent in gas		**Typical concentration of trace compounds**	
Component	**Percent**	**Component**	**Mean concentration (pbV, parts per billion by volume)**
Methane	40-60	Toluene	34,907
Carbon Dioxide	40-60	Dichloromethane	25,694
Nitrogen	2-5	Ethyl Benzene	7,334
Oxygen	0.1-1.0	Acetone	6,838
Ammonia	0.1-1.0	Vinyl Acetate	5,663
Sulfides, Disulfides, Mercaptans	0-0.2	Tetrachloroethylene	5,244
Hydrogen	0-0.2	Vinyl Chloride	3,508
Carbon Monoxide	0-0.2	Methyl Ethyl Ketone	3,092
Trace Constituents	0.01-0.6	Xylenes	2,651

b) Typical chemical in Landfill Leachate (19):

Elements	Concentration (mg/kg)
Sulfates	< 328 000
Copper	< 295
Zinc	< 534
Arsenic	< 385
Benzo-a-pyrene	< 1300
Oils	< 9 000
pH	> 1.2

Typical conditions in MSW landfills are as follows:

- absence of oxygen and ultraviolet light
- humid to wet
- cool and uniform temperature (10-20^{o}C)
- moderate acidity and dissolved organic constituents
- high overburden pressure, with moderate hydraulic head pressure

In MSW landfills, polymeric materials have proven to have acceptable resistance to aging even if depolymerization, and loss of strength occur.

Typical conditions in hazardous waste facilities are as follows:

- vast range of waste directly or not in contact with the material
- exposure to weathering: sunlight, rain, ozone
- wave action of the fluid in the pond
- significant temperature gradient
- ground settlement and movement

The environment in hazardous waste facilities is more aggressive towards the membrane than in MSW landfills

3.6.3 Different stresses to which the liner is subjected

Haxo and Haxo (3) described the different parameters influencing the durability and aging of geosynthetics products in landfill environments. Those parameters can be classified into three groups: chemical, mechanical, and biological stresses, possibly acting simultaneously, and causing different types of aggressiveness to the liner material.

Chemical stresses, which are affected by temperature, are induced by exposure to waste liquid, ultraviolet and infrared radiation, rain water, oxygen and ozone; these have different effects ranging from structure breakdown, cross-linking and gelling, swelling and dissolution of the polymer, volatilization or extraction of plasticizers, and increase of crystallinity.

Mechanical stresses are induced by penetration, overburden weight, hydraulic head, rain, hail, snow, and wind, stresses on slopes, and settlement. Their effects are tearing, cracking, breaking, and creep.

Biological stresses result from biodegradation by microorganisms and attack by rodents, birds, and insects creating clogging of the material.

3.6.4 Environmental effects during construction

During fabrication and through liner construction, geosynthetic products are exposed to different environmental factors, possibly aggressive. Many liner flaws are caused by defects created before or during liner construction, therefore, great care must be taken during this phase of life of the material.

The change in temperature may cause damage since the material is not yet buried. Temperature affects seaming, embrittlement (low temperature), shrinkage, and softening (high temperature).

Humidity, UV, and oxygen may be really harmful to uncovered material. Products that do not include carbon black are even more affected by UV light exposure. Careless placement of geosynthetics, as well as gravel, may result in stretching, tensioning, creep, scratch, tearing, and puncture. This can be prevented by skilled workers.

3.6.5 Environmental effect during service life

Multiaxial stresses are usually present at any location of any geosynthetic liner; uniaxial stresses are very rare in real situations. Anaerobic conditions are present in most landfills at the location of the liner, which reduce and eliminate the existence of microorganisms, and therefore, reduce the risk of biodegradation.
Absence of light and, therefore, UV reduces considerably the risk of degradation but leachate is almost always present at the level of liner. The leachate increases the possibility of loss of the material's compounds, and decreases the geomembrane properties. Temperature may vary from 40 to 70^{o}F, and even higher in certain cases.

Overburden pressure may approach 100 psi, which, in the case for rough soil in contact with the membrane may deform, puncture, or even tear the material. The decomposition of waste creates gases such as carbon-dioxide and methane, which may cause mineralization of the soil, and clog the liner. The presence of ions may also cause clogging.

For hazardous waste landfills, aerobic conditions increase the possibility of bacteria and microorganisms, which can lead to fungal growth that would eventually clog the liner.

3.6.6 Degradation processes

- *Temperature:*

Schneider (4) characterized and summarized the effect of temperature and intensity of radiation on geosynthetic products. Degradation can be caused by weathering factors such as oxygen, radiation, humidity or heat.
Arrhenius developed a governing equation for chemical degradation, Equ. 3.6.1:

$$K_p = A.e^{(-Ea/RT)} \qquad [3.6.1]$$

where:

A = rate constant, $\frac{eKT}{h}.e^{s/R}$ but under certain conditions, A = 10^{-13} at 25 ^{o}C.

Ea: activation energy
R: gas constant
T: absolute temperature

Furthermore, many weathering tests were conducted on PP continuous fiber geomembranes under mechanical loads. It was observed that there was significant remaining strength (specimens are tested after exposition) when the temperature varied and the intensity of radiation was constant.

The temperature may be influenced by different factors and can differ for the surrounding material, geosynthetic surface and its core (difference of 20 ^{o}C between surrounding material and geotextile may exist). When temperatures over 100 ^{o}C are reached, water produced by condensation may cause hydrolytic degradation; however, proper storage will solve this problem.

Not only does the temperature act as an accelerator, but it may also affect the fiber's structure by stabilizing it as well as decreasing the inner stress. Another consequence of temperature is the increase of material's crystallinity associated with an increase of density. Thus, temperature is an important parameter in the aging process due to its capability to influence the reaction rate, mechanical (strength and elongation), and abrasion properties. Temperature in the sample may be significantly higher than in the surrounding environment, this is due to the material's thickness and opacity.

The results of the tests carried out by Fayoux (16) on the durability of PVC geomembranes show that temperature causes the evaporation of plasticizers, which at 40^{o}C is about 0.7 to 3.5 g/m^2/year.

Pierson et al. (5) assessed the thermal behavior of geomembranes exposed to solar radiation, which induces problems (such as wrinkles) and, even flaws at the construction stage, when the geomembrane is still uncovered by waste.

Temperatures may reach 80 ^{o}C in black exposed geomembranes, such temperatures acting on material with high coefficients of thermal expansion cause wrinkles over the entire exposed surface of the geomembrane.
Pierson et al. developed analytical expressions for the coefficient of thermal expansion (CTE), the coefficient of absorption (α), and the expected temperature in the membrane. They validated these expressions by tests and indicated values of CTE and α.

The coefficient of thermal expansion, CTE (m/(m.^{o}C)), is defined in Equ. 3.6.2.

$$\Delta l/l_0 = CTE \times \Delta T \qquad [3.6.2]$$

where $\Delta l/l_0$ (m/m) is the strain and ΔT (^{o}C) is the variation in temperature.
Tests were carried out to assess the values of CTE for different materials, and show that HDPE is the material with the higher CTE, also the variation of CTE with the directionality of testing and the maximum width of the sheet, Table 22 gathers the results.

Table 22: Coefficient of Thermal Expansion of HDPE and PVC (5)

Material	HDPE 1		HDPE 2		PVC	
Direction	width	length	Width	length	width	Length
Irreversible variations after 3 tests (per thousand)	2.2	- 1.7	< ± 1	< ± 1	13	- 13
CTE (m/(m.^{o}C))	2.6 E-4	1.7 E-4	2.9 E-4	3.1 E-4	1.4 E-4	1.2 E-4

The coefficient of absorption α was evaluated for different materials and colors using the heating plate test. Equ. 3.6.3 and 3.6.4 express α in geomembranes resting on ground:

$$\alpha \cdot G = h_H \cdot (T_m(t) - T_{cl}) + \Phi(x=0,t) \qquad [3.6.3]$$

where: α: coefficient of absorption
G: solar radiation (W/m^2)
h_H: constant=25±1 (W.m^{-2}.^{o}C^{-1})
$T_m(t)$: mean membrane temperature at x=0 and time t (^{o}C)
T_{cl}: temperature of the boundary layer (^{o}C)
$\Phi(x=0,t)$: conduction heat flux

The temperature in the membrane can be approximated by Equ. 3.6.4:

$$Tm(t) = Ta + 1/h_H . \left\{ a .G + \frac{3l\,[(Ti - Ta) - a .G/h_H]}{d\,(t) + 3l\ /h_H} \right\} \qquad [3.6.4]$$

where: Ta: air temperature (°C)
δ(t): value of x so that Φ(x=0,t)
λ: soil thermal conductivity

These equations were validated by tests proving their accuracy.

It was proven that a white coating applied on the surface of the membrane reduces considerably the overheating of the material (see Fig. 35). The use of a geotextile over a black geomembrane only delays the overheating, so this is not an appropriate means to eliminate long-term overheating.

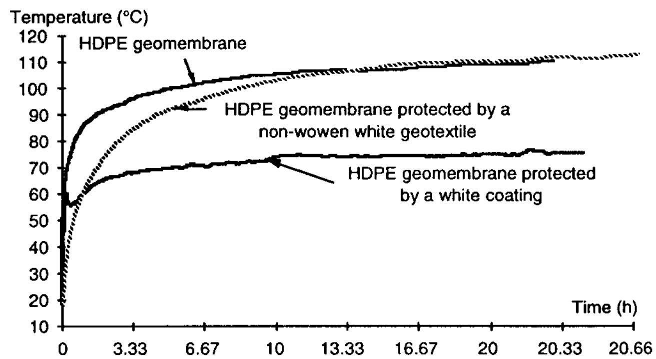

Figure 35: Influence of geomembrane coating on thermal properties (5)

From site tests and observations, the wrinkle phenomena can be outlined as follows:
- large wrinkles propagate along the sheet's length and weld
- small wrinkles propagate perpendicular to the large ones
- due to undulation, the contact between the soil and the membrane is not continuous
- temperatures in the wrinkles are higher than those in the non-wrinkled parts of the sheet
- spacing between two wrinkles does not change, if the temperature and height of the wrinkle increases.

** UV light:*

UV is the worst factor affecting exposed PVC materials (16). A solution to prevent the effect of UV is to include carbon black. Its concentration is limited by the burning phenomena occurring during seaming. Another solution is the combination of light pigments, which by their presence decrease the temperature in the membrane and therefore, the aging, deformation, creep, etc. The study carried out by Fayoux (16) shows that the loss of plasticizers was in the order of 12 g/m^2/year.

Koerner and Koerner (6) analyzed the behavior of field-deployed HDPE geomembranes. Exposed to light, a geomembrane is subjected to three physical phenomena: radiation, conduction, and convection. Radiation is a phenomenon in which the energy is carried by electromagnetic waves (solar radiation ranges between 0.1 to 4 mm). The transference of heat caused by a temperature gradient is the conduction phenomenon. Convection is the transfer of heat by molecular movement.

The first part of the study addressed the testing of black, white, textured and smooth geomembranes, exposed to field conditions throughout the year.

Table 23: Average Temperature in Black and White Geomembrane (6)

Season of Year	Max. Ambient Temperature	Black Geomembrane		White Geomembrane	
		Max. Temp.	Diff. Amb.	Max. Temp.	Diff. Amb.
Winter	5	13	8	2	-3
Spring	22	46	24	38	16
Summer	30	70	40	57	27
Fall	19	35	17	28	10

Table 23 presents the test results, from which it can be concluded that the temperatures in white geomembranes are always lower than those in black ones; only a small difference between the smooth and textured geomembranes exists in the advantage of the textured one in which lower temperature was found.

The second part concerns the analysis of wave occurrence due to light exposure in a 1.5 mm smooth black HDPE geomembrane. The weather conditions (sun, cloud, and wind) are important parameters in the development of waves. Sun and no wind will increase the temperatures in the membranes and the material will expand creating waves. Covering the geomembranes with a geotextile or gravel significantly reduces the temperatures and so the waves formation. The topography of waves was also monitored and is shown in Fig. 36.

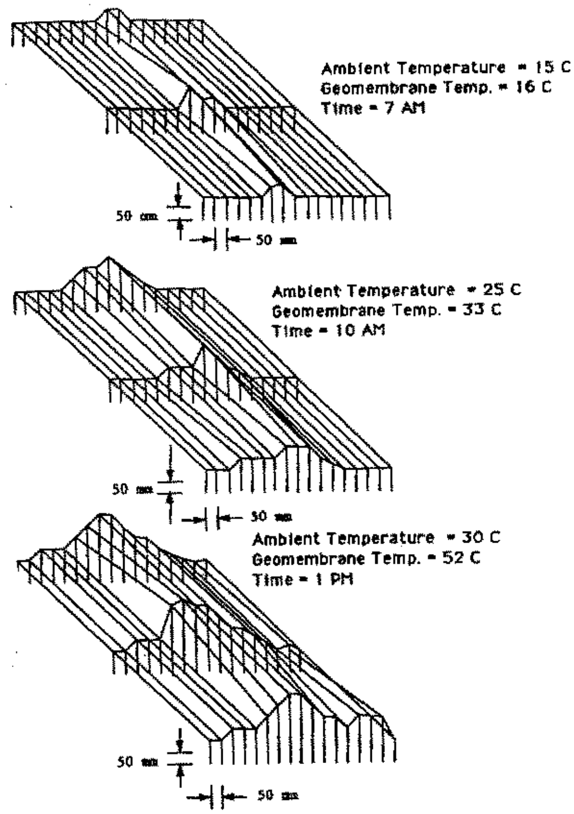

Figure 36: Topography of waves induced by UV radiation (6)

Cazzuffi et al. (7) provided a very detailed analysis of the reason for the degradation in polymeric material due to UV light: photodegradation breaks down the chemical bonds due to UV exposure leading to cracking, chalking, color changes, or loss of physical and mechanical properties. They also compared results of laboratory and outdoor exposure tests of seven different geosynthetics. The laboratory high temperature accelerated tests were performed for periods of 1,000, 2,000, and 3,000 hours, while the outdoor tests were performed for 1,080, 2,060, and up to 17,280 hours.

Geotextiles, geogrids, and geomembranes, made of PET, PP, PE, PVC, and HDPE, were tested for UV exposure effects. For geotextiles, outdoors and laboratory tests results correlated for strength: an exposure of 1,000 hours in the laboratory corresponds to one-year outdoors. Such correlations are also true for geogrids and geomembranes, proving good correlation for any type of material. It was also shown that one of the main parameters for UV resistance is the thickness of the material: the thicker the material, greater the resistance.

Geotextiles were subjected to embrittlement (increase of modulus up to 370%), while geogrids and geomembranes suffered a lot less to an acceptable degree. Moreover, for geogrids and geomembranes, aging is not proportional to the exposure time, and the change occurs only superficially and not in the material core.

Ultraviolet radiation affects uncovered materials and can be dangerous during the installation of the liner and before the placement of the waste. Only the ultraviolet part of the light is harmful to the geosynthetic materials, moreover, each material is sensitive to a particular wavelength (i.e. polyethylene = 300 nm, polyester = 325 nm, and polypropylene = 370 nm).

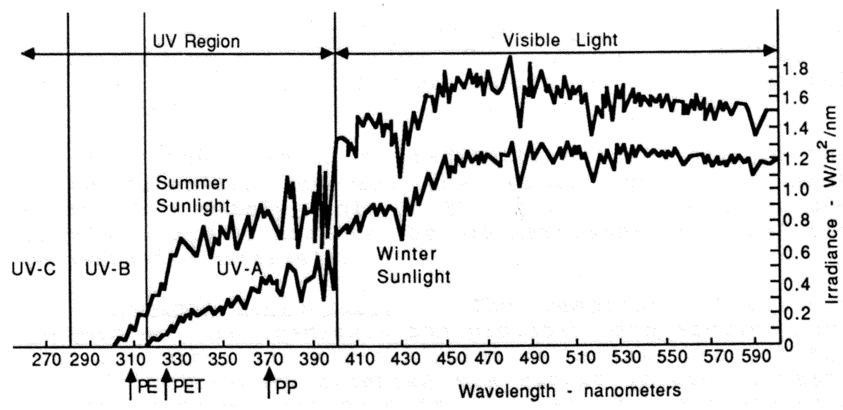

Figure 37: Wavelength Spectrum of UV radiation (12)

The degradation mechanism is due to molecular bond scission (in the primary polymer's backbone) created by the sensitive wavelength within the molecular structure.
Ultraviolet light causes material embrittlement and may induce cracks depending on the intensity of the radiation.

The best solution to prevent ultraviolet damage is to keep a minimum layer (15 cm) of soil, waste, or gravel over the liner so that light cannot penetrate the material. In the case of uncovered geotextiles, carbon black and chemical stabilization must be used. Carbon black is a powder that prevents the light from entering the material microstructure and also absorbs a part of the light energy. Chemical stabilization with (Hindered Amine Light Stabilizers, HALS), in which the free radical is liberated by scission due to the light, stops further degradation.

* *Chemical:*

Chemical stresses are characterized by cross-linking or scission of the polymer chain due to the reaction of oxygen with polymer (2). Organic absorption may cause the material to swell or soften.
An important concern is the crystallinity increase causing the embrittlement of the material that reduces its resistance to cracking. Leachate may extract some compounding ingredients from the geosynthetic.

Artieres et al. (8) analyzed the durability of different geomembranes under chemical stresses induced by the leachate over a period of 6 months. All the materials tested showed no significant modifications in microstructure, or mechanical stress, proving that the leachate has no effect on geomembrane material in a time period of 16 months. However, longer tests should be made since modifications of properties are expected due to the long-term exposure to chemical agent. Moreover, it was proved that bituminous geomembranes should not be used as liners, since they are porous under small deformations.

Billing et al. (9) assessed the chemical and mechanical durability of geotextiles. These synthetic materials are used in landfill as soil-reinforcement materials and can be exposed to chemically aggressive leachate environment.

Certain metal ions such as Fe, Cu, and Mn induce and accelerate the hydrolysis of polyester material. To prevent this problem, ion deactivators were embedded in the material during its processing. The samples were immersed in an extremely acid (sulfuric) solution of pH 3, and in an highly alkaline (calcium oxide) solution of pH 12. The results of this study showed that the different geotextiles (polypropylene, polyester, and polyethylene) were only slightly affected by the pH of the solution, in which they were immersed. Polypropylene showed a slight weight increase at high pH, and a significant tensile strength reduction after immersion in H_2SO_4 (pH 3). Polyester showed a weight loss accompanied by crystal growth, and also a reduction in tensile strength after immersion in pH 12 solution. Polyethylene materials were not affected by the immersion.

Overmann et al. (10) tested the chemical resistance of geomembranes and geotextiles to leachate. Their tests were based on the US EPA method 9091, but the time and temperature of immersion of the samples were increased. The materials tested were as follows: HDPE and Reinforced CSPE for the geomembranes (with seam samples being also tested because of their low resistance to chemical aggression); polyester, polypropylene and high-density polyethylene for the geotextile. The leachate was taken from existing landfills and had a pH of 8.8. The immersion temperatures were higher than those indicated in the EPA Method (25, 45, and 70^{o}C), and the time of immersion varied from 1 to 24 months.

Non-exposed and exposed specimens were physically and mechanically tested and the results compared to assess the chemical effect on the specimens. The results showed that for HDPE geomembranes, there are only small differences between exposed and non-exposed specimens. The thicker the membrane, the better was the resistance against chemical aggression. The R-CSPE specimens performed quite poorly and showed significant increase of volatile content, thickness and mass, as well as tensile and shear strength.

Both geotextile materials performed well at low temperatures, but at 70^{o}C the polyester showed a decrease in properties; polyethylene material seemed to have better properties than polypropylene.

Lord et al. (11) presented an interesting and complete review of the different degradation processes that decrease the durability of a geomembrane. The geomembrane may dissolve in the surrounding liquid, if the solubility parameter matches with those of the compounds of the liquid. This problem is easily avoided by conducting the tests in the appropriate liquid.

HDPE materials are not affected by alcohol or detergents, however, they are moderately affected by hexane, toluene, and carbon tetrachloride provoking stress relaxation. HDPE is severely affected (show high stress relaxation) in halogenated hydrocarbon perchlene. It should be noted that the moderate effect in most hydrocarbons and the severe effects in halogenated hydrocarbon perchlene will cause more or less stress relaxation in HDPE materials coupled with creep.

This paper reviews a study done by the Hoecht group on the chemical resistance of polymer in contact with four different liquids: a) aqueous solutions of strongly oxidizing substances, b) aqueous solutions of non-oxidizing inorganic substances, c) aqueous solutions of wetting agent, and d) organic materials. It was shown that the wetting agent may have the tendency to decrease the material’s lifetime. This tendency may even be more accentuated in swelling agent testing.

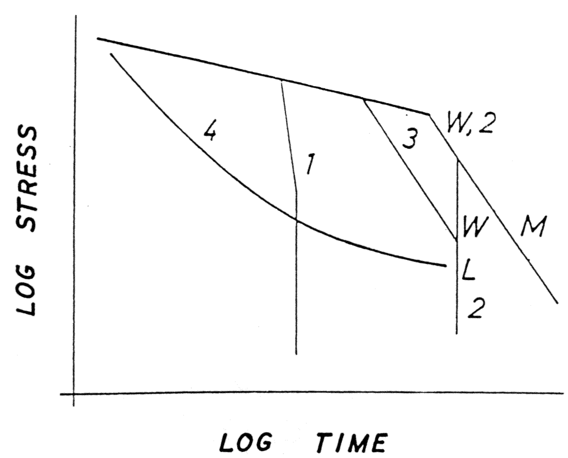

Figure 38: Burst test in presence of different chemicals (11)

Chemical degradation is one of the main phenomena affecting geomembranes (12), since in most of the liners the geomembrane or geosynthetics materials are in contact with the leachate, which is very often aggressive to the polymer. Many studies have been performed using the EPA test method 9090, by comparing exposed and non-exposed samples with physical and mechanical tests. The exposure was in different solutions, duration, and temperatures.

Three degrees of degradation are possible:

If no degradation occurs, the material has been proven to resist the test condition (temperature, leachate, duration, etc.) but not other conditions.

Swelling may occur, which is not a real problem if the phenomenon is monitored with care, since swelling is often the earlier sign of further degradation.

If the physical and/or mechanical tests show degradation, the material is not sufficiently resistant to the test conditions.

Oxidation degradation is the creation of free radicals that may activate chain scission. The reaction between carbon and oxygen atoms creates an hydroperoxy radical, which is passed around the molecular structure and can lead to chain scission.
The chemical reactions are given by:

$$R^{\cdot} + O_2 \rightarrow ROO^{*} \qquad [3.6.5]$$

$$ROO^{\cdot} + RH \rightarrow ROOH + R^{*} \qquad [3.6.6]$$

with R^{*} = free radical
ROO^{*} = hydroperoxy free radical
RH = polymer chain
ROOH = oxidized polymer chain

In order to prevent this problem, anti-oxidants are embedded within the material, they stop the chemical reaction; another procedure is to eliminate oxygen from the material and then cover the geomembrane.

* *Biological:*

Micro-organisms are potentially harmful when only moisture, temperature, and organic matter (5) are present simultaneously, which is not the common case in most current landfills. However, to prevent damage biocides and fungicides may be added to the PVC membrane.

Biological stresses are a little less compromising for geosynthetics, since biological organisms are unlikely to damage the material, however they can clog the drainage system and deteriorate the whole landfill (2). To prevent the material from clogging, special care must be taken by using low surface energy compounds, biocides by either incorporating them in the material, or by coating them, or by flushing the drainage system.

Biological degradation is the formation of bio-organisms (bacteria, actinomycetes, fungi, and algae) that can alter the properties of liner material (12). Polymer degradation is generally unlikely due to the high molecular weight of the resin, however plasticizers or additives may be attacked. Also, small mammals may cause physical damage.

* *Mechanical stress:*

Mechanical stresses are also very harmful to the material: scratch, seaming imperfections, and fabrication flaws may cause crack failures or decrease the creep properties of the material.

* *Swelling:*

The swelling degradation is function of the liquid in which the membrane is exposed. When plasticizers are extracted, the material tends to shrink. Swelling is limited in membranes embedded with high percentage of plasticizers since only the polymeric compound swells. Moreover, swelling is limited by crosslinking phenomena (1).

Degradation by swelling, as seen previously is not a very harmful problem and is not automatically associated with chain scission. But swelling is a good means to judge the material durability: the more the swelling , the less the material is susceptible to liquid absorption (12).

* *Radiation:*

Radiation degradation is due to γ and β rays penetrating and damaging the polymer material. β rays penetrate only the surface (about one millimeter), while the γ rays may penetrate the total thickness (12).

These radiations are only harmful to polymers at high intensities above 10^6 to 10^7 rads, compared to maximum levels of radiation acceptable for human beings, which is only 100 to 200 rads, Thus, except in radioactive environments, the geomembranes should not suffer damage from radiation. However, even at low radiation levels, small degradations may occur especially at the material surface. This degradation may cause loss of strength and stress-cracking.

* *Aging properties of membranes immersed in leachate:*

Surmann et al. (13) carried out two aging tests and studied the effect of irradiation on HDPE geomembranes. The immersion in leachate, combined with a light tensile strength as well as the multifunctional cell test, did not show important differences between virgin and aged geomembranes; even the leachate had no influence on the material tested. However, the test period was only 2 years; an increase of this time up to 5 years may give different results. Comparing the results of virgin and γ irradiated geomembranes, the effects of irradiation are clearly apparent: breaking and branching of the molecular chains results in the loss of the material's thermoplastic characteristics, as well as a change in the atomic arrangement.

Duquennoi et al. (14) tested a wide variety of liner materials to assess their aging properties. After 50 months of immersion in two different leachates and distilled water at 20^oC and 27 months at 50 ^oC, the materials were tested using uniaxial and biaxial tensile tests to determine the macroscopic effect of leachate. They were also tested using Fourier Transform Spectroscopy, which enables evaluation at the molecular level. Sliced samples were analyzed under infrared light providing distribution profiles of the compounds.

However, opaque materials such as EPDM and bituminous geomembranes, cannot be tested by this method. So photoacoustic spectroscopy was used.

EPDM geomembrane made from an elastomer terpolymer of Ethylene-Propylene-Diene-Monomer, loaded with additives for protection against oxidation, showed increase in rigidity but no important differences in tensile properties. No chemical changes were noticed, even if water was absorbed at the surface of the specimen. It also appeared that absorption increases with immersion time. Physical modification of material, as cross-linking, may explain the water absorption and the increase in rigidity of the geomembrane.

SBS/bituminous membranes made of a polyester nonwoven geotextile, impregnated with bituminous and a Styrene-Butodiene-Styrene Copolymer, showed no difference in mechanical properties. Chemical evolution and water absorption were noticed in the leachate and water immersion cases.

PVC membranes with DOP additives are characterized by a material softening in each direction tested (uniaxial and biaxial tests showed identical results). This softening phenomenon may be due to the lubricant effect of absorbed water in the material. Plasticizers were observed varying differently depending on the immersion leachate. However, it was not possible to determine the effect of plasticizers on the mechanical properties. PVC with EVA plasticizer showed an oxidation of the plasticizer of a lower order than PVC loaded with DOP.
HDPE specimens did not exhibit changes in tensile or chemical properties. Nevertheless, at 50^{o}C a small amount of ester-type antioxidant was lost probably indicating possible accelerated aging with high temperature. For PP geomembranes, neither mechanical nor chemical changes were observed.

This study proved the almost identical effect of leachate and distilled water on geomembrane aging, phenomena associated with very low concentration of organisms in the leachate. Accelerated aging occurred at 50^{o}C, but not at 20^{o}C. No chemical evolution occurred in the polymer matrix, but plasticizers were extracted.

Acidic, or basic diluted solutions and salts did not degrade the PVC. To prevent possible effect of hydrocarbons, specific plasticizers need to be used. Since a thicker membrane incorporates more plasticizers than a thin one, the degradation will be spread over a longer time.

* *Extraction:*
The effect of water in the plasticizer loss process may be negligible, if the correct formula is used; in this study a rate of 0.8 g/m^2/year was observed.

Extraction may occur long term by the loss of certain components of the compound; the materials affected by extraction are mainly those incorporating plasticizers or fillers (12). Extraction is associated with material embrittlement, which is characterized by an increase of modulus and strength, as well as a decrease of elongation at failure.

** Combined effects:*

Combined stresses are very harmful to the material, since chemical exposure can change the material composition, the mechanical properties will also change (2). One of the most serious concerns of combined stress is the stress-cracking caused by a change of chemical composition, acting simultaneously with a mechanical stress (see stress–cracking chapter).

All the degradation phenomena can act simultaneously, and become a lot more aggressive to the liner material. Synergetic effects increase the degradation of the material due to elevated temperatures when mechanical stresses are applied and during long exposure (ultraviolet, radiation, chemical agent), (12). Obviously the more simultaneous aggressive parameters, the more the geomembrane is attacked, and the less will be its resistance.

3.6.7 Assessment of long term aging through tests

Cassidy and Bright (15) evaluated the durability of geosynthetics materials after 9 years of natural weathering. PP, HDPE, and HMW uncovered membranes were exposed to field conditions in the Atlanta region. The results show that chain scission occurs in PP material, and cross-linking in HDPE. The changes are a function of the quantity of additives included in the product; generally the more additives, the more resistant the membrane. It was also shown that a concentration of 5 % of additives in the total weight will prevent a large amount of deterioration in tensile strength for the long-term exposure. Carbon black is a very effective means for preventing damage from UV light, a minimum of 2% by weight will be sufficient.

Fayoux et al. (16) assessed a PVC geomembrane after 10 years of utilization in a collective waste disposal site. Samples were taken at different locations of the liner, some samples were exposed to the leachate, some to UV light, and others to contact with stones. It was noticed that after 10 years the elongation and stress at failure are not affected and their values correspond to those at initiation of exposure.

At the bottom of the pond, the material was affected by a slight increase in modulus. The critical zone was located at the water table, where the geomembrane was subjected to simultaneous action of light, wave, and leachate. The loss of plasticizer was about 0.35 % per year in and outside the water, a value which is not dangerous for the integrity of the material. The minimum effect of the liquid on the material is explained by the very low concentration of solvent in the leachate, making the leachate not so aggressive to the liner.

Rollin et al. (17) investigated a seven-year old geomembrane placed in a landfill. After seven years of activity, the geomembrane was excavated and tested to assess the effect of aging. Samples from different locations were taken and tested for comparison of mechanical properties (tensile strength, tensile and peel resistance of seam, brittleness of sheet and seams, and microanalysis of cracks) with those of the initial liner.

Differences between the initial and the used membranes properties indicate that aging is more important at the bottom of the liner than at the slope and cover. The aging is

characterized by an increase of yield strength, decrease in the tensile resistance at rupture, and a reduction in the elongation at break.
Seams did not suffer much, since they were only subjected to a decrease of strength of the order of 5 to 20 percent. Also, no seams were debonded and only 2 cracks were observed.

3.6.8 Summary

Haxo et al. (1) summarized the effect of membrane exposure to weathering and waste in Table 24.

Table 24: Effect of Geomembrane Exposure to Weathering and Waste (1)

Process	Effect on membranes
Weather exposure:	
- oxidation	- stiffen and lose tensile strength, elongate, tear
- elevated temperature	- reduction of mechanical strength and degradation, generally stiffen, but sometimes softens
- ozone	- cracks at points of strain
- UV light	- stiffen and crack
- Loss of volatile plasticizer	- stiffen and can become brittle
- High humidity	- water absorption, leaching of anti-degradant resulting in greater susceptibility to oxidation and UV
Waste exposure:	
- Swelling	- soften accompanied by loss of properties, including increase in permeability
- dissolving	- hole or general loss of barrier function
- extraction of plasticizer	- may stiffen and lose elongation
- extraction of anti-degradant	- make more susceptible to degradation
- stress	- creep of liner, cracking, and breaking
Combination of waste and weather exposure:	combination of weather and waste exposure, often more severe than either alone
Biodegradation if oxygen is present:	plasticizers, oils and monomeric organic molecules can be degraded

Haxo et al. (1) summarized the factors affecting durability as follows:
Compatibility factors with waste liquids:
- chemical

- physical

Weathering factors – geographic location:
- solar radiation
- temperature
    - elevated
    - depressed
    - cycles and fluctuations
- water: solid, liquid and vapor
- normal air constituents: oxygen and ozone

Stress factors:
- stress, sustained, and periodic
- stress, random:
    - physical action of rain, hail, sleet, and snow
    - physical action of wind
    - movement due to other factors: settlement
    - discontinuity at penetration

Use and operational factors:
- design of system, groundwork and installation
- operational practice

Biological factors

3.6.9 References

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3.7 Other Problems Affecting Geomembranes Life

The previous sections of this report presented the main problems associated with liners. This section deals with other important problems that have not been very well addressed in the literature.

3.7.1 Contaminated lifespan and stochastic analysis

Rowe and Fraser (1) assessed the long-term behavior of engineered barrier systems and developed a stochastic analysis for service life. The lifespan of a contaminated landfill corresponds to the period during which the environmental hazardous contaminants are produced by the landfill. It is obvious that to ensure the integrity of the landfill, the material used, especially the liner and any other material used to contain leachate, must have a service life longer than the contaminated landfill lifespan.

The contaminating lifespan is a direct function of the landfill rate of infiltration through the cover. Hence, large landfills with low infiltration rates may have lifespans as long as 600 years, while large landfills with high infiltration rates may have lifespans of the order of 200 years. Stochastic analysis provides information on the effect of leachate concentration on uncertain service life, by using Monte Carlo simulation.

3.7.2 Residual stresses

Lord et al. (2) carried out an interesting and complete study of residual stresses in geomembrane sheets and seams. Residual stresses are a very likely in geomembranes; they are induced by the fabrication and placement of the membrane. Those stresses are more likely to occur in high crystalline polymers, which are often more brittle.

The authors measured residual strains with the drilled hole technique. The results showed reasonable residual stresses with compressive stresses of about 5 to 10 percent of the yield value.

3.7.3 Geomembrane uplift by wind

Giroud et al. (3) published a very detailed paper on the effect of wind on geomembranes. As in airplane wings, a geomembrane is uplifted either by suction or wind flow between the soil and the membrane, see Fig. 39 for actual geomembrane uplift. Most of the time, an uplifted membrane will not be damaged but will be either torn, pulled out off its anchor trench, or ripped off a rigid structure.
Fig. 40 and 41 show the pressure distributions on a geomembrane due to wind for two different cases.

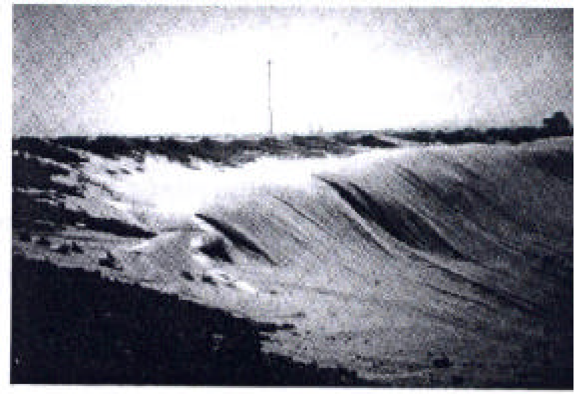

Figure 39: Geomembrane uplift (3)

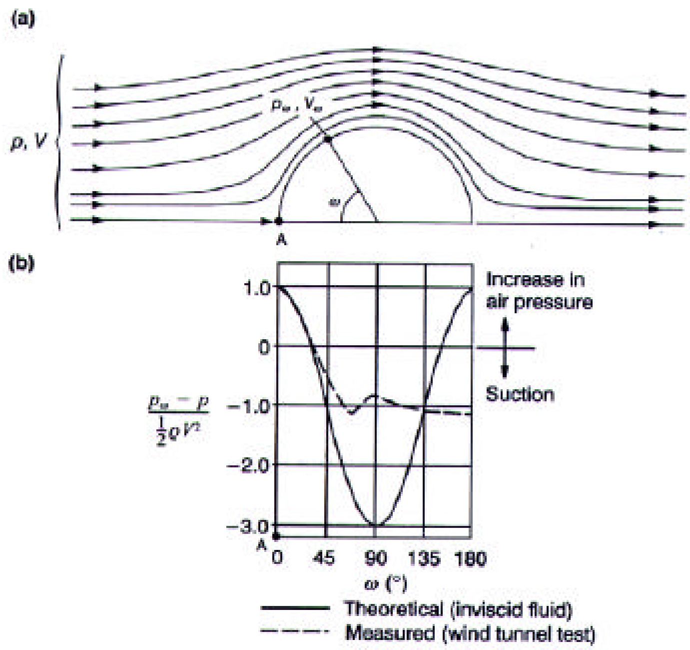

Figure 40: Pressure distribution on the surface of a cylinder (3)

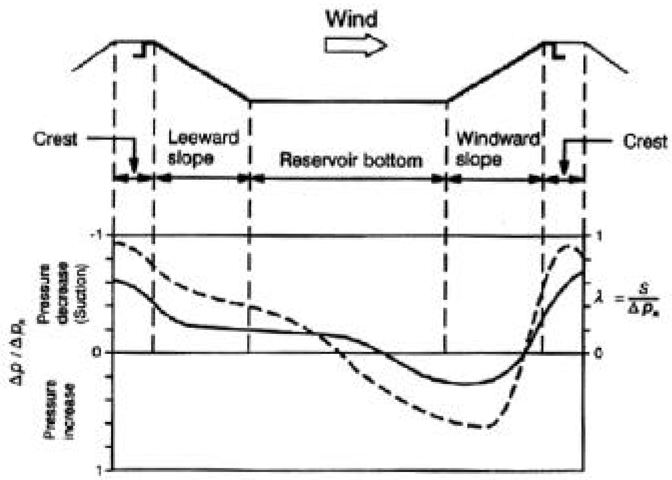

Figure 41: Wind blowing over an empty reservoir (3)

The authors presented equations validated by experimental data, relating the maximum available wind velocity to the required thickness, and strain induced in the geomembrane.
Factors affecting geomembrane uplift are the wind velocity, altitude above sea level, and location of the membrane in the facility (the crest of a dike is a more sensitive location than the bottom). The membrane unit weight is also a very important parameter in the case of slow or medium speed wind: the heavier the geomembrane the less sensitive it is to wind effects.
High modulus material will deform less than the low modulus one, but will be affected by a larger tension. At low temperatures, the geomembrane will deform less but the internal forces will be greater. The authors also presented different means to prevent geomembrane uplift. The most effective procedure is to place a protective cover over the membrane (soil, rock, concrete slab or bituminous revetment). Sandbags spread over the liners are efficient only for low speed wind.

3.7.4 Rate of leakage through membranes
The EPA (4) provides a complete report on geomembrane liner leakage, that was based on studies made by Giroud and Bonaparte (11), Brown et al. (12), and Fukuoka (13, 14). The report lists the different methods of leakage through membranes, as well as the equations associated with leakage phenomena.

- Vapor diffusion through intact geomembrane is due to the liquid or vapor pressure difference on each side of the membrane. This transport takes place only at the molecular level, since the voids between the molecular chains of the polymer are very small. Darcy and Fick laws are used to establish the geomembrane leakage rate.

- Leakage through holes in geomembranes is due to the presence of flaws resulting from pinholes (generally polymerization deficiencies), seaming errors, abrasion and puncture. The rate of leakage of the leachate depends on the nature of contact between the geomembrane and the surrounding soil, the worst case corresponds to free flow in the case of very poor contact, the better case corresponds to a perfect contact which decreases the leakage rate.

The following equations were derived:

For free flow:

$$q_{L1}(k)_i = K_g(k)\frac{h_g(k)_{i+}T_g(k)}{T_g(k)}$$

…………[3.7.1]

where:

q_{L1} $(k)_I$ = geomembrane leakage rate by diffusion during time step i.

$K_g(k)$ = equivalent saturated hydraulic conductivity of geomembrane in subprofile k, (inches/day)

$H_g(k)_i$ = average hydraulic head on geomembrane liner in subprofile k during time step (I, inches)

$T_g(k)$ = thickness of geomembrane in subprofile k, (inches)

Free flow through geomembrane defects:

$$q_{L3}(k)_i = \frac{86{,}400 C_B n_3(k) a_3 \sqrt{2gh_h(k)_i}}{4046.9}$$

…………..[3.7.2]

where:

$q_{L3}(k)_I$= leachate rate through defects in subprofile k during time step I (inches/day)

C_B = head loss coefficient for sharp edged orifices, 0.6

$n_3(k)$ = installation defect density for subprofile k, #/acre

a_3 = defect area, 0.0001 m^2

$h_g(k)_I$ = average hydraulic head on geomembrane liner in subprofile k during time step I, (inches)

For pinholes in geomembrane with perfect contact:

$$q_{L2}(k)_i = \frac{p\, n_2(k) K_s(k) h_g(k)_i\, 0.04}{6{,}272{,}640}$$

………………………..……[3.7.3]

where:

$q_{L2}(k)_i$ = leachate rate through pinholes in subprofile k during time step I, (in/day)

$N_2(k)$ = pinhole density for subprofile k, #/acre

$K_s(k)$ = saturated hydraulic conductivity of soil layer at the base of subprofile k, (in/day)

a_3 = defect area, 0.0001 m^2

$h_g(k)_i$ = average hydraulic head on geomembrane liner in subprofile k during time step I, (in)

0.04 = diameter of a pinhole, 0.04 in

6,272,640 = units of conversion, 6,272,640 in^2 per acre

Leakage can occur vertically through the membrane or flow horizontally in-between layers of geomembranes and soil, causing soil erosion, Fig. 43.

Shivashankar et al. (6) reported experimental determination of flow patterns in geonets and presented new design formulation. The work was based on previous study by Giroud (7,8,9,10) who formulated an expression for the rate of leachate through liners. The experiments were done using a box mounted on a tilt-table, a constant flow was ensured by a system of tanks, Fig. 42. This study presents a new methodology for prediction of more accurate values of wetted areas in the geonet due to top liner leak, and also provides information on the probability of zero leakage into the ground. Finally, the authors developed modifications for the Giroud equations.

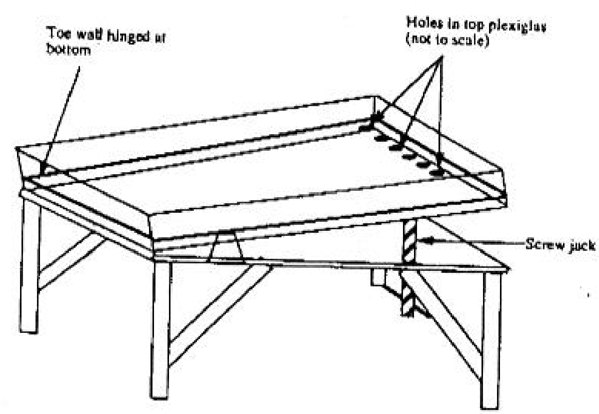

Figure: 42: Schematic of a tilt-table (6)

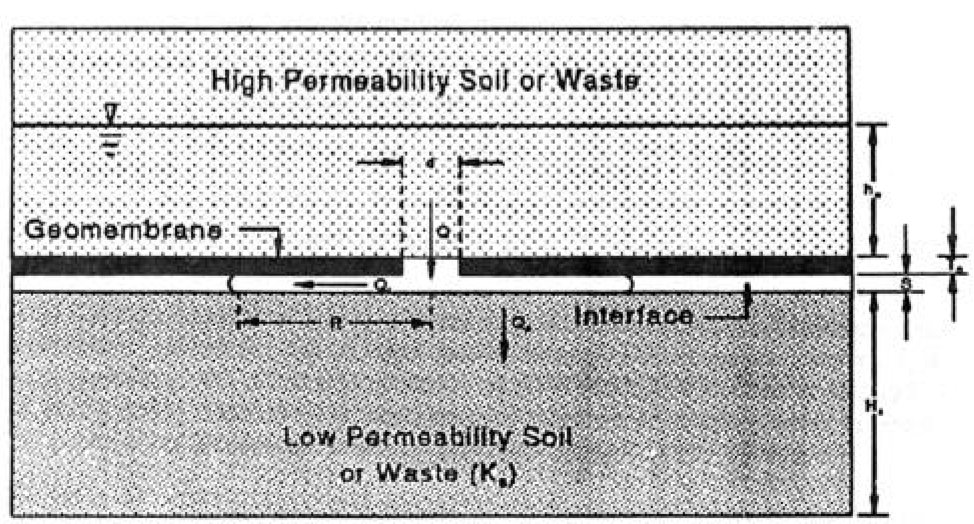

Figure 43: *Horizontal flow between the soil and the geomembrane (4)*

To conclude this section, reference must be made to the paper "Geomembrane Liners: Accidents and Preventive Measures" by Giroud (5), which summarizes all the problems that a geomembrane liner may encounter. The geomembrane deficiencies are listed for the different stages of the membrane life: manufacturing, fabrication, transportation, storage, placement, seaming, and placement of the material on geomembrane. The causes of the defects are listed for each stage.

Then the characteristics of the aging process are listed as follows: blistering, delaminating, cracking, increase of stiffness, shrinkage. The causes for induced distributed and concentrated stresses are as follows: uplift by wind, earth slides on slopes, erosion of ground supporting the liner, punctures, abrasion, and tear. Finally the measures to solve the problems are outlined.

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4 Design, Construction, and Quality Program

4.1 Design

Koerner (1), devotes a complete section of his book to the design of landfill liners with geomembranes. The design consists of the following steps: site selection, geometric layout, geotechnical considerations, cross-section determination, geomembrane material selection, thickness determination, side-slope and cover soil details, anchor trench details, seam type decision, seam testing strategy, design of connections and appurtenances, leak scenarios and corrective measures, proper MQC (Manufacturing Quality Control) and CQC (Construction Quality Control), and finally proper MQA (Manufacturing Quality Assurance) and CQA (Construction Quality Assurance). The author provides detailed information on the different aspects of the liner design, and also summarizes the different problems to consider during design.

Richardson and Koerner (2) summarized the problems associated with the design of liners, Table 25.

Table 25: Problems Associated with Liner Design (2)

Problem	Liner Stress	Required Properties		Typical Factor of Safety
		Geomembrane	Landfill	
Liner self weight	tensile	G, t, σ_{allow}, δ_L	β, H	10 to 100
Weight of filling	tensile	t, σ_{allow}, δ_L, δ_u	β, h, H, γ	0.5 to10
Impact during construction	impact	I	D, W	0.1 to 5
Weight of landfill	Compression	σ_{allow}	γ, H	10 to 50
Puncture	puncture	σ_P	γ, H, P, A_p	0.5 to 10
Anchorage	tensile	t, σ_{allow}, δ_L, δ_u	β, γ, ϕ	0.7 to 5
Settlement of landfill	shear	τ, δ_u	β, γ, H	10 to 100
Subsidence under landfill	tensile	t, σ_{allow}, δ_L, δ_u, χ	α, γ, H	0.3 to 10

where:

Geomembrane properties:
G = specific gravity
T = thickness
σ_{allow} = allowable strength
τ = shear strength
I = impact resistance
σ_P = puncture strength
δ_u = friction with material above

Landfill properties:
β = slope angle
H = landfill height
γ = unit weight
h = lift height
α= subsidence angle
ϕ = friction angle
d = drop height

δ_L = friction with material below
χ = mobilization distance

W = weight
P = puncture force
A_p = puncture area

Giroud et al. (3) described a design method based on strain calculations. Geomembranes are usually not structural elements, so it is more convenient to base the design on strain than stress. The first step is the determination of the maximum allowable strain ε_{max}. ε_{max} separates the safe part from the failure part of the membrane behavior. For HDPE, ε_{max} corresponds to the yield strain. This value may be determined using a biaxial test. In order to obtain a correct factor of safety, it is necessary to obtain an accurate ε_{max}.

The second step is the determination of the effective strain accounting for the stress concentration factor. Strains are induced by deformation of the membrane due to thermal contraction, differential settlement, etc.

Finally, the factor of safety was obtained by calculating the ratio of the maximum allowable strain to effective strain. Obviously, to ensure proper use of the membrane, the factor of safety must be larger than the one selected by the designer.

4.2 Safety Analysis

Heibrock and Jessberger (4) presented a safety analysis for a composite liner system, explaining the different properties that a safe liner should feature. These properties are listed in Table 26:

Table 26: Requirement of a Safe Liner System (4)

Requirements	Properties that need to be checked	Site specific influences
Imperviousness Pollutant migration through the liner system should be comparable to that for a definable standard size	a) Permeability of the liner system hydraulic conductivity, diffusion coefficient, retention capacity b) Sensitivity of the system to imperfections	• hydraulic gradient • kind of pollution • amount of soluble pollutant • concentration of pollutant in solution • temperature If a composite liner is considered: • kind of clay • zone of higher permeability • deformation or desiccation • overburden loads
Stability The liner system should be stable with respect to the mechanical influences	Shear resistance Cohesion (residual/non residual values)	Mechanical influences: • forces resulting from deformation • forces resulting from overburden loads and

without significant change in its leachate behavior		inclination • forces resulting from construction procedures
Resistance If proved that the lining system being exposed to the site specific influences is still stable and sufficiently impermeable. Combination of influences should be considered	Resistance to leachate Resistance to gas Resistance to temperatures Hydraulic resistance Resistance to exposure	Chemical influences: • kind of composition of leachate • duration of exposure Thermal influences: • low/high temperature • duration of exposure hydraulic influences: • forces resulting from water movements • climate, hydrogeology of the site

The authors also presented the different criteria listed below to ensure the safety of the liner.

- Description of the liner system:
  Design of liner system, description of the materials and function of elements. Definition of requirements for the liner system and its elements.

- Description of the basic landfill concept:
  Type, amount, and geotechnical parameters of the waste, geometry of the waste disposal facility, hydrogeology and climate of the site, basic description of the operation phase (biological treatment, duration of waste placement, time of placement of the capping system, etc.), maintenance.

- Assessment of the controlling factors:
  Quantification of the controlling mechanical, thermal, chemical, biological, and hydraulic factors with respect to construction, operation, and the post-operation phase. Simplifying and idealizing assumptions may be necessary.

- Description of the time-dependent development of the properties of the liner system

- Proof of the stability of the liner system

- Analysis of material properties after construction
  Interpretation of test fields, description of varying properties

- Analysis of the leakage behavior of the liner system
  Description of contaminant migration with respect to the assessed influences and the material properties after construction.

- Description of a monitoring program
  Documentation of the operation phase, measurements to check the assumptions concerning the controlling factors.

As an example, the safety of a composite liner system made of HDPE geomembrane layer associated with a clay layer was studied. By analyzing the properties of the geomembrane and clay, before and after construction, and the assessment of the leakage behavior of the system it was concluded that this type of lining system (composite HDPE and clay) was very safe.

The estimated safe life of this lining system is approximately 80 to 100 years for the geomembrane, if no mechanical stress is induced by different mechanisms such as movement at the interface of the waste/geomembrane.

4.3 Construction/Installation

Voskamp et al. (5) listed the problems occurring during the installation of a liner. Those problems can be attributed to two separate causes: improper design and/or improper execution.

Problems due to improper design:

- The soil supporting the liner may cause a certain number of problems, depending on the degree of compaction, geometrical shape, or the presence or absence of a crust layer.
- The geomembrane is placed as a safety feature in an already designed system; the design of this system does not include the membrane, which can lead to a component that is exposed to a load larger than its capacity.
- Wrong installation can be extremely harmful; for example leaving a membrane exposed to sun radiation will damage its structure.
- Wrong requirement of the condition of the fill over the membrane may induce damage, since excessive compaction will increase the stress inside the material possibly leading to rupture.

Problems due to improper installation:

- The use of prefabricated sheets seems efficient as it requires less seams, but a major drawback is the difficulty to handle the roll which can weigh as much as 1500 kg.
- Exposed membranes will be damaged by weathering action, so they should always be protected from exposure.
- Installation not in accordance with the specifications, such as uncontrolled dumping of stone on membrane should not be allowed.
- It is possible that a different geomembrane from the specified one is installed which can lead to catastrophic consequences since the properties may differ totally. To prevent this problem the whole membrane roll should be marked.
- Damage during installation may result from equipment driven directly on themembrane, use of improper equipment (too heavy), improper handling of the membrane, or uncontrolled dumping of fill.

The book "Geotextiles and Geomembranes in Civil Engineering" (6) treats the design of geomembranes. The problems to be taken care of during the design are explained, and equations provided to determine the bearing capacity of the geomembrane submitted to normal, tensile, and shear forces. Also listed are the different failure mechanisms affecting the membrane's life, which can be avoid by proper design. These failure parameters (chemical attack, micro-organisms, UV radiation, etc.) have been addressed in chapter dedicated to geomembrane aging.

The authors also present some specific aspects for geomembrane installation: as indicated many times, the process of member fabrication and installation must be carried out with the greatest care to minimize the damage that may be induced. The ground on which the membrane is laid down must be stable, uniform, and free from sharp objects. The soil should also be uniformly compacted, using a Proctor test to verify the soil density. The installation site must be clean and free for easy access of the workers and equipment.

During the laying of the prefabricated sheet, special care must be taken to ensure that it is the correct side of the sheeting that faces up, also the sheet must be placed without tension or folds, and anchored properly. The sheet should be at least 5 m wide to minimize the seam areas. The seaming must be done carefully to decrease the possibility of flaws (the chapter dedicated to seams provides more detailed information).

The membrane interface conditions should ensure that no stress concentration is induced (since settlement differences induce stress concentrations). A good solution to prevent this problem is to a use flexible membrane, which can absorb the differences in settlement. Damaged geomembranes or seams can be repaired with a patch large enough to cover the flaws.

Fig. 44 to 46 give examples of some details that must be considered during design and construction. Fig. 44 presents the details of pipe penetration emphasizing the manner with which the liner covers the pipe and is attached to both the soil and pipe. Fig. 45 shows the set-up of a roll spread bar that should be used when lining the geomembrane. Finally, Fig. 46 presents a U anchor trench of 15' deep x 2'.

Fabrication details:

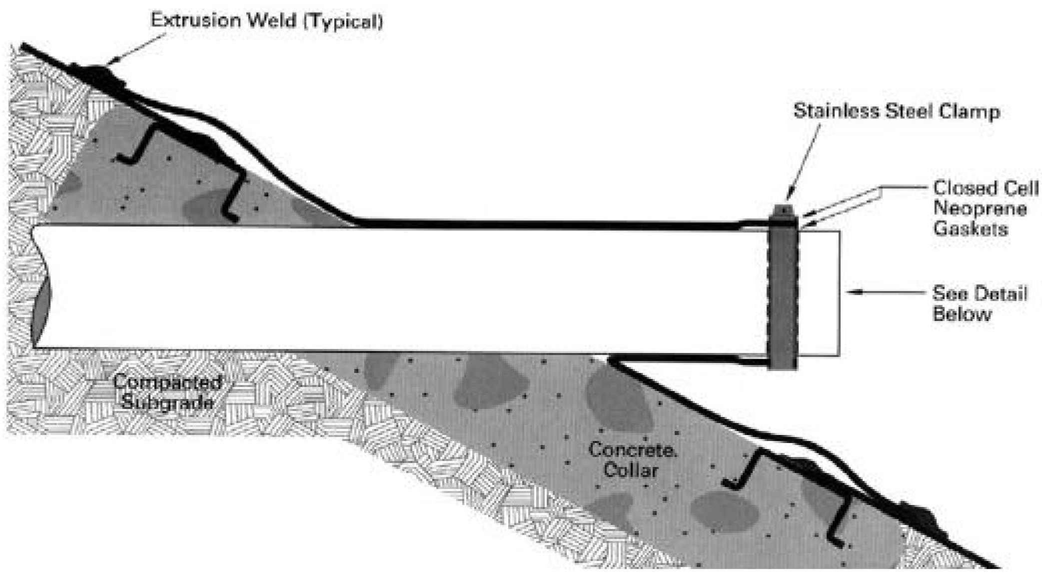

Figure 44: Pipe penetration (13)

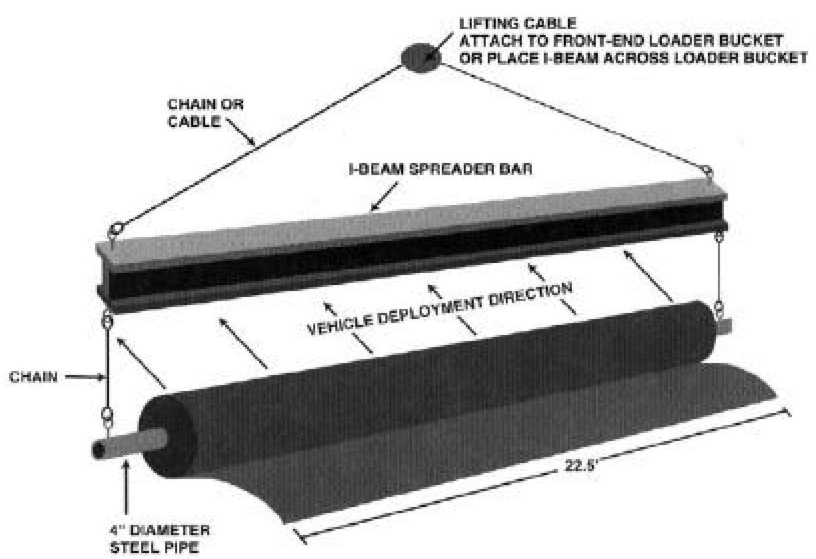

Figure 45: Roll spreader bar (13)

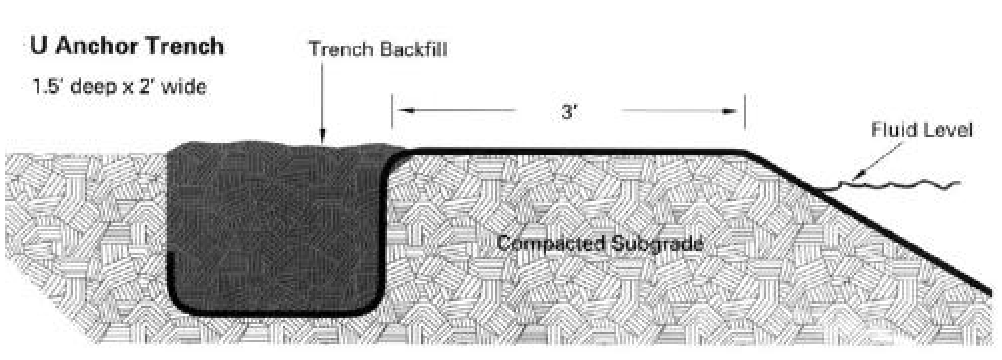

Figure 46: Anchor trench (13)

4.4 Quality Control

Inspections of the correct installation and functioning of the liner must be based on quality control (QC) and quality assurance (QA) criteria. Koerner (1) has defined the differences between the tools used for quality control:

- Manufacturing Quality Control (MQC) is a planned system of inspection specifically used for the control and monitoring of a product fabrication, usually followed by the geomembrane manufacturer.

- Manufacturing Quality Assurance (MQA) is a planned system of activities assuring the proper manufacturing of product vis-a-vis the specification document. This includes fabrication facility inspection, verifications, audits and inspections of the raw material. This is also the responsibility of the manufacturer.

- Construction Quality Control (CQC) is a planned system of inspection used to control and monitor the quality of a construction project by the geomembrane installer.

- Construction Quality Assurance (CQA) is a planned system of activity assuring that the facility is constructed according to the design.

In order to optimize quality control it is necessary to associate MQC/CQC and MQA/CQA., since MQA/CQA will allow the detection of flaws occurring during the MQC/CQC phase.
Fig. 47 presents the structural organization of MQC/CQC and MQA/CQA.

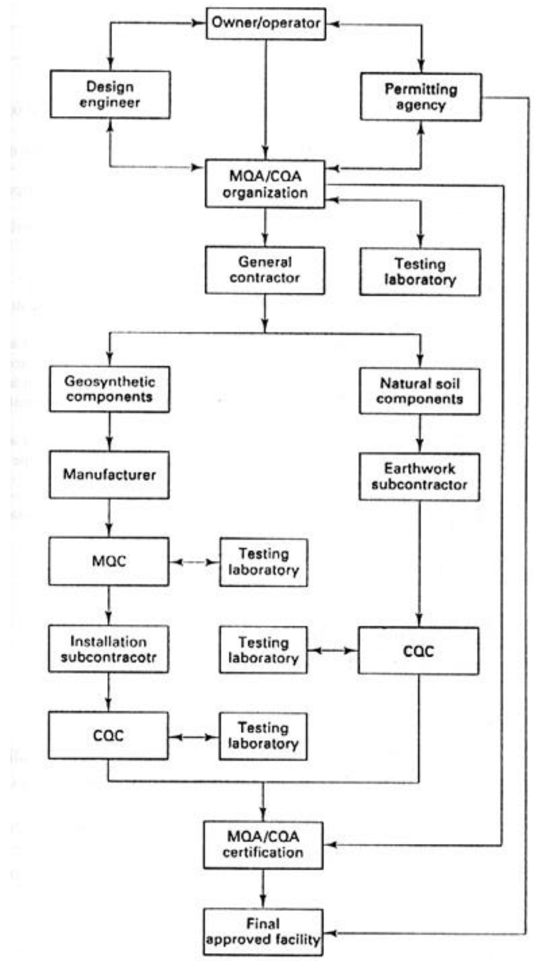

Figure 47: Structural organization of MQC/MQA and CQC/CQA (14)

The three basic components of a proper CQA program have been described by Giroud and Peggs (7) as follows:

- Conformance verification which ensures that the delivered geomembrane meets the specifications.
- Integrity verification, which ensures that the geomembrane is, installed to conform to the design and installation specifications.
- Survivability verifications, which ensure that the membrane will fulfill its functions in the expected time period.

Before shipping the geomembrane rolls to the installation site, a CQA plan must be adopted, and the following actions must be implemented:

- Visual inspection of the rolls.

- Carry out tests following the QC plan and sign the QC report to indicate the material conformity
- Remove and submit samples to the testing laboratory
- Monitor the loading of the roll for transport, only approved rolls should leave the plant.

Peggs (8) suggested the additional procedures to complete a CQA plan for the installation of HDPE. Those will reduce the stress cracking phenomena that mainly affect HDPE material:

- The slackness criterion must be incorporated into the design and construction of the liner, the amount of folds, and wrinkles must be minimized to a number close to zero.
- Damaged or improper seams must be repaired by extrusion seams, since it has been shown that re-seaming does not reduce the stress cracking resistance of the member.
- During the grinding operation, no defect larger than 10% of the sheet thickness must be left.
- Peel tests must be carried out on double hot wedge seams.

To ensure the proper design, installation, and functioning of a geomembrane, the following procedures must be carried out:

At the design stage:

- Select the two best geomembranes based on stress cracking and seam properties
- Select the best two based on chemical compatibility
- Chemical resistance evaluation must include both thermal and chemical structural analyses.

At the pre-construction stage:

- Monitor production and QC testing in the plant
- Perform testing before the rolls leave the plant

At the construction stage:

- Conduct destructive testing of the seams, and assess the shear and peel resistance of the seams
- Carried out non-destructive tests on seams: vacuum box, air pressure, ultrasonic, or electrical survey methods

At the post-construction stage:

- Conduct an electrical survey to detect holes in the geomembrane under drainage/ protective soil cover

A report by the Solid Waste Authority (9) lists all the factors that need to be taken into account in the fabrication and installation of a liner with minimum flaws.

Geomembrane quality control documentation:

- A meeting should be convened before the commencement of the work with the following participants involved in the installation of the liner:
  - owner's representative
  - field installation manager
  - installation manager
  - master seamer
  - contractor's representative
  - engineer's field representative
  - quality control laboratory representative
  - quality control technician

- The following documentation should be kept on site during the project duration:
  - start-up
  - liner pre-delivery
  - liner delivery
  - daily checklist
  - geomembrane panel placement
  - onsite geomembrane welding report
  - damage and failure report
  - post installation check list
  - daily field log

- Qualifications of the personnel:
  - The manufacturer must have proved his/her ability for the production of the liner: 5 years of continuous experience and fabrication of a minimum of 50 million square feet. The company should be certified and registered by NSF standard 54.
  - The installer should be the manufacturer or an approved installer.

- Packaging and shipping must be carried out with great care to prevent damage to the geomembrane.

- The rolls should be stored properly to protect them from puncture, dirt, yearn, water, moisture, mechanical abrasion, and excessive heat.

- The manufacturer should warranty the material against manufacturing defects for an exposed period of 20 years.

- The contractor should provide a two-year warranty against installation or workmanship defects.

- The material should be made of new prime first quality product. No pinholes, holes, blisters, or flaws must be present in the material. The rolls should be at least 22.65 feet seamless wide and labeled.

- Extrudate welding rods must be of the same compounds as that of the raw material.

- The quality control documentation should comprise the following:

  - origin identification and production of the resin
  - copies of quality control certificates issued by the resin supplier
  - Manufacturer's certification verifying that the quality of the resin used for the fabrication meets the specifications.
  - Identification of information for each roll: manufacturer name, product identification, thickness, roll number, and dimensions.
  - Quality control certificates featuring identification number, sampling procedure, frequency, and test results.

- Conformance testing (thickness, density, tensile properties, tear resistance, carbon black content and dispersion) must be carried out by an independent quality assurance laboratory.

- The surface sub-base must be smooth and uniform, without depression or protrusions larger than one inch, free from rocks, stones, or debris. No water must be present during installation and seaming.

- The installation of membranes should be done in the temperature range of 40 ^{o}F and 104 ^{0}F, and no installation should be done during precipitation, excessive moisture, or excessive wind.

- The panels must be rolled out and installed in accordance with the approval shop drawings, ensuring that the seams are perpendicular to the top of the slope. The engineer's field representative should inspect each panel, after placement and prior to seaming, for damage or defects. The sheets must not be dragged on a rough sub-base. The geomembrane must be anchored according to the drawings. The personnel working on the liner should not smoke, wear damaging shoes, or induce any damage.

- The edge of the membrane sheet must be bonded with weights to prevent uplift by wind. No vehicular traffic on the geomembrane should be permitted. All equipment must be placed on a protective layer, and must not remain on the geomembrane overnight.

- Seaming must be done in the temperature range of 40 ^{0}F and 104 ^{0}F.

- The field quality control consists of a start-up test to assess the seam quality and tune-up of the seaming equipment. Then non-destructive seam tests must be carried out on each seam using vacuum or air pressure tests. Finally, destructive seam testing must be carried out: one test sample per 500 feet of seam length; the location should be chosen by the engineer's field representative.

- Any flaw in the liner must be repaired as required by the engineer. The repair procedures include patching, spot welding or seaming, capping or replacement of seam with a strip of material welded in place.

- Any large wrinkles resulting from temperature expansion must be removed. To do this, the lower down-slope edge of the wrinkle should be cut, overlapped, and repaired.

Giroud and Peggs (10) presented an overview of the construction quality of geomembrane liner and summarized it in three steps:
- Verification and documentation by conforming tests that the geomembrane meets the specifications
- Verification and documentation by a number of monitoring operations, that the geomembrane is installed in conformance with the design and installation, and verification and documentation that the adjacent materials next to the geomembrane are placed according to the specifications.

The paper describes in detail the different steps and actions required to follow a correct quality assurance plan. The CQA operations are documented and compiled in a final report including, data, in situ reports, observations and records taken during the construction of the liner. An important part of this paper is dedicated to the seams, the mechanisms associated with seam failures, how to prevent those failures, and the different tests that establish the characteristics of the well being of a seam.

A CQA plan may vary from five to twenty percent of the cost of the material and construction of the geomembrane. However, this additional cost is justified by the increase of geomembrane and installation quality that decreases the material defects by a factor 30. The CQA plan allows a safer installation vis-a-vis the environment, which is probably the most important advantage of the plan even at relatively high cost.

Landreth (11) presented in detail the different type of seams, their uses, properties and applications to provide the required information for a proper QA/QC program (see Chapter "Seam" for more details). The EPA developed a quality manual to be followed for the proper design and installation of geomembranes. It has been proven, effectively, that the use of a QA/QC program during installation will significantly decrease the amount of leachate leakage in the landfill.

4.5 Cost of Quality Control

The cost of CQA and the different liner components have been summarized by Shepherd et al. (12) and are presented in Table 27:

Table 27: Typical Range of Quality Costs (12)

ITEM	TYPICAL RANGE OF COSTS
Independent CQA: single composite liner double composite liner	 $31 000 - $74 000/ha $52 000 - $121 000/ha
1.5 mm HDPE liner	$42 000 - $62 000/ha
GCL	$52 000 - $74 000/ha
Extra Sump Liners	$1 000 - $5 000
Detection System, Sumps	$15 000 - $30 000
Extra Liner Under Pipes	$25 000 - $49 000/ha
30 cm Compacted Clay	$12 000 - $62 000/ha

Ha: Hectare

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5 Life Prediction

5.1 Viscoelasticity

Plastics are viscoelastic materials, with deformation and strength properties varying with temperature and duration of loading. They are also affected by certain environmental conditions. As the name implies, viscoelastic materials respond to stress by superposition of elastic and viscous elements. The springs in the highly simplified model of Fig. 48 represent the elastic elements of a polymer (e.g., chain rigidity, chemical bonds, and crystallinity), each spring having a different constant that represents a time-independent modulus of elasticity. The dashpots represent the viscous fluid elements (e.g., molecules slipping past each other), each having a different viscosity or time-dependent response.

When a constant load is applied and sustained on this model, it results in an initial deformation, which continues to increase indefinitely, Fig. 49. This phenomenon of continuing deformation, which also occurs in concrete, soft metals, wood, and structural metals at very high temperatures, is called creep. If the load is removed after a certain time (say, at point t_i in Fig. 49), there is a rapid initial strain recovery, followed by a continuing recovery that occurs at a steadily decreasing rate; in this model the recovery is never complete. However, if the creep strain does not cause irreversible structural changes and sufficient time is allowed, the strain recovery will be almost complete. The rate and extent of deformation and recovery are sensitive to temperature, and can also be influenced by environmental effects such as absorption of solvents or other materials with which the plastics may have come in contact while under stress. An analogous response of viscoelastic materials is stress-relaxation. The initial load required to achieve a certain deformation will tend to gradually relax when that deformation is kept constant, Fig. 50. Initially, stress-relaxation occurs rapidly and then steadily decreases with increasing time.

HDPE is a viscoelastic material for which the history of deformation has an effect on the response. For example, if a load is continuously applied, it creates an instantaneous initial deformation that then increases over time. The stress and strain are related by a modulus that depends on the duration of load and magnitude of the applied stress at a given temperature, Fig. 51. Viscoelastic behavior becomes nonlinear at high stress or strain or elevated temperatures, exhibiting logarithmic decay of the modulus over time, Fig. 52.

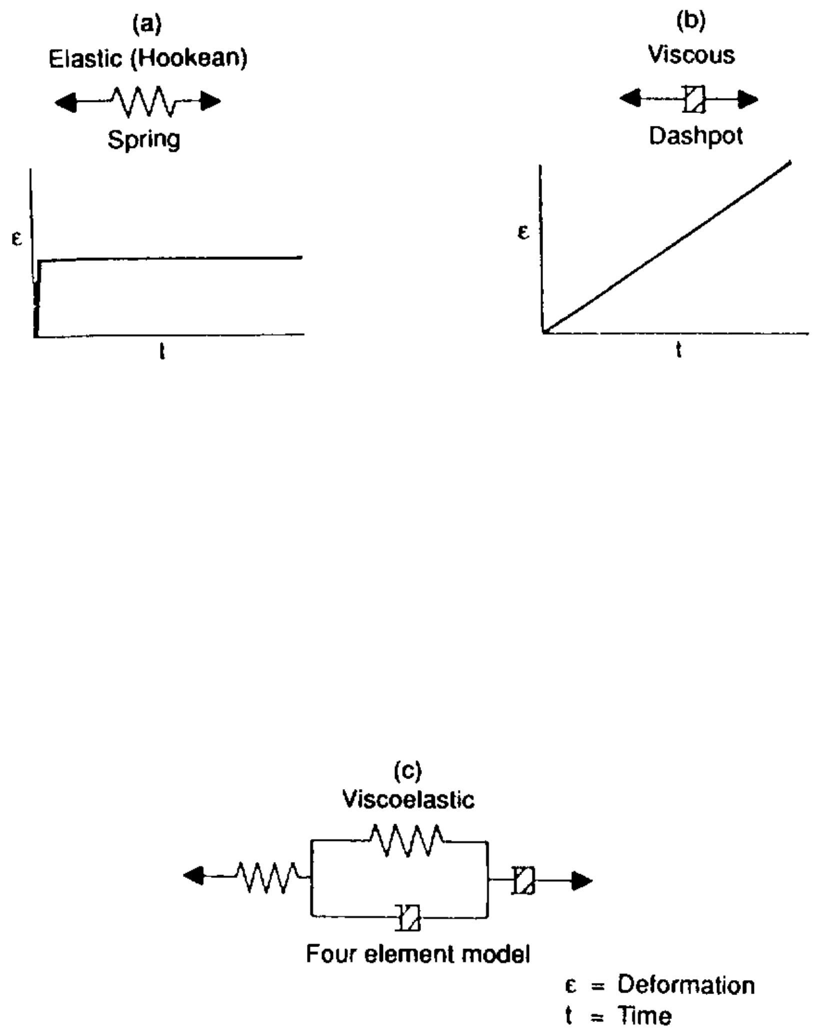

Figure 48: Model of viscoelastic behavior

Creep, expressed in terms of the increasing compliance contributing to increasing deformation, (i.e. loss of stiffness), and creep-rupture, expressed in terms of decreasing life with increasing stress and temperature, are important parameters for life prediction. The transition from ductile to brittle behavior enables the realistic estimation of life from the creep-rupture plot.

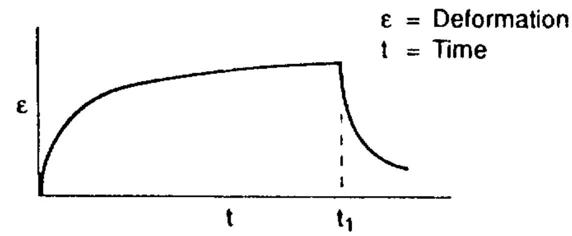

Figure 49: Viscoelastic response, creep (constant load)

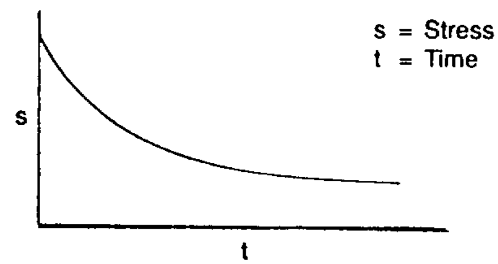

Figure 50: Viscoelastic response, stress relaxation (constant deformation)

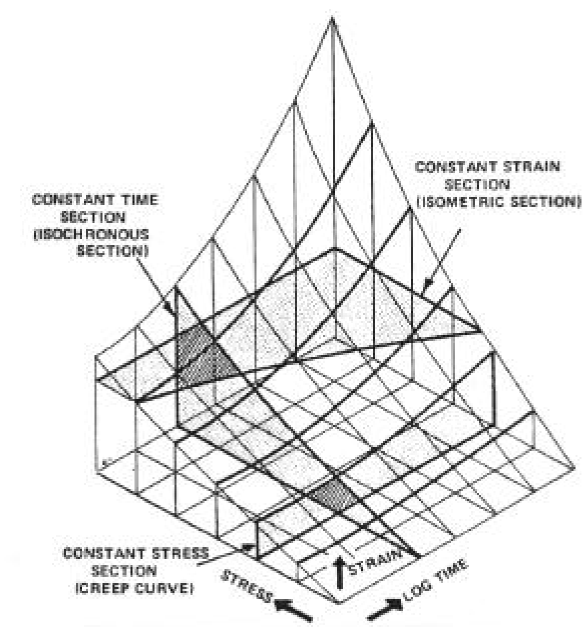

Figure 51: Constant stress-strain time coordinates (1)

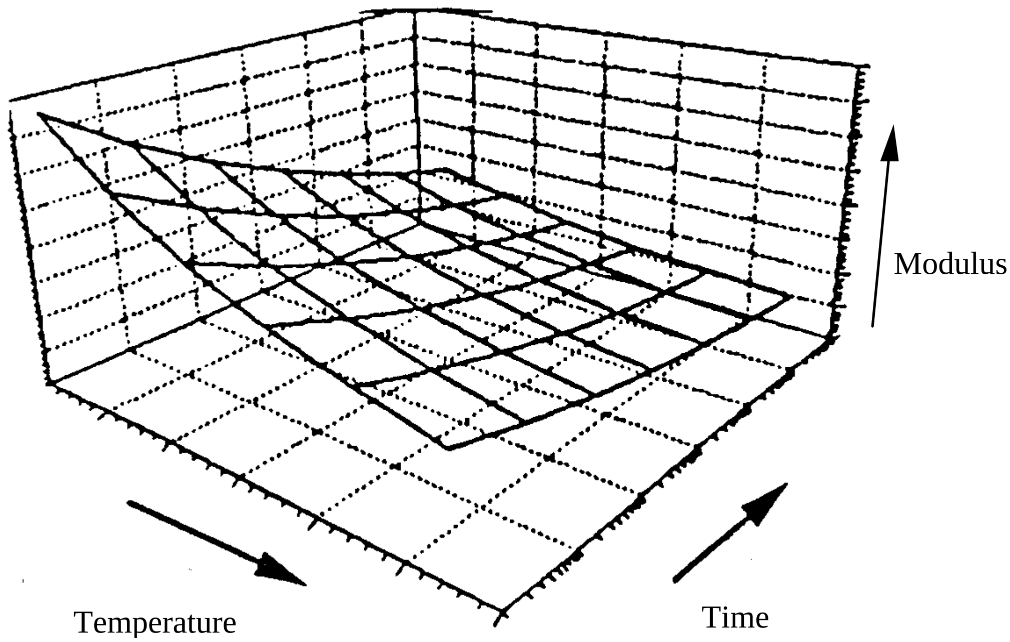

Figure 52: Schematic of the viscoelastic behavior of polymers

Woods et al. (2) conducted tensile creep-rupture testing on HDPE pipe material, based on ASTM D 638, and observed the occurrence of the ductile-brittle transition at a very early stage with a high stress level; no "knee" was seen in the tensile stress vs. time plot.

The predominant mode of premature failure of thermoplastic material, as indicated earlier is quasi-brittle fracture, initiated at stress concentrating surface notch geometries, imperfections (initial pinpoint depressions, etc.) and/or unexpected point stresses. Prediction of life, based on only long-term material properties, ignoring the geometry, would overestimate the predicted life. The creep and creep-rupture schematics for life prediction are shown in Fig. 53. It is necessary to identify unexpected failure-initiating defects, and to understand at what rate induced cracks will propagate, and how much they affect the reduction of service life.

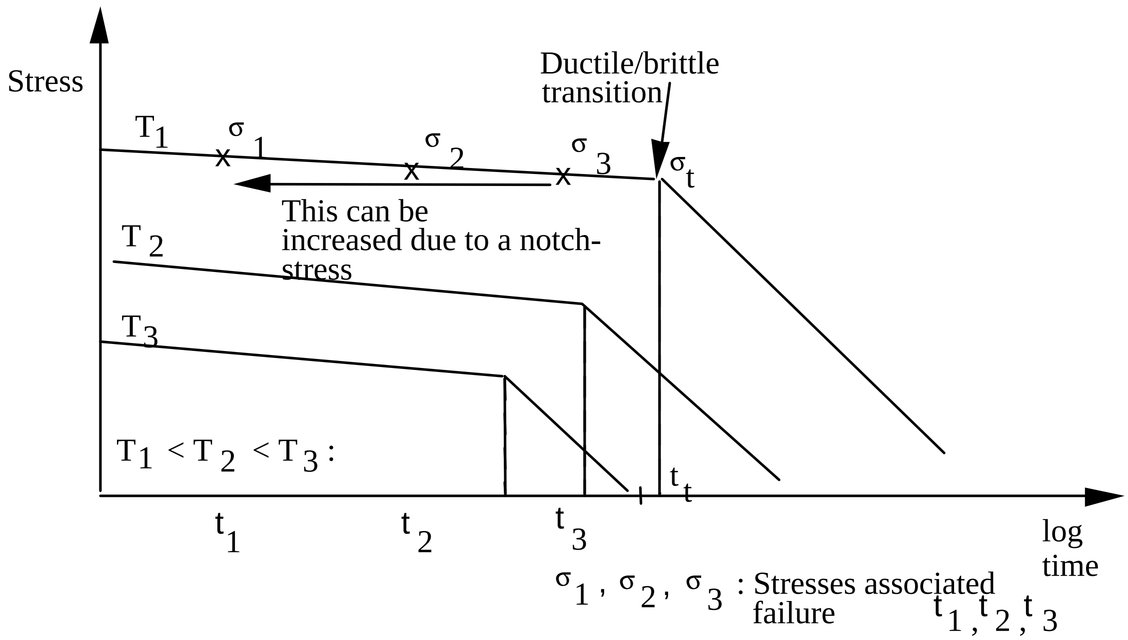

Figure 53: Creep-rupture behavior for semi-crystalline polymers (2)

5.2 Life Prediction

There is an identified need to investigate the long term behavior in relatively short laboratory time scale, by evaluating the effect of soil degradation mechanisms at field-related temperatures and stresses, compounded by synergistic effects, with accelerated testing, high stress, elevated temperatures, and/or aggressive liquids.

It is noteworthy that the type of thermoplastic material qualification testing, used for natural gas distribution piping has very effectively screened out one failure mode; ductile failure. This has been done by testing of pressurized pipe at temperatures and pressures that are well above the expected operating conditions. Because of the strong time and temperature dependence of polyethylene and other thermoplastic materials, it is both possible and necessary to accelerate the failure mechanism. The key is the use of time-temperature shifting functions that can reliably connect high temperature/high pressure performance to actual service conditions.

The long term properties can be predicted based on viscoelastic behavior: i) the time-temperature (WLF) superposition (3), which describes the equivalence of time and temperature, ii) the Arrhenius equation (4), which describes the temperature dependency of the degradation reaction on time and temperature, iii) the rate process method, describing which curve fits time-to-failure test data at elevated temperatures to enable predictions of times-to-failure at lower temperatures (5), and iv) the bidirectional shifting method (5). Ahn and Reddy (8) have illustrated the application of WLF, Arhenius, and Bidirectional Shifting Methods for HDPE piping.

5.2.1 WLF Method

Based on the time-temperature (WLF) superposition principle, for each of the three load levels, creep curves are plotted for different temperatures, and superposed by horizontal shifts along a logarithmic time scale to give a single curve covering a large range of times, termed a master curve. The shift factor, a_T', is function of temperature and described as follows:

$$\log a_T' = [-C_1 \times (T-T_r)] / [C_2 + (T-T_r)] \qquad [5.1]$$

where,
a_T' = shift factor
C_1 and C_2 = universal constants, which vary from polymer to polymer
T_r = reference temperature
T = absolute temperature.

The extended time-scale master curve enables the determination of the long term mechanical properties and service life, Fig. 54 (3). Fig. 55 shows the three master curves (modulus-time curves at three different stress levels) obtained by time shifting. The extrapolation equation for any other loading condition will be determined, similar to the procedure used for the Hydrostatic Design Basis (HDB) test described in the ASTM Standard D2837.

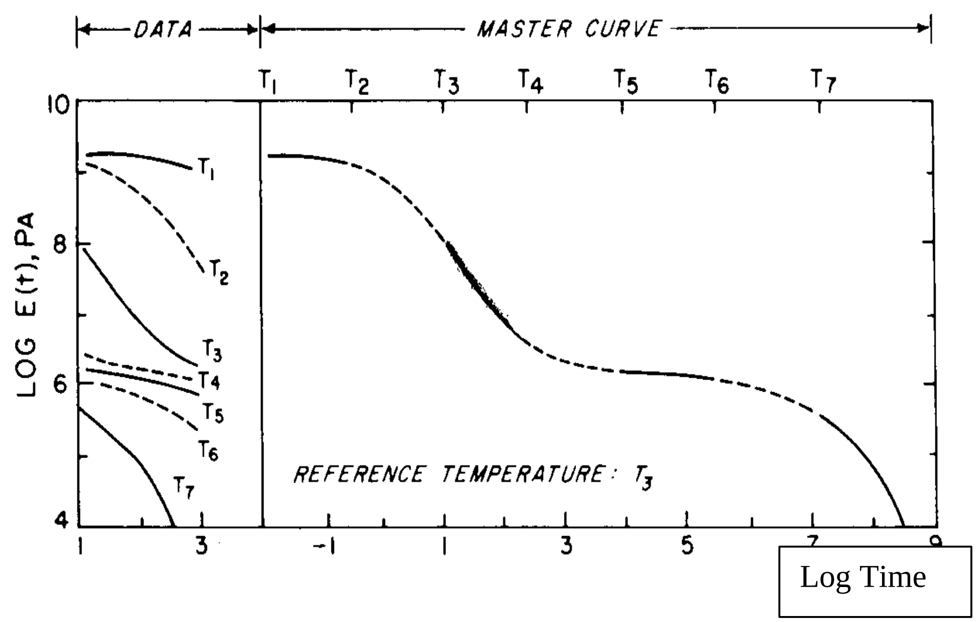

Figure 54: Master curve from experimentally measured modulus-time curves various temperatures (3)

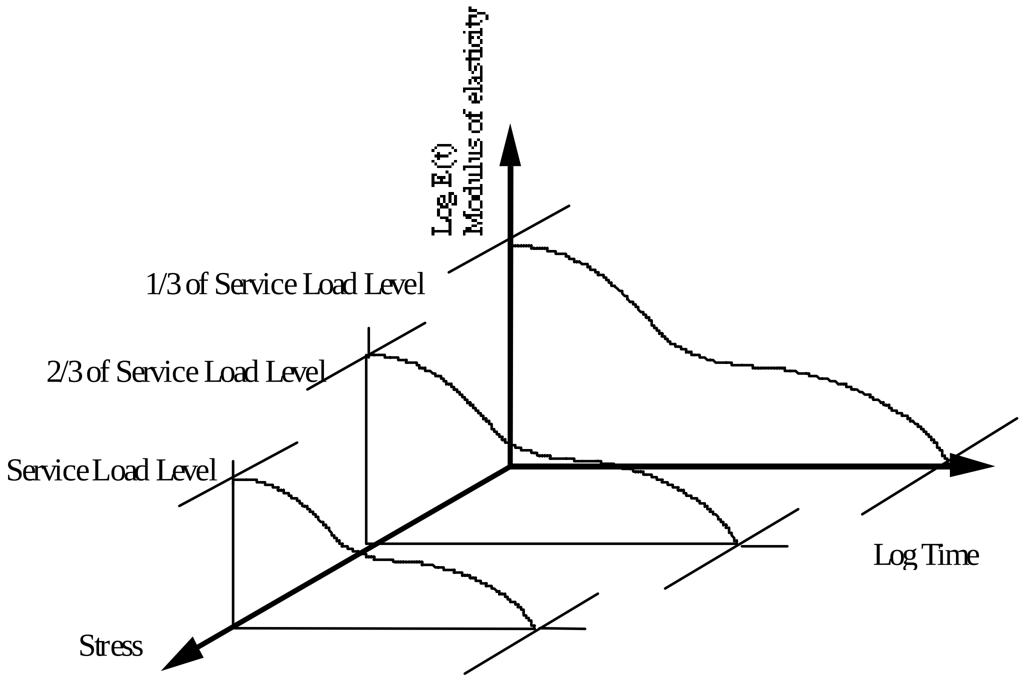

Figure 55: Master curves at different load levels

5.2.2 Arrhenius equation

A considerable amount of data shows that the rate of most chemical reactions has a strong dependence on the temperature and the concentration of reagents involved. In fact, such dependence can be used advantageously to develop relationships, which can be used for extrapolation purposes. A common form of this important extrapolation tool is as follows:

$$\ln (t/t_o)=(E_{act}/R)(1/T - 1/T_o) \quad \text{[5.2]}$$

where
t=time to given strength loss, usually 50%, at the test conditions
T=temperature of the test environment, in ^oK
t_o=time to the same given strength loss as for t, but in the in-situ environment
T_o=temperature of the in-situ environment, in ^oK
R=universal gas constant, which is 8.314 J/mole
E_{act}=effective activation energy, J/mole

In the Arrhenius plot, degradation is plotted as the logarithm of the reciprocal of time versus the reciprocal of temperature using the previous equation. A schematic plot is provided in Fig. 56. It is noted that the temperature has an exponential effect on the time required for a specified level of degradation based on this model, and the data used in the previous equation is obtained at a constant level of degradation (indicated by the modulus decay) in the material. The extrapolation for failure time is similar to that used in the WLF Method. The WLF method and Arrhenius equation-based analyses are accurate for amorphous polymers, but catastrophic failure that occurs at ductile-brittle transition make the prediction difficult for semi-crystalline polymers. This problem should be addressed, and the life predictions given by the two methods compared, and their equivalence studied using the procedure developed by (6).

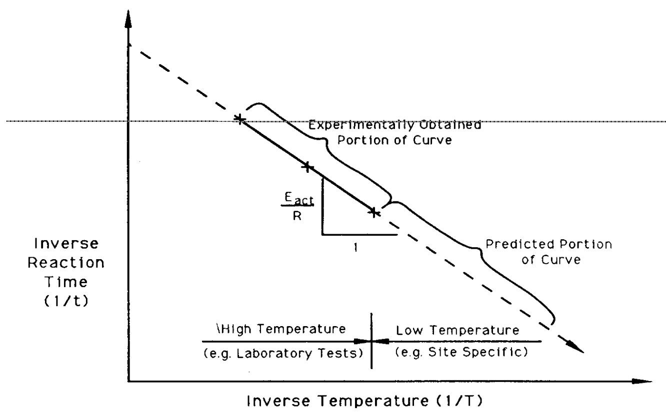

Figure 56: Generalized Arrhenius, for a specified stress level, used for life prediction from super-ambient temperature experimental data (7)

5.2.3 Rate Process Method (RPM)

The conventional time-temperature shifting procedure for pressurized pipe is the rate process method (RPM) which, in essence, curve fits time-to-failure test data at two elevated temperatures to enable predictions of times-to-failure at lower temperatures. The time to failure for thermoplastic pipe depends upon the operating temperature and the induced stress. The RPM has been used by the gas industry to extrapolate design parameters at the operating temperature from elevated temperature-based hydrostatic pressure tests of pipes (4) and (5). RPM, that has evolved from analyzing numerous test data, assumes that the time to failure is governed by an Arrhenius relation wherein the activation energy varies linearly with the logarithm of stress (4) and (5).

The RPM equation for the time to failure, t_f, at the absolute temperature, T, and hoop stress, σ, is expressed as follows:

$$\log t_f = A + (B/T) + (C/T)\log\sigma \quad [5.3]$$

An implication of this equation is that the data plots as a straight line in the $\log t_f – \log\sigma$ plane. The fitting of the previous equation requires that time-to-failure data be available for a minimum of two temperatures.

5.2.4 Bi-directional shifting method (BSM)

The bi-directional shifting method was introduced by Popelar and al. (5), as an alternative method to predict geosynthetics material's life. In this method no curve fitting is needed enabling a single data point, which represents any viscoelastic phenomenon determined at a given test temperature, to be shifted to another temperature.

Based on the time-temperature superposition principle, the horizontal and vertical shift functions, a_T and b_T, respectively, are given by the following equations:

$a_T = \exp[-0.109(T-T_r)]$……………………………..……..[5.4]

$b_T = \exp[0.0116(T-T_r)]$……………………………….…..[5.5]

5.3 REFERENCES

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6 Conclusions

Based on the review, the following conclusions are drawn for cost-effective use of landfill liner systems for long-term performance.

1) Creep can be considerably reduced using a resin, which is moderately affected by creep, and by proper design that limits the high stresses in the geomembrane.
2) Stress Cracking, the brittle fracture of a geosynthetic material under significantly lower stress than the material yield strength, can be minimized by using a UV and chemical resistant-resin and limiting high stress in the liner.
3) Static puncture, due to weight of the waste, can be prevented by using protective layers made of geonets and rounded soil particles, as well as stiff and thick geomembranes. Dynamic puncture, due to the fall of objects during construction, can be avoided by considerable care in construction (skilled workmanship is required).
4) Seam problems, mainly cracking, can be prevented by using proper equipment, proper seam geometry, adequate and constant temperature, skilled workmanship, and flaw inspection soon after the seam is completed.
5) Seismic and general stability of the landfill at the liner interface can be minimized by using a rough, stiff material under high vertical pressure, and by eliminating leakage at the interface level, since liquid decreases the shear properties of the interface.
6) Aging of geomembranes due to environmental conditions, such as temperature, UV, oxidation, and chemical agents, can be prevented or reduced by using proper material with adequate precaution to eliminate damage before installation.

Quality assurance and quality control procedures need to be developed and followed strictly to ensure safety of the liner systems. The criteria for design, construction, and maintenance are listed below:

a) *Design*: Design a liner system with a composite liner made up of a geomembrane to prevent leaking, geogrids for leak collection; and a protection layer, comprised of either geosynthetics or fine aggregate material, to prevent puncture damage. Each material must be carefully chosen to reduce the creep, stress cracking, and aging phenomenon.
b) *Installation*: Proper construction should be done with great care by skilled workmen and supervised following the design specifications.
c) *Monitoring*: A proper and very detailed quality control plan should be followed throughout the entire life of the liner and landfill, to monitor the long-term performance with respect to liner integrity and landfill stability. This will significantly reduce liner damage-related risks.

Illinois Pollution Control Board
R2014-10
Testimony of Keir Soderberg
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Southern Environmental Law Center (2013, 11-19) Santee Cooper Agrees to Remove Coal Ash from the Waccamaw River and Conway

Southern Environmental Law Center

Santee Cooper Agrees to Remove Coal Ash from the Waccamaw River and Conway

In a groundbreaking settlement with conservation groups, Santee Cooper has agreed to remove 1.3 million tons of coal ash from the banks of the Waccamaw River in Conway, South Carolina. The settlement resolves lawsuits filed by the Southern Environmental Law on behalf of the Waccamaw Riverkeeper, the Coastal Conservation League, and the Southern Alliance for Clean Energy to require removal of the coal ash.

“This is an historic agreement that removes toxic coal ash from beside the Waccamaw River and from Conway,” said Frank Holleman, Senior Attorney for the Southern Environmental Law Center. “This settlement is good for Conway, for the River, and for Santee Cooper, and we thank Santee Cooper for reaching this agreement.”

This is the second settlement in South Carolina that requires a utility to remove coal ash stored beside a major river. In 2012, the Southern Environmental Law Center and the Catawba Riverkeeper settled a suit with SCE&G under which SCE&G agreed to remove 2.4 million tons of coal ash from the Wateree River in Richland County, three miles upstream of the Congaree National Park.

For decades, Santee Cooper has stored coal ash from its Conway Grainger generating station in unlined lagoons in wetlands beside the Waccamaw River. The lagoons discharge arsenic into the groundwater and the neighboring Waccamaw River, at times at levels 300 times the legal limit. The South Carolina Department of Health and Environmental Control (SC DHEC) has found that the arsenic pollution violates the S.C. Pollution Control Act. Santee Cooper closed the Grainger plant and had proposed a closure plan that would leave the coal ash beside the river indefinitely in a “vault.”

This proposal was opposed by local community members at a public hearing, and Conway City Council adopted a resolution opposing the proposal and asking Santee Cooper to remove the ash from Conway.

Under the settlement, Santee Cooper must remove the ash from Conway and the Waccamaw

River within seven to ten years. Santee Cooper will also remove one foot of soil from beneath the lagoons. If it stores the ash, Santee Cooper must put the ash in a Class 3 or better landfill. Santee Cooper will withdraw the closure plan that includes the proposed vault and will propose a closure plan providing for removal of the ash. The settlement also contains requirements for groundwater testing and for action to be taken if the arsenic level in the groundwater does not decline.

“This settlement provides for the protection of our beautiful black water Waccamaw River”, said Christine Ellis, the Waccamaw Riverkeeper. “On behalf of our members and supporters, and our community as a whole, we are grateful to Santee Cooper for agreeing to remove its toxic coal ash and helping us to achieve our goal of fishable, swimmable and drinkable water for our families and our future. This is a great day for the Waccamaw River and for Conway, our Rivertown.”

The removal of the coal ash will eliminate the source of the arsenic pollution from the wetlands beside the Waccamaw River. The removal will also eliminate a potential liability for Santee Cooper. The removal will also remediate wetlands in the center of Conway, just feet away from the Conway City Marina and near the Conway Riverwalk.

“This settlement is a landmark agreement for South Carolina’s Lowcountry,” said Nancy Cave, North Coast Office Director for the Coastal Conservation League. “The settlement removes toxic coal ash from endangering the river and communities along the river. It also provides further precedent for the handling of coal ash in the future.”

“Coal ash is a toxic legacy of old coal-fired plants,” said Ulla Reeves of the Southern Alliance for Clean Energy. “To protect our rivers, our people, and groundwater, the coal ash must be stored properly, and this settlement shows what all utilities across our region ought to be doing.”

As part of an earlier settlement with the Conservation Groups, SC DHEC has issued a new water pollution control permit for the Grainger facility. That new permit, once it is final, will apply while the ash is being removed.

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About the Southern Environmental Law Center

The Southern Environmental Law Center is a regional nonprofit using the power of the law to protect the health and environment of the Southeast (Virginia, Tennessee, North and South Carolina, Georgia, and Alabama). Founded in 1986, SELC's team of nearly 60 legal and policy experts represent more than 100 partner groups on issues of climate change and energy, air and water quality, forests, the coast and wetlands, transportation, and land use. www.SouthernEnvironment.org.

About the Waccamaw Riverkeeper
The Waccamaw RIVERKEEPER® is a program of Winyah Rivers Foundation, a non-profit environmental organization whose mission is to protect, preserve, monitor and revitalize the health of the lands and waters of the greater Winyah Bay watershed. Our goal is to protect our community's right to fishable, swimmable and drinkable water. We pursue this goal through education and advocacy programs in support of our mission to protect our river resources. These programs are developed and implemented to increase the scientific literacy of our community, including local decision makers, and to engage them in environmental stewardship and planning for river resource protections.

About the Coastal Conservation League
Since 1989, the Coastal Conservation League has been working with communities, businesses, other conservation and citizen groups to protect what we love about the South Carolina coast. From the white sand beaches and pristine marshes to the freshwater swamps and pine savannahs, we focus on the most efficient and effective ways to protect natural habitats, the wildlife that depends on them and the variety of benefits they bring to this state. We also believe that the communities we live in, the air we breathe and the water we depend upon are important and that our quality of life deserves the same high level of attention. To learn more, go to www.scccl.org.

About Southern Alliance for Clean Energy
Founded in 1985, the Southern Alliance for Clean Energy is a nonprofit organization that promotes responsible energy choices that create global warming solutions and ensure clean, safe, and healthy communities throughout the Southeast. Learn more at www.cleanenergy.org.

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TECHNICAL REPORT

DESIGN AND EVALUATION OF TAILINGS DAMS

August 1994

U.S. Environmental Protection Agency
Office of Solid Waste
Special Waste Branch
401 M Street, SW
Washington, DC 20460

DISCLAIMER AND ACKNOWLEDGEMENTS

This document was prepared by the U.S. Environmental Protection Agency (EPA). The mention of company or product names is not to be considered an endorsement by the U.S. Government or the EPA.

Sections of this document rely heavily on Steven G. Vick's *Planning, Design, and Analysis of Tailings Dams* (BiTech Publishers Ltd. 1990). This is particularly true of certain concepts and organizational emphases, as well as many of the tables and figures. In some cases, this document presents a digest of Vick's overall approach to tailings dam planning and design. Permission to use *Planning, Design, and Analysis of Tailings Dams* as a major source was provided by Mr. Vick, who is not responsible for any errors of omission or interpretation in the present document.

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DESIGN AND EVALUATION OF TAILINGS DAMS

1. INTRODUCTION

In order to obtain the metals and other minerals needed for industrial processes, fertilizers, homes, cars, and other consumer products, large quantities of rock are mined, crushed, pulverized, and processed to recover metal and other mineral values. A fine grind is often necessary to release metals and minerals, so the mining industry produces enormous quantities of fine rock particles, in sizes ranging from sand-sized down to as low as a few microns. These fine-grained wastes are known as "tailings."

Until recent decades, the majority of mines were small underground operations with correspondingly modest requirements for tailings disposal. Since that time, due to increasing demand, it has become economical to mine large lower-grade deposits by utilizing advances made by mining equipment manufacturers and developments in mining and milling technology. This has greatly increased the amount of tailings and other wastes generated by individual mining projects and by the mining industry as a whole.

There are approximately 1,000 active metal mines in the United States (Randol, 1993) Many of these have at least one tailings impoundment and often several impoundments grouped together in cells. EPA estimates that there may be several thousand tailings impoundments associated with active non-coal mining, and tens of thousands of inactive or abandoned impoundments.

By far the larger proportion of ore mined in most industry sectors ultimately becomes tailings that must be disposed of. In the gold industry, for example, only a few hundredths of an ounce of gold may be produced for every ton of dry tailings generated. Similarly, the copper industry and others typically mine relatively low-grade ores that contain less than a few percent of metal values; the residue becomes tailings. Thus, tailings disposal is a significant part of the overall mining and milling operation at most hardrock mining projects. There are several methods used for tailings disposal. These include disposal of dry or thickened tailings in impoundments or free-standing piles, backfilling underground mine workings and open-pits, subaqueous disposal, and the most common method, the disposal of tailings slurry in impoundments. Modern tailings impoundments are engineered structures for permanently disposing of the fine-grained waste from mining and milling operations. At some projects, tailings embankments reach several hundred feet in height and the impoundments cover several square miles.

Historically, tailings were disposed of where convenient and most cost-effective, often in flowing water or directly into drainages. As local concerns arose about sedimentation in downstream watercourses, water use, and other issues, mining operations began impounding tailings behind earthen dams, which were often constructed of tailings and other waste materials. The impoundments served the dual purpose of containing the tailings and, particularly in the arid west, allowing the re-use of scarce water.

More recently, concerns have been raised about the stability and environmental performance of tailings dams and impoundments. Stability concerns are raised in part by the use of tailings material in tailings dams/embankments; to mitigate these concerns, such embankments often rely on a certain amount of controlled seepage to enhance stability, which in turn affects environmental performance. Ritcey (1989) has speculated that the need for sound impoundments in the uranium industry "probably" accounts for much of the recent attention paid to impoundment design in other types of facilities. Perhaps triggered by the initial attention to uranium impoundments, the increasing concern for environmental performance has led to better engineering design of tailings dams in other mining industry sectors, for both stability and environmental performance. For instance, experience gained with leach pad liners is being transferred to linings for tailings ponds, and the use of synthetic lining materials is growing (although use of liners is still far from being the industry norm). In addition, the use of cyanide and other toxic reagents in mill processes has raised special concerns for some tailings and is leading to increased treatment prior to disposal as well as increased attention to containment. Finally, continuing concerns over acid mine drainage is resulting in a growing body of research and emerging concepts of long-term control or mitigation.

Inactive tailings impoundments also are receiving more attention due to the long-term effects of windblown dispersal, ground water contamination, and acid drainage. In many cases, the costs of remediation can be considerable, exceeding the costs of original design and operation of the tailings impoundment.

While this report discusses general features of tailings dams and impoundments, actual designs for tailings disposal are highly site-specific. Design depends on the quantity and the individual characteristics of the tailings produced by the mining and milling operation, as well as the climatic, topographic, geologic, hydrogeologic and geotechnical characteristics of the disposal site, and on regulatory requirements related to dam safety and to environmental performance. What may work for one type of tailings may not work for another type, and may not work for the same tailings at different sites. Hence each situation requires its own design process. The estimated quantity of tailings to be disposed of is particularly important given the evolving nature of most mining projects. Tailings quantity estimates are based on estimated reserves that change continuously as mine development progresses. Accordingly, the final size and design of tailings impoundments can differ substantially from initial projections. This presents major challenges to Federal land managers and State permit writers, who are faced with reviewing and overseeing tailings impoundment planning, design, and performance, and to the general public, who may ultimately pay for miscalculations resulting in environmental damages.

The purpose of this report is to provide an introduction for Federal land managers, permit writers, and the general public to the subject of tailings dams and impoundments, particularly with regard to their engineering features and their ability to mitigate or minimize adverse effects to the environment. The report is based on the current literature on tailings impoundment engineering. While broad in scope, the report is necessarily limited in depth: a comprehensive guide to the design and evaluation of tailings impoundments would incorporate most of the materials in a number of examinations of tailings dam engineering and environmental performance, including those in texts by Vick (1990), Ritcey (1989), and CANMET (1977), among others.

It should also be noted that tailings dam engineering is continually evolving. The relatively recent emphasis on environmental performance is leading to many changes in the field, many of which are as yet not fully tested. Vick (1990) may be the most recent and most comprehensive examination of the topics covered by this report. Consequently, certain sections of this report rely heavily on Vick's approach.

The next section of this report provides an overview of the various methods used to dispose of mine tailings and the types of impoundments that are used. Section 3 describes the basic concepts used in the design of impoundments, including a number of site-specific variables of concern. Section 4 discusses tailings embankment and stability, while Section 5 briefly discusses water management in tailings impoundments. A case study on a lined tailings impoundment is presented in Section 6. Finally, Section 7 lists all references cited in the text.

2. OVERVIEW OF TAILINGS DISPOSAL

The ultimate purpose of a tailings impoundment is to contain fine-grained tailings, often with a secondary or co-purpose of conserving water for use in the mine and mill. This has to be accomplished in a cost-effective manner that provides for long-term stability of the embankment structure and the impounded tailings and the long-term protection of the environment. In the process of designing any tailings embankment and impoundment, these three interests, cost, stability, and environmental performance, must be balanced, with situation-specific conditions establishing the balance at each stage of the process. It is worth noting that the long-term costs of tailings disposal depend in part on mechanical stability and environmental integrity, such that stable and environmentally acceptable structures promote cost effectiveness.

Impoundment of slurry tailings is the most common method of disposal and are the main focus of this report. Impoundments are favored because, among other things, they are "economically attractive and relatively easy to operate" (Environment Canada 1987). Tailings impoundments can be and are designed to perform a number of functions, including treatment functions. These include (Environment Canada 1987):

- Removal of suspended solids by sedimentation
- Precipitation of heavy metals as hydroxides
- Permanent containment of settled tailings
- Equalization of wastewater quality
- Stabilization of some oxidizable constituents (e.g., thiosalts, cyanides, flotation reagents)
- Storage and stabilization of process recycle water
- Incidental flow balancing of storm water flows.

There are, however, a number of disadvantages to tailings impoundments requiring attention in design, including (Environment Canada 1987):

- Difficulty in achieving good flow distribution
- Difficulty in segregating drainage from uncontaminated areas
- Difficulty in reclamation, particularly with acid-generating tailings, because of the large surface area and materials characteristics
- Inconsistent treatment performance due to seasonal variations in bio-oxidation efficiency
- Costly and difficult collection and treatment of seepage through impoundment structures
- Potentially serious wind dispersion of fine materials unless the surface is stabilized by revegetation, chemical binders, or rock cover.

2.1 Methods for Tailings Disposal

Because mine tailings produced by the mill are usually in slurry form, disposal of slurry tailings in impoundments made of local materials is the most common and economical method of disposal. There are four main types of slurry impoundment layouts; valley impoundments, ring dikes, in-pit impoundments, and specially-dug pits (Ritcey 1989). These impoundment configurations are explained in more detail below, with major emphasis on valley impoundments, as they are the most common. Before describing impoundments, several other methods of tailings disposed are briefly described below.

In some cases, tailings are dewatered (thickened to 60 percent pulp density or more) or dried (to a moisture content of 25 percent or below) prior to disposal. The efficiency and applicability of using thickened or dry tailings depends on the ore grind and concentrations of gypsum and clay as well as the availability of alternative methods. Except under special circumstances, these methods may be prohibitively expensive due to additional equipment and energy costs. However, the advantages include minimizing seepage volumes and land needed for an impoundment, and simultaneous tailings deposition and reclamation. (Vick 1990)

Slurry tailings are sometimes disposed in underground mines as backfill to provide ground or wall support. This decreases the above-ground surface disturbance and can stabilize mined-out areas. For stability reasons, underground backfilling requires tailings that have a high permeability, low compressibility, and the ability to rapidly dewater (i.e., a large sand fraction). As a result, only the sand fraction of whole tailings is generally used as backfill. Whole tailings may be cycloned to separate out the coarse sand fraction for backfilling, leaving only the slimes to be disposed in an impoundment. To increase structural competence, cement may be added to the sand fraction before backfilling (Environment Canada 1987).

Open-pit backfilling is also practiced, where tailings are deposited into abandoned pits or portions of active pits. The Pinto Valley tailings reprocessing operation, located in Arizona, uses this method to dispose of copper tailings. In active pits, embankments may be necessary to keep the tailings from the active area. However, since seepage from the tailings can adversely affect the stability of the pit walls or embankments, it is unusual to see disposal in active pits. Williams (1979), for example, discusses a failure due to pore water pressure in the floor of a pit in Australia. Ritcey (1989) notes that the hydrogeological parameters affecting the migration of seepage and contaminants are poorly understood, so tailings with toxic contaminants or reactive tailings may be poor candidates for this type of impoundment. The U.S. Bureau of Mines points out that other limitations for using active open pits for tailings disposal are loss of the pit areas for future resources, and subsequent mine operating and design restrictions to which mine operators would be subjected.

Subaqueous disposal in a deep lake or ocean is also a possible disposal method. Underwater disposal may prevent the oxidation of sulfide minerals in tailings, thus inhibiting acid generation. Subaqueous disposal has recently been practiced by eight mines in Canada, with three still active as of 1990 (Environment Canada 1992). Subaqueous disposal is used in areas with high precipitation, steep terrain, or high seismicity or, in Canada, where its use predated current regulations. This method is also limited to coarse tailings that can settle quickly. CANMET (Canadian Centre for Mineral and Energy Technology) completed a bench-scale 16-year simulation of deep-lake disposal using Ottawa River water (Ritcey and Silver 1987). They found that the tailings had little effect on pH when using ores with a low sulfide content. Ripley, et al. (1978), found that the tailings can cover large areas on the ocean or lake floor and cause turbidity problems if the disposal practice is not designed correctly. There is little data on the long-term effect of subaqueous disposal (Environment Canada 1987), although it is being studied in Canada and peer reviewed by CANMET (CANMET 1993).

A variation on subaqueous disposal in the ocean or lakes would be permanent immersion of tailings in a pit or impoundment. This could present many of the same advantages of underwater disposal (i.e., reduced oxidation of sulfide minerals) but also would require long-term attention to ensure constant water levels and possibly monitoring for potential ground water impacts.

2.2 Types of Impoundments

There are two basic types of structures used to retain tailings in impoundments, the raised embankment and the retention dam. Because raised embankments are much more common than retention dams, they are emphasized in this report. Either type of structure, raised embankments or retention dams, can be used to form different types or configurations of tailings impoundments. The four main types of impoundments include the Ring-Dike, In-Pit, Specially Dug Pit, and variations of the Valley design. The design choice is primarily dependent upon natural topography, site conditions, and economic factors. Most tailings dams in operation today are a form of the Valley design. Because costs are often directly related to the amount of fill material used in the dam or embankment (i.e., its size), major savings can be realized by minimizing the size of the dam and by maximizing the use of local materials, particularly the tailings themselves.

Retention dams are constructed at full height at the beginning of the disposal whereas raised embankments are constructed in phases as the need for additional disposal capacity arises. Raised embankments begin with a starter dike with more height added to the embankment as the volume of tailings increases in the impoundment.

Tailings retention dams (Figure 1) are similar to water retention dams in regard to soil properties, surface water and ground water controls, and stability considerations. They are suitable for any type of tailings and deposition method.

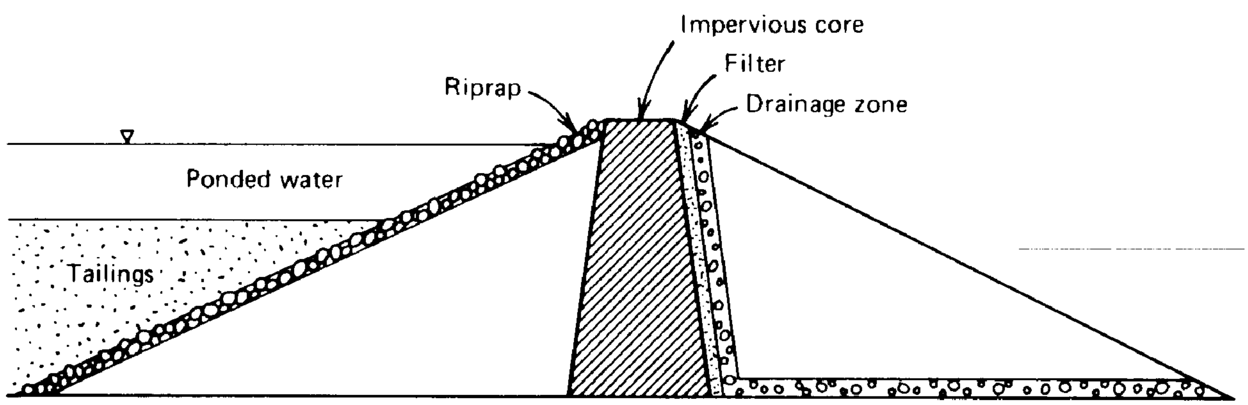


Figure 1. Water-Retention Type Dam for Tailings Disposal

(Source: Vick 1990)

Raised embankments can be constructed using upstream, downstream, or centerline methods, which are explained in more detail in a later section (see Figure 2). Each of the structures in Figure 2, for instance, is constructed in four successive lifts, with constructing material and fill capacity increasing incrementally with each successive lift. They have a lower initial capital cost than retention dams because fill material and placement costs are phased over the life of the impoundment. The choices available for construction material are increased because of the smaller quantities needed at any one time. For example, retention dams generally use natural soil whereas raised embankments can use natural soil, tailings, and waste rock in any combination. (Vick 1990)

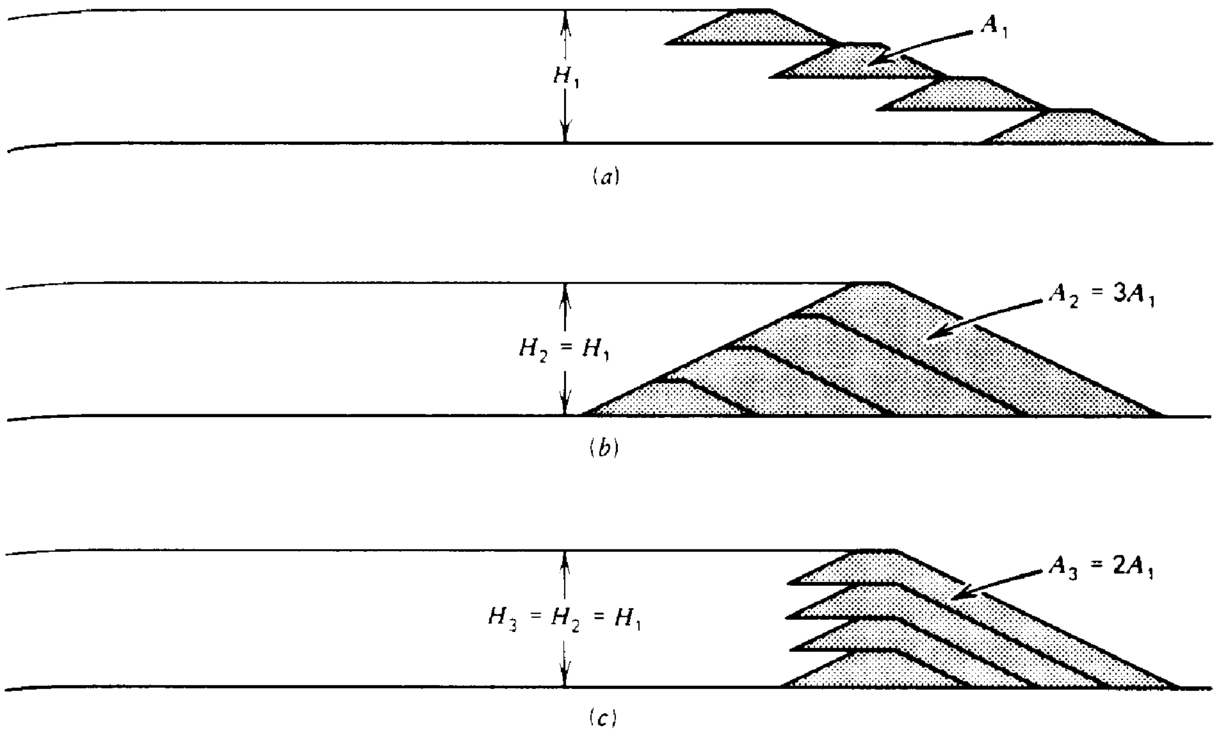


Figure 2. Embankment Types: (a) Upstream, (b) Centerline, (c) Downstream or Water Retention Type

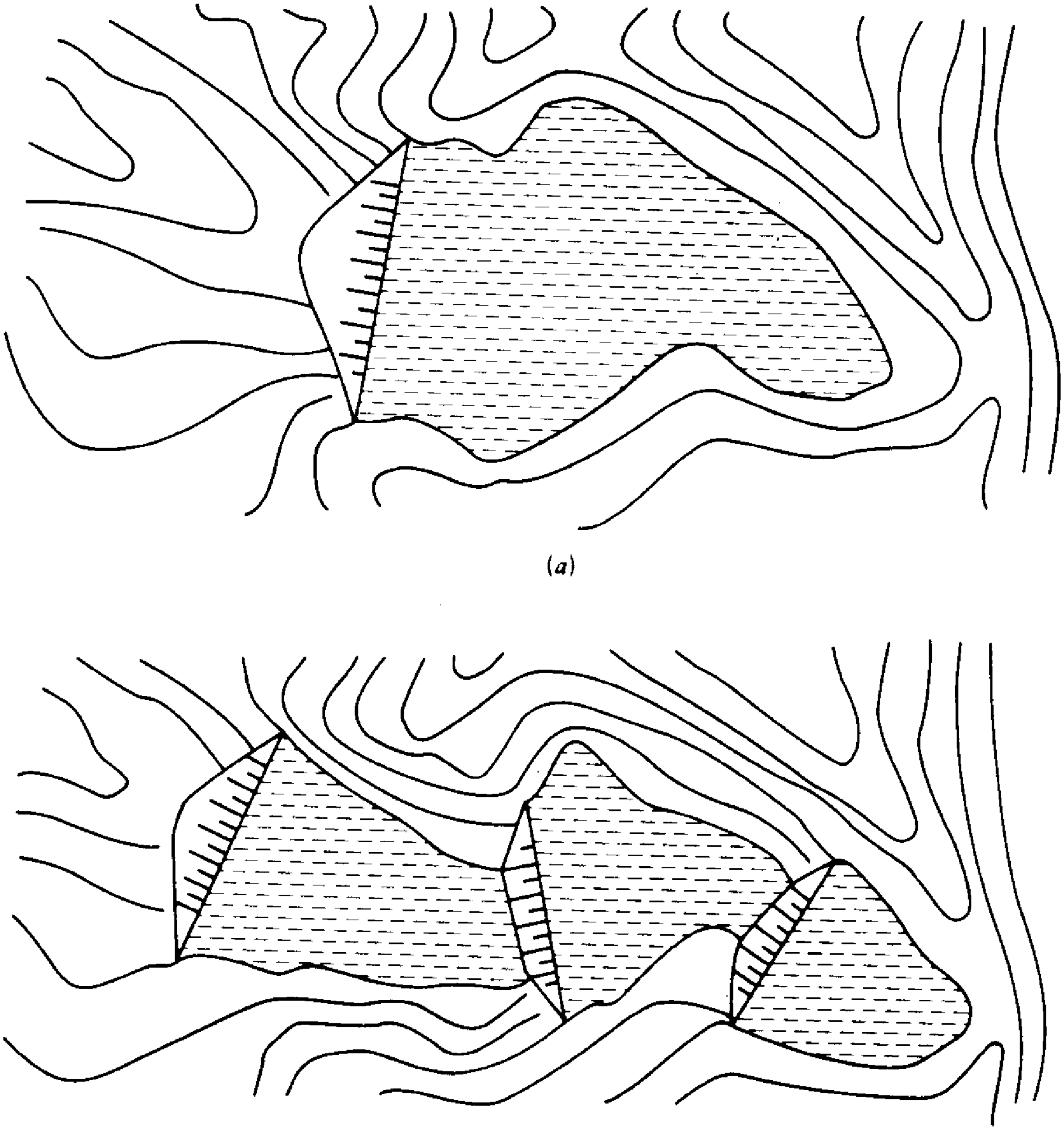
(Source: Vick 1990)

Finally, the phased nature of raised embankments makes it possible to attempt to address problems that may arise during the life of a tailings impoundment. For example, at the Rain facility in Nevada, unplanned seepage under and through the base of the tailings embankment made design changes necessary. The fact that this was a raised embankment made it possible to attempt engineered solutions to the problem as the dam was enlarged and raised during later phases of construction, and this could be accomplished without taking the impoundment out of service and without moving enormous quantities of fill material or impounded tailings.

2.2.1 Valley Impoundments

Other things being equal, it is economically advantageous to use natural depressions to contain tailings. Among other advantages are reduced dam size, since the sides of the valley or other depression serve to contain tailings. In addition, tailings in valleys or other natural depressions present less relief for air dispersion of tailings material. As a result, valley impoundments (and variations) are the most commonly used. Valley-type impoundments can be constructed singly, in which the tailings are contained behind a single dam or embankment; or in multiple form, in which case a series of embankments contain the tailings in connected "stair-step" impoundments.

There are several variations of valley-type impoundments. The Cross-Valley design is frequently used because it can be applied to almost any topographical depression in either single or multiple form. Laid out similarly to a conventional water-storage dam, the dam is constructed connecting two valley walls, confining the tailings in the natural valley topography. This configuration requires the least fill material and consequently is favored for economic reasons. The impoundment is best located near the head of the drainage basin to minimize flood inflows. Side hill diversion ditches may be used to reduce normal runon if topography allows, but large flood runoff may be handled by dam storage capacity, spillways, or separate water-control dams located upstream of the impoundment. Figure 3 shows single and multiple cross-valley impoundment configurations.



(a)

(b)

Figure 3. Single (a) and Multiple (b) Cross-Valley Impoundments

(Source: Vick 1990)

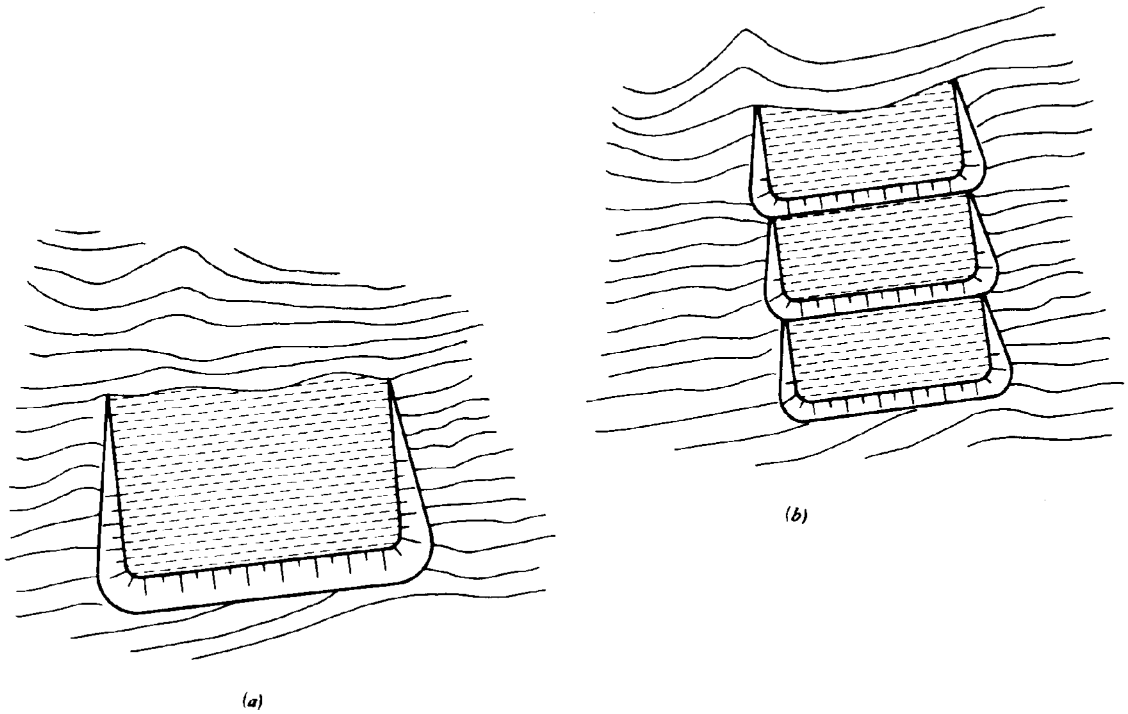


Figure 4. Single (a) and Multiple (b) Side-Hill Impoundments

(Source: Vick 1990)

Other types of valley impoundments may be employed when there is an excessively large drainage catchment area and/or there is a lack of necessary valley topography. Two variations are the side-hill impoundment and the valley-bottom impoundment. The side-hill layout consists of a three-sided dam constructed against a hillside (Figure 4). This design is optimal for slopes of less than 10% grade. Construction on steeper slopes requires much more fill volume to achieve sufficient storage volume (especially when using the downstream method of construction).

If the drainage catchment area is too large for a cross-valley dam and the slope of the terrain is too steep for a side-hill layout, then a combination of these two designs, the valley-bottom impoundment, may be considered (Figure 5). Valley-bottom impoundments are often laid out in multiple form as the valley floor rises, in order to achieve greater storage volume. Because the upstream catchment area is relatively large, it is often, or usually, necessary to convey upstream flows around (and/or under) valley-bottom impoundments.

The valley dam configurations are often the optimum choice for economic reasons. This is because the valley walls form one or more sides, so that the dam length is reduced, minimizing construction costs. However, decreased construction costs and low average depth of tailings in the embankment may be offset by increased environmental mitigation and increased costs of shut-down and reclamation.

The valley dam design is particularly sensitive to overtopping by flood waters, erosion near the intersection of the dam and the valley hillside, and liquefaction due to higher volumes of surface water inflow from drainages within the natural catchment basin and from high precipitation runon/runoff. As is described in more detail later, the stability of a valley dam depends largely on the level of hydrostatic pressure within fill material and the embankment. An unusual, one-time rise in the hydrostatic pressure above design levels may be sufficient to trigger failure. The control of inflows across, around, or under the impoundment is important to retaining structural stability and to controlling environmental impacts. Providing adequate internal drainage can help guard against liquefaction, and improve the permeability and consolidation of the tailings, thereby improving the stability of the structure.

Because a shorter embankment is required in this configuration, it is more feasible to consider impervious cores and internal drains as a means of controlling the phreatic surface and promoting stability of the embankment. Surface water controls may also be necessary. Diversion channels may not always be an option due to the difficulty of construction along steep valley sides. However, closed conduits may be an alternative diversion method. Another alternative surface water control in the valley layout is to construct a smaller water-retaining dam upstream of the tailings dam to collect the water to divert it around the tailings or use it in the mill. A water-related factor that also must be considered, particularly in valley impoundments, is the presence of shallow alluvial ground water. Ground water can infiltrate the tailings, thus raising the level of saturation within the tailings; this can be seasonal, in response to seasonal high surface water flows that interconnect with the alluvium upgradient of the impoundment (or under the impoundment itself).

It should be noted that any design that calls for diverting or otherwise controlling water flows during the active life of the impoundment has to consider later periods as well. The water balance may be more favorable after tailings slurry water is no longer being added to the impoundment/and the dam stability may be less of a concern. However, if there are toxic contaminants in the tailings, or if the tailings are reactive, the design must account for environmental performance following surface stabilization and reclamation.

The stability of the tailings impoundment is also dependent on (or at least related to) foundation characteristics, such as shear strength, compressibility, and permeability. Depending on soil characteristics, the valley layout can be adapted to account for high permeability materials in the design through the use of liners and/or adequate internal drainage. Soil characteristics often can be improved through soil compaction. In addition, the method of tailings deposition and construction have an increased impact on the valley impoundment layout. The deposition of tailings affects consolidation, permeability, strength and, subsequently, the stability of the embankment material. All these factors are discussed in later sections.

In some cases, liners or zones of low permeability may be appropriate means of controlling seepage to enhance stability or environmental performance. The upstream face of tailings dams/embankments (i.e., the side that contacts the tailings), for example, is frequently designed to provide a layer of low permeability or to be impermeable. The effect is to lower the phreatic surface through the embankment. This is usually accomplished with the slimes fraction of tailings and/or with synthetic materials.

Lining the entire impoundment area is more problematic, both because of the expense and because irregularities in valley side walls and floors make it difficult to ensure consistent liner integrity. Liners or layers of low permeability may be necessary, however, to impede flows to and from underlying ground water. More common than impermeable synthetic or clay liners is the practice of compacting native soil, including any available local clays, to reduce permeability to an acceptable level; dewatered or dried-in-place slimes may also be used in some cases. Should a liner or low-permeability layer be necessary, it must be designed to account for impoundment loadings, differential settlement, toxic or corrosive seepage, and weathering effects. If impoundments will desaturate after reclamation, for example, clay or slimes can crack and provide a pathway for ground water to enter the tailings or for contaminated seepage to enter ground water. Similarly, layers of clay or slimes that are prepared in anticipation of late impoundment expansion can develop cracks if they are allowed to dry before being covered with tailings.

2.2.2 Ring-Dike Impoundments

Where natural topographic depressions are not available, the Ring-Dike configuration may be appropriate (Figure 6). Instead of one large embankment (as in the valley design), embankments (or dikes) are required on all sides to contain the tailings. Construction can be similar to valley dams, with tailings, waste rock, and/or other native materials typically used in later phases of construction. Because of the length of the dike/dam, more materials are necessary for this configuration, and material for the initial surrounding dikes is typically excavated from the impoundment area.

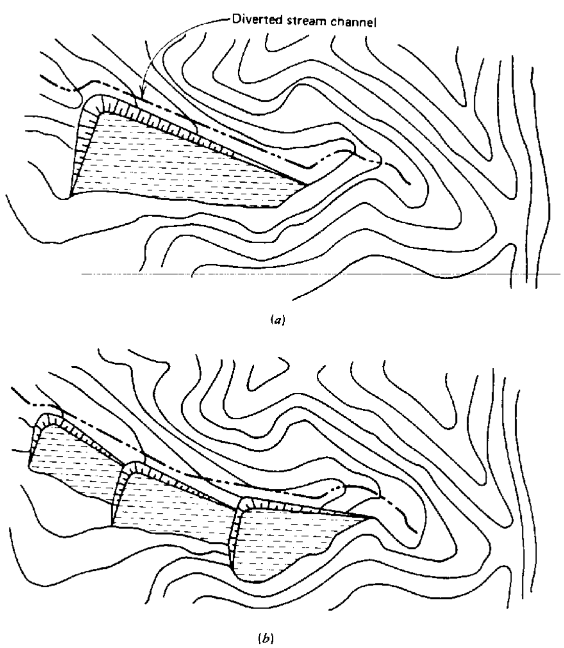


Figure 5. Single (a) and Multiple (b) Valley-Bottom Impoundments

(Source: Vick 1990)

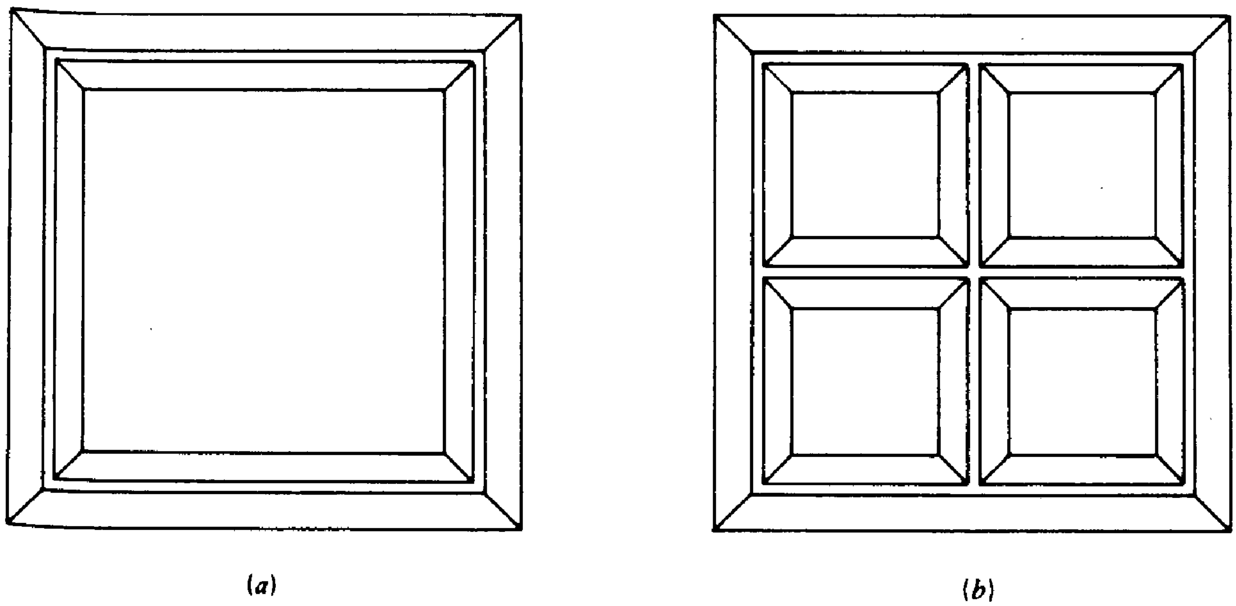


Figure 6. Single (a) and Segmented (b) Ring-Dike Impoundment Configurations

(Source: Vick 1990)

According to Ritcey (1989), most recent dike dams have been built using downstream or centerline methods rather than the upstream method (see below for descriptions of the various types of construction); Ritcey cites Green (1980) as reporting that long-term stability of upstream dikes is not certain.

Embankments are required on all sides, so this method utilizes a large amount of embankment fill in relation to the storage volume. This layout can be arranged in single or segmented form. The regular geometry typically used with this configuration makes it amenable to the installation of various kinds of liners. (Vick 1990)

If the terrain is flat and thus suitable for ring-dikes, this configuration allows maximum flexibility in actually selecting a site. Since the dikes are relatively low in height, the design is often simpler than a high valley dam design. Containment can be achieved by using an impervious core in the dikes and/or the use of a liner below the impoundment.

Unlike valley impoundments, which are located in a natural catchment area, the ring-dike design enables better maintenance of water control. The quantity of pond water is limited to that transported with the tailings and any precipitation falling directly onto the impoundment. There is no runoff other than from outer slopes. Since surface runoff and flood impacts are reduced, a smaller pond area and/or less elaborate water control measures are required. A trade-off can be made with a high tailings depth that reduces surface area and results in less seepage. There are also drawbacks to this design, including the relatively large volumes of material necessary for construction, and its effect on cost. The increased length of the embankment walls also may increase the possibility of failure (Robertson 1984, cited in Ritcey 1989). Other disadvantages of the ring dike system are that the impoundment rises above the surrounding terrain, creating an aesthetic problem in some locations, and there can be considerable wind erosion of the tailings. In many areas, also, there is no flat terrain suitable for ring-dike designs.

Although each situation needs to be evaluated on its own merits, the ring dike system has the potential for better control of seepage than that found in most valley dam locations. If warranted by the characteristics of a particular tailings, almost total containment and collection of effluent can be achieved using a suitable combination of low permeability cores, liners, and drainage system. Since seepage control is often a pressing environmental concern with tailings impoundments, the ring dike system can have an important advantage over most other layouts.

2.2.3 In-Pit Impoundments

This method is much less common than the valley and ring-dike impoundments. It consists of disposing tailings material into a previously mined pit. The design initially eliminates the need for dike construction.

Since the tailings are protected by pit walls, wind dispersion is minimized. Good drainage can be incorporated into the design. Many of the failure modes common to tailings embankments (e.g., piping, liquefaction) do not apply to this design. The lack of dam walls reduces the possibility of slope failure, but the stability of the pit slopes do have to be checked.

Unless the purpose is to isolate sulfide tailings underneath water, the water table should be below the tailings disposed in the pit. This may require backfilling with mine rock or overburden. If backfilling underneath the tailings is necessary, and/or if the surrounding rock is not sufficiently impermeable, a liner may be required. Ritcey (1989) notes that the hydrogeological parameters affecting the migration of seepage and contaminants are poorly understood, so tailings with toxic contaminants or reactive tailings may be poor candidates for this type of impoundment.

When mining in an active pit is proceeding laterally, the mined-out portion of the pit may be suitable for tailings disposal. In such cases, dikes would be constructed to impound the tailings in the mined-out area. This embankment could then be raised in a phased approach (Ritcey 1989).

2.2.4 Specially Dug Pit Impoundment Design

This design is fairly unusual and involves the excavation of a pit specifically for the purpose of tailings disposal. The impoundment consists of four or more cells with impermeable liners and surrounded by an abovegrade dam. Material removed from the pit is used in construction of the dam. This dug pit/dam design has some of the same advantages as the ring-dike design, including site independence and uniform shape.

Site independence benefits the design, since less effort and cost are needed to counteract topographic obstacles, soil conditions, climatic conditions, and construction obstacles. The uniform layout, shape, and flat terrain prevents surface runoff from entering the impoundment and decreases the requirements for flood control measures.

3. TAILINGS IMPOUNDMENT DESIGN

The actual design of a tailings dam and impoundment occurs only after the site has been selected. However, the site selection and design are best considered to be a dynamic process. A number of design principles should affect the site selection process as well as the determination of the embankment type and the impoundment configuration. This section first describes some of these fundamental design principles as well as major design variables and site-specific factors that influence ultimate design. As noted previously, the major considerations in the design of a tailings dam and impoundment are stability, cost, and environmental performance.

3.1 Basic Design Concepts

In general, tailings impoundments (and the embankments that confine them) are designed using information on tailings characteristics, available construction materials, site specific factors (such as topography, geology, hydrology and seismicity) and costs, with dynamic interplay between these factors influencing the location (or siting) and actual design of the impoundment. Because water is a major component in any tailings impoundment system, principles of hydrology (applied to flow of water through and around the tailings embankment) dictate many of the rules of tailings impoundment design. Indeed, because impoundment and dam stability are in large part a function of the water level, these principles are of fundamental concern in the design of any tailings impoundment.

One of the basic principles used in the design of impoundments and their embankments is the maintenance of the phreatic surface within the embankment. The phreatic surface is the level of saturation in the impoundment and embankment (the surface along which pressure in the fluid equals atmospheric pressure (CANMET 1977)); in natural systems it is often called the water table. The phreatic surface exerts a large degree of control over the stability of the embankment, under both static and seismic loading conditions (Vick 1990). The major design precept is that the phreatic surface should not emerge from the embankment and should be as low as possible near the embankment face (Vick 1990). This basically maintains a pore pressure at the face of the embankment lower than atmospheric pressure plus the weight of the embankment particles and maintains the face of the dam. Thus any factors that might affect the phreatic surface in the embankment may also affect stability of the embankment. The primary method of maintaining a low phreatic surface near the embankment face is to increase the relative permeability (or hydraulic conductivity, since water is the fluid) of the embankment in the direction of flow. (See Figure 7.)

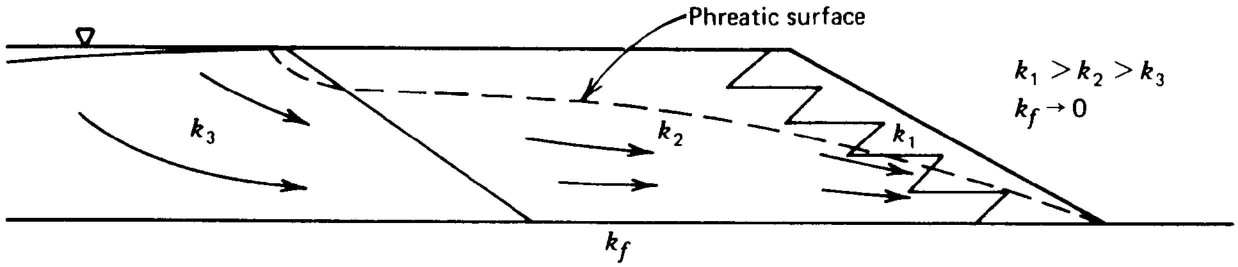


Figure 7. Phreatic Surface Through a Tailings Impoundment

(Source: CANMET 1977)

Creating a relative increase in permeability downstream can be accomplished in one of two ways, or a combination of the two: by incorporating lower permeability zones in the upstream areas of the embankment (typically by constructing embankments with low permeability cores) and by using higher permeability zones downstream (typically using internal drainage zones). The selection of which technique to use is often based on the availability of materials, such as clays for cores and/or clean sands for drains. The use of cores and drainage zones to maintain embankment stability are further discussed in a later section. It should be kept in mind, however, that major changes in phreatic surface require permeability differences in adjacent zones to be two or more orders of magnitude (Vick 1990).

The low permeability layer generally controls the overall flow rate through the impoundment. This allows higher permeability layers located downstream of the low permeability layer to drain and avoid increased pore pressure. The rule on increasing permeability in the direction of flow only applies in areas near the embankment face; if a low permeability core in the center of the embankment is used and permeability increases downstream toward the face, permeability of the material on the upstream side of the embankment may have little effect on the phreatic surface downstream of the low permeability core (Vick 1990).

In most embankments, materials in the various zones are also arranged to meet filter requirements, which are designed to prevent migration of tailings and finer materials into coarser zones. Otherwise voids will be produced that can form a pathway through the dam along which water can escape. As seepage rates accelerate along the pathway, erosion of the dam material occurs leading to failure of the dam. Such failures are referred to as piping failures, because of the natural "pipe" that is formed through the embankment. Piping failures can be avoided by the proper application of various filter rules that have been established in the design of water-retention dams. (Vick 1990)

Factors that affect the phreatic surface in the embankment affect its stability. These factors include the depositional characteristics of the tailings (permeability, compressibility, grading, pulp density, etc.) and site-specific features such as foundation characteristics and the hydrology and hydrogeology of the impoundment area and its upstream catchment area. Changes in the phreatic surface in a waste embankment will change the pore water pressures and consequently the resistance of the dam materials to sliding. Changes to the phreatic surface can be caused by: malfunction of drainage systems, freezing of surface layers on the downstream slope of the dam, changes in construction method (including the characteristics of the placed material), and changes in the elevation of the pond. The level of the water table also may be altered by changes in the permeability of the underlying foundation material; sometimes these are caused by strains induced by mining subsidence (Vick 1990).

In addition to maintaining the phreatic surface for stability purposes, dam design now includes factors related to environmental impacts associated with tailings seepage. By the use of liners, drains, and pumpback systems, tailings seepage may be controlled. These techniques are discussed in more detail in a later section of this report. The design should also address the future reclamation of the site.

3.2 Design Variables

3.2.1 Tailings-Specific Factors

Tailings composition, pulp density, grading, and other characteristics are used in the design of tailings impoundments in three basic ways: tailings analysis to assess the potential use of tailings sands in constructing the embankment, analysis of tailings to be placed in the impoundment to determine their potential impact on structural stability and seepage characteristics, and mineralogical analysis to determine the potential chemical aspects of seepage or other discharges from the impoundment. In addition to the physical characteristics, the method of deposition of tailings into the impoundment plays a role in the "engineering characteristics." (Vick 1990)

Tailings sands are often used as an inexpensive source of material for embankment construction; by removing the sands for embankment construction the volume of tailings to be disposed of is reduced. Depending on the gradation (grain size distribution) of the tailings, a cyclone may be used to separate sufficient amounts of coarse sand from the whole tailings to construct the embankment, leaving a higher percentage of slimes to be deposited behind the embankment. Cycloned sands can have both high effective strength and high permeability, the two major characteristics necessary for downstream embankment material. In addition, cycloning results in the deposit of the less permeable slimes behind the embankment, possibly reducing impoundment seepage.

With regard to their general physical properties, tailings are considered to be soils, subject to traditional soil mechanics patterns of behavior. Index properties (gradation, specific gravity, and plasticity) are determined by relatively simple tests that can be performed on tailings produced in bench testing of the mill process. These index tests are a guide to the engineering properties of the tailings. Caution is required, however, since tailings differ in subtle ways from soils having similar index properties (Vick 1990).

Tailings properties that impact design, stability and drainage of the impoundment include in-place and relative density, permeability, plasticity, compressibility, consolidation, shear strengths, and stress parameters (Vick 1990). In-place density is an important factor in determining the size of impoundment required for a specific operation while relative density influences dynamic strength behavior. In-place density refers to the mass/unit volume of an undisturbed sample of material where the sample volume is much greater than the average particle size. Gradation is a factor of in-place density, with well graded materials typically having a higher density (CANMET 1977). Permeability (or hydraulic conductivity) of tailings in-place in the tailings impoundment varies in both horizontal and vertical directions due to the layered way most tailings are deposited. Plasticity refers in a general way to the amount of clay present. More specifically, the Plasticity Index is the range of moisture content over which a soil is plastic; numerically, it is the difference between the Liquid Limit and the Plastic Limit of the soil. Tailings with a high Plasticity Index are finer-grained and have low permeability and drainage characteristics, while tailings with a low (or zero) Plasticity Index are more coarse and have high permeability drainage properties. Consolidation and compressibility are related to particle size (sands vs. slimes) and density or void ratio. These are a measure of the change in overall volume the tailings may experience over time with dewatering and/or added load. Tailing sands and slimes, for example, are more compressible than otherwise similar soils. Shear strengths and stress parameters of tailings are functions that affect stability and are impacted by pore pressure. The interaction of all of these factors is complex and affects the phreatic surface in impoundment and embankment. For more information, see Vick 1990; and CANMET 1977.

In addition to tailings characteristics that affect stability and seepage quantity, tailings can be analyzed to determine seepage water quality. Besides process chemicals (e.g., cyanide) that may be present, metal mine tailings may contain an array of minerals originally present in the host rock that can contaminate tailings seepage. Contaminants including arsenic, copper, lead, manganese, selenium and other metals. Tailings also can have significant levels of radioactivity.

Tailings and effluent may be acidic or caustic, and in some cases are neutral but later become acidic. The oxidation of sulphides, particularly pyrite (FeS) and pyrrhotite ($Fe_{1-x}S$: Fe_6S_7 to $Fe_{11}S_{12}$) can result in the generation of acid drainage. In the presence of free oxygen, the pyrite oxidizes to produce acidic conditions. The chemical reaction is the combination of metal sulfide and water to produce a metal hydroxide and sulfuric acid. In addition to chemical oxidation, a bacterium (thiobacillus ferrooxidans) causes bacterial oxidation which may become the dominant process in the later stages of acid production. The acidification of tailings ponds can occur in tailings that were initially alkaline; as water levels drop within the tailings impoundment, they introduce air into the void spaces and the subsequent oxidation produces acids. Analysis of the ore and tailings prior to disposal is useful in anticipating water quality problems and the need to adjust seepage flows. Water management and the associated fate and transport of contaminants is addressed in a later section.

3.2.2 Site-Specific Factors

Site-specific factors play a major role in the design of an impoundment. Siting considerations include: (1) physical considerations such as volume of tailings and area required by the dam, (2) financial considerations such as the amount and cost of fill material, water controls, and tailings depositional methods, and (3) environmental requirements such as flood control, ground water and surface water contamination, and wildlife habitats.

The process of selecting the most favorable site typically is a screening process wherein less suitable sites are successively removed from further consideration. The screening criteria include cost, design constraints, and environmental conditions/performance; the importance of each of the criteria may vary depending on the operation and the site being screened. In selecting an appropriate site, the constraints are imposed mainly by the mill location, topography, hydrology, geology, and hydrogeology (Vick 1990). Consideration of all potential factors and full investigation of the potential site can alleviate design problems once a site has been selected. Because design factors also influence site selection, a dynamic iterative process of site selection can result in the most favorable outcome.

Mill Location

Tailings are generally transported from the mill in slurry form, typically with a solids content from 15 to 55 percent by weight. This requires an extensive piping system for the tailings, as well as for pumping reclaim water back to the mill. Vick (1990) quotes an average cost of about $500,000/mile for these systems. Consequently, sites close to the mill are favored on a cost basis over those further away. Initial site screening usually considers sites within about five miles of the mill; this distance may be expanded later if no suitable sites are found. Ideally, sites are located downhill from the mill to allow gravity flow of the tailings to the impoundment and to minimize slurry pumping costs; however, pipelines with steep gradients are avoided where possible. Sites having small elevation rises from mill to impoundment may not be ruled out.

Topography

In addition to distance and elevation, natural topography is one of the main considerations for the given impoundment volume required. The aim is to achieve maximum storage capacity with the least amount of embankment fill. Natural valleys and other topographical depressions are usually investigated first. As a rule of thumb, embankment heights are kept below 200 feet. High embankments (greater than 400 ft) often pose design and construction problems that could be avoided by better siting. (Vick 1990) Topography is also an important factor in the site's hydrology.

Hydrology

Surface water hydrology factors generally favor water diversion around the impoundment and the minimization of water inflows into the impoundment (unless one of the objectives is to collect water for the mill operation). In general, these flows are minimized both for normal and flood conditions. If possible, this is achieved by locating the impoundment as close as possible to the head of the drainage basin to minimize the costs of constructing surface water diversion structures. In order to avoid excessive water handling requirements, the total catchment area should be less than 5 to 10 times the impoundment surface area (Vick 1990). Even then, there must be provisions for controlling runon and runoff after the impoundment is "closed."

Because location, topography, and hydrologic considerations and constraints are relatively easily evaluated, they assume great importance in the screening process. As site investigations proceed (and more costly investigations are necessary), it may be appropriate to re-examine some sites that are eliminated from further consideration early in the process.

Geology and Ground Water

Once the site screening criteria of mill location, topography, and hydrology have been applied, the number of siting options usually has been considerably reduced. Geologic considerations then assume a critical role. In particular, site geology affects the foundation of the embankment, seepage rates, and the availability of borrow materials for embankment construction. Soft foundations, for example, may limit the allowable rate of embankment build-up in order to allow for adequate pore pressure dissipation. Sloping foundations and the presence of weak layers in the foundation will need to be investigated since they may contribute to slope failure of the embankment.

Although geologic details are critical to siting and design, they often play a secondary role in actual siting decisions. This is because there are usually a limited number of sites available at this stage (the rest having been eliminated by consideration of mill location, topography and hydrology). In addition, the lack of detailed information often precludes any meaningful comparisons of alternative sites. The tendency is to try to engineer around any geologic problems. If, following the site investigation, a "fatal" geologic problem is discovered, the site will have to be abandoned at that time. The search will then continue for one or more suitable sites.

Ground water conditions are usually related to the geology, and also affect siting conditions. A high water table limits the amount of dry borrow material available for construction, and shortens the distance for seepage to enter the ground water system. In addition, shallow ground water can infiltrate tailings and increase the amount of water in the impoundment.

Initially, various observations and assessments can assess broad geologic factors, including the availability of construction materials, special construction problems with respect to nearby structures, drainage conditions at the site, and apparent ground stability of the site (such as slumping, evidence of weak planes within the rock, faulting, etc.). The type of vegetation present can indicate subsoil characteristics. Test pits and trenches may be dug and test holes may be drilled to obtain soil and/or rock samples. *In situ* permeability tests also may be run in holes drilled at the site of the proposed tailings impoundment area.

A proposed site will undergo a geotechnical site investigation. The investigation will assess site geology, including the depth, thickness, continuity, and composition of the strata; site hydrogeology; geotechnical properties of soil and rock affecting design; and availability of suitable construction materials for building dams, dikes, drains, and impervious liners.

Geotechnical testing on soils is generally undertaken to determine water content, grain-size distribution, Atterberg limits (moisture content in soil as measured in the boundary stages of four states of soil: liquid, plastic, semi-solid, and solid), consolidation, shear, permeability, and ion exchange capacity (of clays considered for liners). For rocks it is usually necessary to know the shear strength along weak layers, and the permeability and strength of the various strata.

These tests are usually performed in combination with *in situ* tests such as standard penetration, static cone, vane shear, and pressure meter, in order to obtain useful data on field properties. While estimates of soil permeability may be determined in the laboratory, these values need to be confirmed through field testing, which may include borehole *in situ* methods, and large scale pumping methods. In addition, ground water measurements, including piezometric pressures in the underlying soil/sand rocks, and water sampling are usually undertaken to establish baseline conditions prior to construction of the impoundment.

Foundations

The foundation area beneath the embankment is assessed using the geotechnical and other methods noted above. Weak material beneath the slope, such as buried slopes once exposed to weathering, snow covered surfaces over which additional material has been deposited, layers of fine material included in a coarse material embankment, and foundation strata of low shear strength, can cause rotational sliding. If a deposit of clay is extensively fissured, water penetrating into the fissures can seriously weaken the deposit due to the dependency of the shear strength on the softened material strength adjacent to the fissures. Compression or consolidation of the foundation can cause appreciable settling of the overlying material, sometimes causing cracks in tailings embankments (or zones of embankments) that can lead to seepage or piping.

The permeability of the foundation significantly affects the stability of an embankment. When an embankment is constructed on a foundation of saturated impervious clay, for example, the loading of the embankment will create excess pore water pressure in the foundation material. Because the immediate loading is taken by the water phase in the foundation material, there is no increase in shear strength and the rapid increase in loading can precipitate embankment failures extending through the foundation. If the foundation material beneath the tailings dam is pervious, excessive seepage can lead to piping failure. All of these foundation factors are taken into account during design.

Seismicity

The design of tailings impoundments usually has to consider potential seismic activity at the site. This requires the selection of a design earthquake for the site in question. A method commonly used to determine the effects of the design earthquake on a particular site is to assume that the earthquake occurs on the closest known possibly active fault. The fault is selected on the basis of the geological studies previously conducted in the area. Attenuation tables are then used to estimate the magnitude of the earthquake forces reaching the site as a result of the design earthquake occurring on the selected fault.

4. EMBANKMENT CONSTRUCTION, STABILITY, AND FAILURE

4.1 Embankment Construction

Tailings embankment design investigations, described above, lead to the selection and refinement of a starter dam that will serve as the starting point for embankment construction. The starter dam design specifies the internal and external geometry of the structure, and should include specifications for drainage, seepage control, and in some cases liner systems required to maintain embankment stability and control releases to the environment. It is important to emphasize that final embankment design may differ substantially from initial expectations. If embankment construction continues throughout the active life of the impoundment, experience gained from ongoing monitoring and analysis allow for changes and improvements in the design to better meet project goals.

In general, if the starter dam design includes liners and/or drainage systems, such systems must be developed prior to or concurrently with initial dam construction, as well as with each successive raise of the embankment. Environmental considerations may create a need for liners since tailings may have a potential to leach toxic or undesirable constituents to underlying strata; similarly, it is desirable to limit the flow of shallow ground water into the tailings. Liners may be composed of compacted native soils, compacted tailings slimes, imported or local clays, synthetic materials, gunite, etc. For economic reasons, compaction of native soils or tailings slimes are the preferred methods of reducing the permeability of impoundment bases where these methods will meet objectives. Further, as a practical matter, some impoundment designs, such as cross-valley impoundments, may not be amenable to any other type of liner; with very large surface areas and uneven terrain, the use of synthetic liners or other imported materials is generally prohibitively expensive for this type of impoundment, even if it is technically feasible.

Drainage systems may be required for structural reasons. As discussed above, a primary concern accompanying the use of tailings for embankment construction is the control of pore water pressure within and beneath the embankment. Excessive pore pressure within the embankment may lead to exceedence of the sheer strength of the fill material, resulting in local or general slope failure. Additionally, high pore pressures within or beneath the embankment face may result in uncontrolled seepage at the dam face leading to piping failure (discussed below). Similarly, seepage through weak permeable layers of the foundation may result in piping or exceedence of soil shear strength, causing foundation subsidence and compromising the stability of the overlying embankment. These and other threats to embankment stability may be partially reduced through seepage control. Generally speaking, seepage control may be affected through the establishment of zones of differing permeability up-stream of, beneath, and within the embankment, either through drainage systems or low permeability layers or cores, or both.

The primary function of drainage systems is the dissipation of pore pressure across the embankment. Drainage systems allow the control of the phreatic surface by providing low-pressure conduits for seepage. A number of methods are available to accomplish this goal. In particular, chimney drains and blanket drains, each composed of materials of permeability at least two orders of magnitude greater than that of the embankment fill itself (Vick 1990), may be installed within and beneath the embankment to allow dissipation of pore pressure. Chimney drains are vertical curtains of high permeability material, while blanket drains are horizontal layers of high permeability material. Variations of each may be used depending on design requirements. The location of such drainage zones depends on the method of construction of the embankment, discussed below.

Critical to the performance of drainage systems is the prevention of clogging; this can occur, for instance, when tailings fines infiltrate the drainage zone. Filters or filter zones may be employed to help prevent clogging and hence maintain differences in permeability across zones. Filter zones may be constructed of graded sands or synthetic filter fabrics (Vick 1990).

The foregoing discussion underscores an important concept common to tailings impoundments in general: seepage through tailings embankments is essentially unavoidable and often necessary. Since the purpose of the tailings embankment is to impound tailings slurry (and allow for reclamation of mill process water), and since tailings sands used for construction of the embankment are never impermeable, hydraulic head across the embankment will never be zero. Some water will migrate through and/or under the embankment.

4.2 Construction Methods

A variety of construction methods and materials are used in the construction of tailings embankments. In general, mines choose materials and methods to provide the required stability at the lowest cost. If the tailings dam is near the mine, the use of waste rock can significantly lower the cost of materials, while also reducing the need for waste rock disposal areas. If borrow materials are to be used, they can be obtained from the impoundment area and increase impoundment capacity. The materials also should meet permeability, compressibility and shear strength requirements. They also must be chemically stable, so potentially acid-generating waste rock is not suitable for embankment construction, particular in drainage systems. The most frequently used material in embankment construction is tailings.

4.2.1 Construction Using Tailings Material

The use of tailings material is generally the most economical construction method. As discussed previously, some of the disadvantages of using tailings as dam-building material include: high susceptibility to internal piping, highly erodible surfaces, and high susceptibility of the fine tailings to frost action. Also, loose and saturated tailings are subject to liquefaction under earthquake shocks. During construction of the tailings dam, the two major ways to improve these qualities are use of coarse fractions of tailings and compaction. Generally, the sand fractions, after being separated from the slimes, may be easy to compact using vibratory compactors. By compacting this coarse fraction of the tailings, the end result is a dense mass of strong material that has greatly increased resistance to liquefaction. Tailings separation most commonly occurs by spigotting or cycloning. The three methods of construction using tailings are upstream, downstream and centerline. A comparison of these methods is presented in Table 1.

Table 1. Comparison of Embankment Types

Embankment Type	Mill Tailings Requirements	Discharge Requirements	Water-Storage Suitability	Seismic Resistance	Raising Rate Restrictions	Embankment Fill Requirements	Relative Embankment Cost	Use of Low Permeability Cores
Water retention	Suitable for any type of tailings	Any discharge procedure suitable	Good	Good	Entire embankment constructed initially	Natural soil borrow	High	Possible
Upstream	At least 60% sand in whole tailings. Low pulp density for grain-size segregation.	Peripheral discharge, well-controlled beach necessary	Not suitable for significant water storage	Poor in high seismic areas	Less than 15-30 ft/yr most desirable. Over 50 ft/yr can be hazardous	Native soil, sand tailings, waste rock	Low	Not possible
Downstream	Suitable for any type of tailings	Varies according to design detail	Good	Good	None	Sand tailings, waste rock, native soils	High	Possible (inclined cone)
Centerline	Sands or low-plasticity slimes	Peripheral discharge of at least nominal beach necessary	Not recommended for permanent storage. Temporary flood storage can be designed.	Acceptable	Height restrictions for individuals raises may apply	Sand tailings, waste rock, native soil	Moderate	Possible (Central cone)

(Source: Vick 1990)

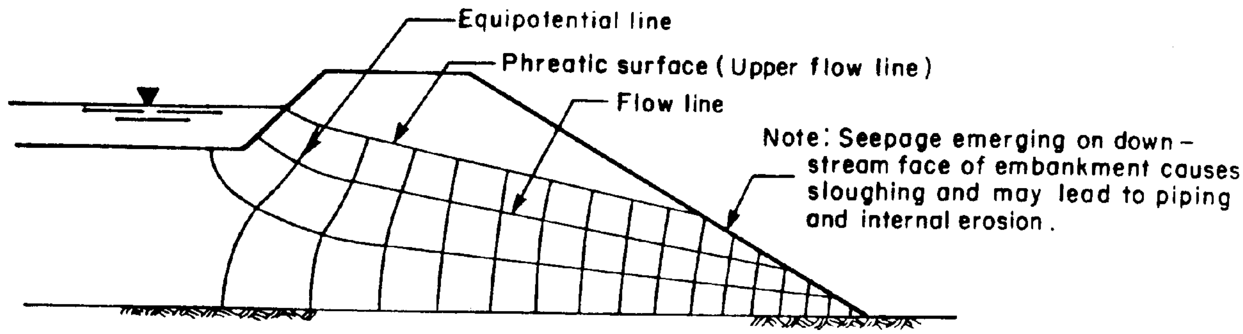


Figure 8. Upstream Tailings Embankment Construction

(Source: Vick 1990)

4.2.2 Upstream Method

Upstream construction, the oldest and most economical method, begins with a starter dam constructed at the downstream toe (Figure 8). The starter dam should be capable of passing seepage water and the downstream portion should be resistant to piping. The tailings are discharged peripherally from the crest of the starter dam using spigots or cyclones. This deposition develops a dike and wide beach area composed of coarse material. The beach becomes the foundation of the next dike. In some applications, the dikes are mechanically placed and the discharge is used to build the beach only (in addition, slimes may be used to coat the upstream face of the dike to reduce permeability). These dikes can be built with borrow fill, or beach sand tailings can be excavated from the beach and placed by either dragline or bulldozer. Either way, some type of mechanical compaction of the dike is typically conducted before the next stage of the dam is constructed.

The single most important criteria for the application of the upstream construction method is that the tailings beach must form a competent foundation for the support of the next dike. Vick (1990) states that as a general rule, the discharge should contain no less than 40 to 60 percent sand. This can preclude the use of the upstream method for those mill tailings that contain very low percentages of sand. Other references state that the determining factor for upstream versus downstream construction is grain-size distribution of the tailings. In addition to grain size tests, Brawner, et al, (1973) suggested that, "If a tractor cannot be operated on the first 100 to 200 feet of beach, the grind is too fine for upstream construction methods."

In addition to tailings gradation, several other factors can limit the applicability of this method. These factors include phreatic surface control, water storage capacity, seismic liquefaction susceptibility and the rate of dam raising. Upstream embankment construction offers few structural measures for control of the phreatic surface within the embankment. Vick (1990) identified four important factors influencing the phreatic surface location: permeability of the foundation relative to the tailings, the degree of grain-size segregation and lateral permeability variation within the deposit, and the location of ponded water relative to the embankment crest. Only the pond location can be controlled through operational practices. The other factors must be planned for in the construction design phase. Both proper decanting and spigotting procedures can be used to control the distance between the pond's edge and the embankment crest. Although the pond's location can be controlled to some extent during operation, a tailings pond that is expected to receive high rates of water accumulation (due to climatic and topographic conditions) should be constructed using a method other than upstream construction. Any change in environmental or operating conditions (heavy rainfall, blockage of seepage outlets, rise in water levels of the pond, etc.) resulting in a rise of the phreatic line and complete saturation of the outer sand shell could quickly lead to failure by piping or sliding. An outer rockfill shell may mitigate failure potential from piping or sliding.

Tailings embankments constructed using the upstream method generally have a low relative density with a high water saturation. This combination can result in liquefaction of the tailings embankment in the event of seismic activity. In addition, vibration of sufficient intensity and magnitude caused by blasting, trains, heavy trucks, etc., may cause liquefaction. The shear strength can be reduced to near zero such that the fluidized slimes easily burst through the remaining thin, unsaturated sand-dike shell and the dam collapses and flows. This can occur at very low heights and slope angles. Therefore, upstream construction is not appropriate in areas with a potential for high seismic activity.

The rate of embankment raises is limited by the build-up of excess pore pressures within the deposit. This build-up of pore pressures can lead to a shear failure, which may result in breaching of the dam and the release of contained tailings (Brawner 1973). The height at which potential failures are triggered depends on the strength of the tailings within the zone of shearing, the downstream slope of the dam, and the location of the phreatic line.

Horizontal drainage zones may be installed during starter dike construction to help maintain low pore pressure within the embankment. Vick (1990) states that a blanket drain extending well upstream of the starter dike may be effective in lowering the phreatic surface in the initial and subsequent embankment rises. He notes, however, that special effort must taken to ensure against blockage of blanket drains when used in upstream embankments.

4.2.3 Downstream Method

The design requirements for the downstream method of construction are similar to conventional water storage dams. As in upstream construction, downstream construction also begins with a starter dam constructed of compacted borrow materials, however, this starter dam may be constructed of pervious sands and gravels or with predominately silts and clays to minimize seepage through the dam (Figure 9). If low permeability materials are used in the starter dike, internal drains will need to be incorporated in the design. The downstream method is so named because subsequent stages of dike construction are supported on top of the downstream slope of the previous section, shifting the centerline of the top of the dam downstream as the dam stages are progressively raised.

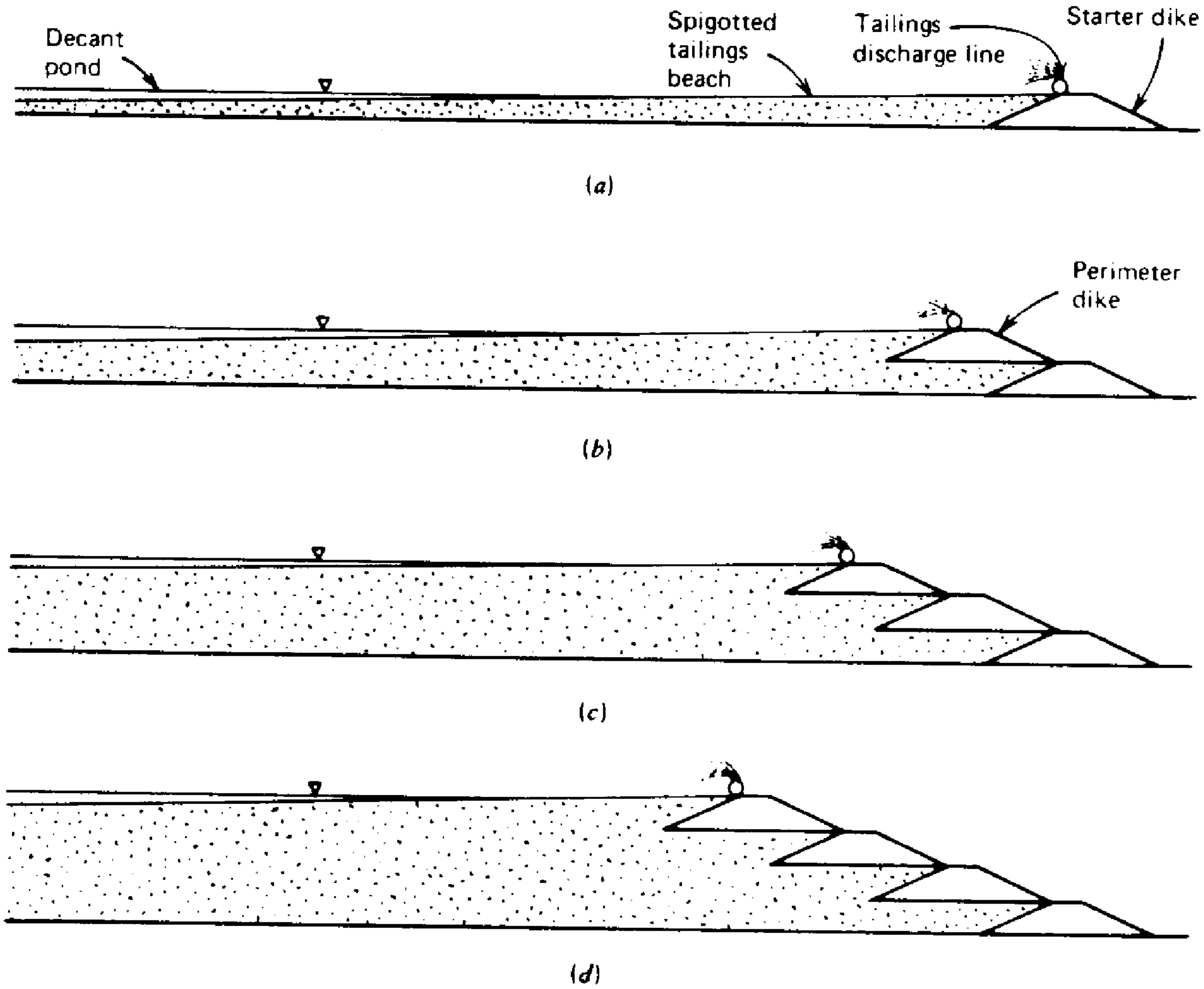


Figure 9. Downstream Embankment Construction

(Source: Vick 1990)

A variety of tailings depositional techniques can be used in conjunction with the downstream construction method, but peripheral spigotting of tailings is very common. Coarse tailings can be spread in thin layers utilizing on-dam cycloning, or they can be hauled from a central cycloned stockpile, then spread and compacted. If the volume of coarse tailings is not sufficient to construct the dam, local borrow materials may be incorporated for part of the structure. If coarse rock is used, due to its porosity, a filter or impervious upstream membrane is required to prevent piping of the tailings through the rock. If spigotting is controlled to create a wide tailings beach and the embankment has been made of permeable tailings, the phreatic surface may be controlled without the need for internal impervious zones or drains. However, Brawner, et al. (1973) recommend that if the dam will be constructed in a potential earthquake zone and/or its height is to exceed 50 ft, the downstream extensions must be compacted to a higher relative density than is typical to minimize the risk of liquefaction.

The downstream construction method allows for the incorporation of drains and impervious cores to control the phreatic surface. Brawner, et al. (1973) recommended the placement of a pervious sand underdrain layer or alternative drainage system prior to each downstream extension. Several other drain designs can also be incorporated into the design. For example, an inclined chimney drain near the upstream face of the dike, and connected to a blanket drain at the dikes base, may be installed with each successive raise of the embankment. (Vick 1990) Drainage controls help to control the phreatic surface and minimize the chance for build-up of pore water pressures which reduce shear strength. Due to the ability to incorporate drains into the design, this method of construction is well-suited to conditions where large volumes of water may be stored along with the tailings solids.

The downstream method of construction provides a degree of stability not found in upstream construction due to the ability and ease of compaction, the incorporation of phreatic surface control measures and the fact that the dam raises are not structurally dependent upon the tailings deposits for foundation strength. A major disadvantage of this method is the large volume of fill material required to raise the dam. The increased volume of fill required can dramatically increase the cost of this method of construction if the tailings from the mill cannot provide a sufficient volume of sand. Embankments constructed with downstream raises also cover a relatively large area, which can be a major disadvantage if available space is limited.

4.2.4 Centerline Method

Centerline construction is similar to both the upstream and downstream construction methods in that the embankment begins with a starter dam and tailings are spigotted off the crest of the dam to form a beach. The centerline of the embankment is maintained as fill and progressive raises are placed on both the beach and downstream face (Figure 10). The tailings placed on the downstream slope should be compacted to prevent shear failure. The centerline method of construction provides some of the advantages over the other two methods while mitigating some of the disadvantages.

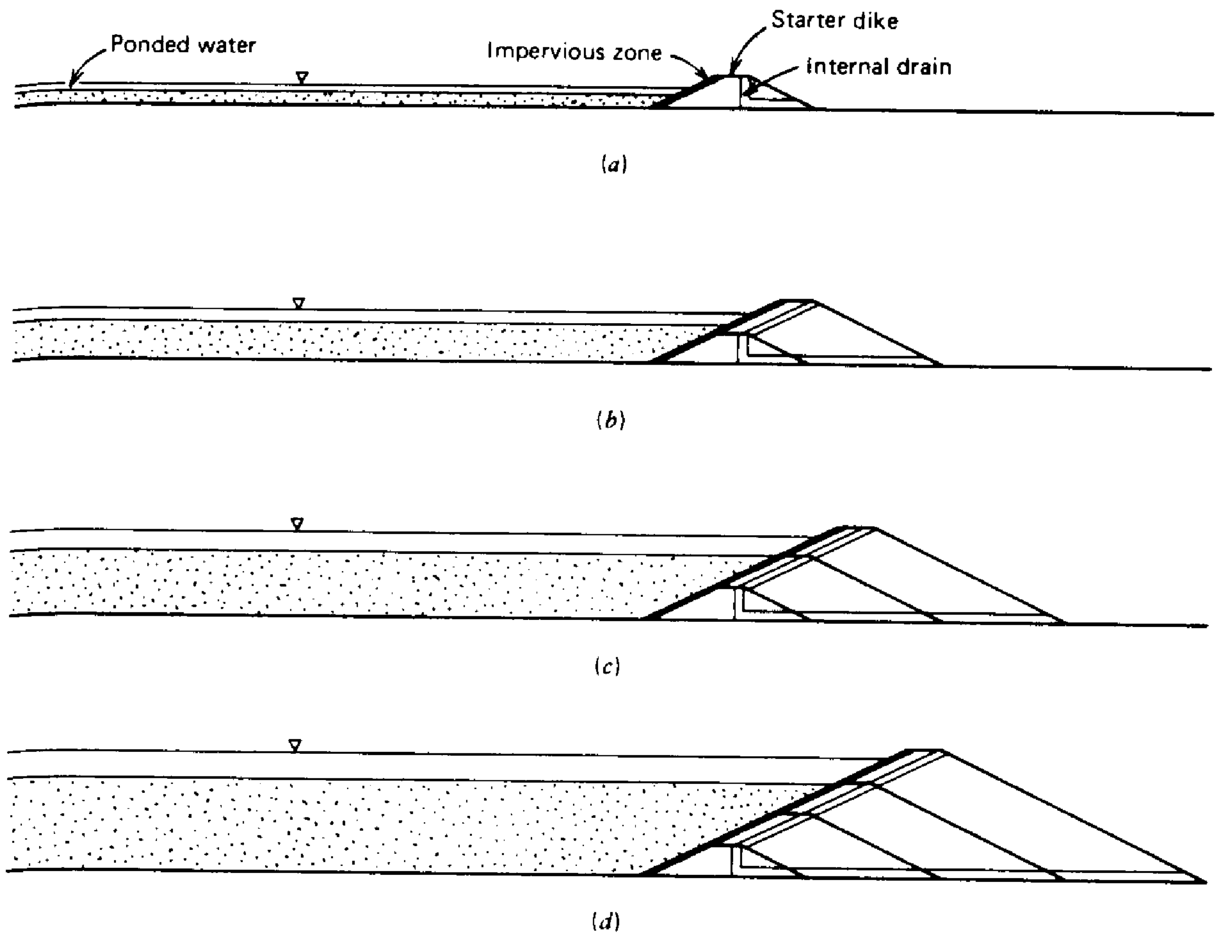


Figure 10. Centerline Embankment Construction

(Source: Vick 1990)

As in the downstream method, drainage zones can be incorporated into the construction. A wide beach is not mandatory and this method is amenable for use with tailings that contain a relatively low percentage of sand. Since less sand is required, the dam raises may be added faster than in the upstream or downstream methods. Coarse gradation of the tailings is necessary if rapid drainage is required to provide support for construction equipment.

Although this embankment type is not amenable to permanent storage of large volumes of water, short term storage of water due to heavy precipitation events or mill shutdown will not adversely affect the stability of the dam.

If the embankment has been properly compacted and good internal drainage is provided, this embankment type is resistant to seismic activity. Even in the event that the slimes placed against the upstream slope liquefy, the central and downstream portions of the dam may remain stable due to their good compaction and drainage characteristics.

4.2.5 Embankments Constructed Using Alternative Materials

Although the three embankment construction methods discussed above are typically built with large volumes of coarse tailings, portions of the dams (particularly the starter dam) may incorporate a variety of borrow fill materials. For example, waste rock and overburden excavated during open-pit stripping can be used to construct embankments. However, waste removed from the mine may not keep pace with the demand to raise the dam crest. Also, waste rock that may potentially be acid-forming is not suitable for embankment (or drainage) construction.

In general, where natural materials are used exclusively for dam construction, standard earth dam (water retention) design may be followed. A water retention dam constructed with native materials should contain internal zoning such as an impervious core, drainage zones, and appropriate filters. These designs are best suited when large volumes of water are planned to be stored with the tailings. Design changes are required to account for the higher unit weight of saturated tailings. In addition, since water retention dams are designed to limit the drainage through the core, placement of spigotted slimes on the upstream face usually produce a moderately impervious upstream seal.

4.3 Tailings Deposition

Generally, tailings slurry is transported through pipelines from the mill to the tailings impoundment for deposition. Once the tailings reach the impoundment, a variety of options may be employed to deposit the tailings. In determining which method is best suited for a particular operation, tailings engineers (generally civil engineers specializing in the disposal of mine tailings) study the characteristics of the tailings materials, the deposition cycle, and the climate. They will also consider the impoundment layout and the embankment design. In the discussion that follows, it is assumed that the embankment is not of the water-retention type, and that the tailings will be used to provide most of the material for construction of the embankment.

Three general methods of tailings deposition are typically recognized: single point discharge, spigotting, and cycloning. There are variations on all these methods and the methods may be used in combination to meet the design criteria set by the tailings engineers.

4.3.1 Single Point Discharge

Single point discharge is the technique of discharging tailings from the open end of a tailings pipeline. This method is often employed at impoundments that discharge tailings slurry upstream of the pond and dam (i.e., not from the crest of the dam). This technique is not appropriate when the pond (and/or the fine fraction of the tailings) must be kept well away from the embankment. Single point discharge can also be used to discharge slurry into the dam, but this requires that the discharge point be periodically moved to another section of the dam to prevent unequal raising of the dam sections. Further, the low surface area to volume ratio afforded by single point discharge makes this method attractive in extremely cold environments, where freezing of smaller discharge streams may occur (Lighthall 1989).

4.3.2 Spigotting

Spigotting is the technique of discharging tailings through small pipes (spigots) that originate from multiple points at regular intervals along a tailings header line (Lighthall 1989). The method is used to achieve a more or less uniform flow of tailings, which in theory, will create uniform beaches. However, the location of the discharge points may require rotation to create these uniform beaches. Spiggotting forms a gently sloping beach where the coarsest fraction settles near the point of discharge and the fine fraction (slimes) is deposited progressively farther away from the discharge points. As a result of this variable gradation, the density, shear strength, and permeability of the settled solids decrease with increasing distance from the discharge point. As discussed above, these distributional characteristic could be very favorable in reducing the phreatic surface before and across the embankment. However, observations of actual particle size, permeability, and shear strength distribution with distance from the point of discharge suggest that the smooth ideal gradation theoretically achievable may be rarely achieved in practice (Vick 1990, Lighthall 1989). Nevertheless, consideration of the header tailings velocity, the solids concentration in the header and spigot lines, and the point of discharge (among other factors) may allow the development of beaches which provide structural stability to the main embankment while also creating a long seepage path (providing consequent dissipation of pore pressure) from the pond to the embankment (Lighthall 1989).

4.3.3 Cycloning

Tailings sands (the coarse fraction of the tailings) may be used to construct tailings dams during active deposition. Mining companies typically view cost savings as the major advantage of using the coarse fraction in this manner. Since the sand is produced from the material to be deposited (the tailings), any costs related to acquiring borrow fill for the construction of embankments is eliminated or significantly reduced. This practice also reduces the overall volume of tailings to be deposited in the impoundment, since at least part of the coarse fraction has been used in the dam construction. The method used to separate the fines from the coarse fraction in the total tailings slurry is cycloning.

Cyclones are simple mechanical devices used to separate coarse and fine particles from a slurry through centrifugal action. As the slurry, moving under pressure, enters the cyclone, the fine particles and most of the water rise to the top outlet. The coarse particles spiral downward through a conical section and exit the bottom. The separated fine fraction is referred to as overflow and the sand fraction is known as the underflow. It is the underflow that is used to construct the tailings embankments, while the overflow is discharged through a separate slimes pipeline to the impoundment itself. The underflow and overflow should be monitored regularly to measure pulp densities, gradation, and cyclone inlet pressures. Adjustments of the cyclones are routinely required to maintain pulp density and grain size objectives.

Certain criteria should be considered when evaluating whether cycloning can be an effective tool in the construction of a tailings embankment. The cycloned sands should have a permeability that is sufficiently higher than the slimes deposited in the impoundment such that the phreatic surface can be adequately controlled in the dam. The sands should also allow quick drainage upon discharge to ease handling and spreading of the sands. The volume of the cycloned sand recovered from the whole tailings must be great enough to allow for dam raises as needed to maintain adequate volume in the impoundment for slimes. If the volume of cycloned sand falls short of the amount needed for dam raises, costs could increase as borrow materials are required to maintain adequate impoundment volume. Tailings that contain less than 60 percent particles passing the number 200 sieve are generally considered to contain acceptable sand quality for use in cycloning. Two-stage cycloning, employing two cyclones in series, is often used to produce a sand fraction that contains less fines than single-stage cycloning.

Two basic methods of cycloning are in common use for tailings dam construction: central cycloning (or stationary cycloning) and on-dam cycloning. A third method, hydraulic cell cycloning, is a more sophisticated application that is less commonly used. The central cycloning method establishes a single permanent or semi-permanent high capacity cyclone at a strategic location, often on a dam abutment higher in elevation than the projected dam crest. The cyclone underflow creates a tailings sand stockpile for use in embankment construction while the overflow from the cyclone is discharged to the center of the impoundment. Earth-moving equipment moves the tailings sand from the stockpile to the embankment where they dump and compact it. The mechanical placement and compaction results in sands with a high relative density. Therefore, the method is well suited for use in areas susceptible to seismic activity.

The on-dam cycloning system consists of several cyclone units set up on towers, skids, trucks, scaffolds or suspended from cranes established along the dam crest. The number of cyclones is determined by the size of the cyclones and the mill throughput. The underflow sand from the cyclones is deposited on the embankment face while the overflow is discharged to the impoundment. The high pulp density underflow (typically 70 to 75 percent solids) results in the deposition of steep-sided sand piles at a slope of 3:1 to 4:1 (horizontal to vertical) on the slope of the embankment that is under construction. The cyclones are moved as the sand cones raise the height of the embankment. Normally the grade of sand placed by the cyclones does not vary with distance from the discharge point. However, this may differ between sites: Lighthall, et al. (1989) reported that if high pulp density underflows are used, tailings operators may sometimes lower the pulp density of the underflow to wash out the cones rather than move the cyclones too frequently. This practice could result in not meeting the grain size objective for the face of the embankment.

The on-dam cycloning system is cost-effective since the sands are placed in their final resting place hydraulically and no mechanical action is necessary. One disadvantage of this method is that the nonmechanical placement results in lower relative densities, ranging generally from 30 to 68 percent as reported in Lighthall, et al. (1989). Although relative densities between 45 and 50 percent can normally be achieved, relative densities below 30 percent are not uncommon. These low relative densities may eliminate this method of deposition from use in areas of high seismic activity.

The hydraulic cell method deposits diluted cyclone underflow (i.e., sands) into bermed cells on a tailings embankment. The tailings are cycloned at a central cyclone and the water is added to the underflow to ease pipeline transport to the cells on the embankment. The solids in the cells are then allowed to settle before the excess water is decanted from the end of the cell opposite the point of discharge. Some mines use wide-track bulldozers to compact the sands in the cells during deposition. Lighthall, et al. (1989) and Mittal and Hardy (1977) report that relative densities in excess of 60 percent can be achieved with the hydraulic cell method and mechanical compaction. Without mechanical compaction, Lighthall, et al. (1989) and Mittal and Morgenstern (1977) report that relative densities of tailings in excess of 50 percent can be achieved.

A major advantage of the hydraulic cell method is the achievement of high relative densities using direct hydraulic deposition (and possibly mechanical compaction). The method presents limitations for use on narrow embankments since a relatively wide, flat embankment area is required for cell construction. Furthermore, fines should be limited to 5 to 10 percent in the cyclone underflow to achieve highly permeable sands that allow quick drainage of water in the cell. This limitation of the fines component in the underflow may result in reductions in total overall sand recovery and, hence, the reduction in sand available for dam construction.

4.4 Stability Analysis

From initial trial embankment design to final site closure, the stability of the tailings embankment remains an important consideration. The primary objective of the impoundment engineer is to develop a reliable waste containment structure at the lowest possible cost. Choices regarding materials, slope angles, drainage control, raising rates, etc., all affect the cost as well as the stability of the structure. Therefore, stability analysis is performed to optimize the structure with respect to cost and other objectives while maintaining reliability.

Slope stability analysis begins with an estimation of the reliability of the trial embankment. Typically, the embankment designer proposes the internal and external geometry of the trial embankment and then calculates the safety factor of the design. Using detailed information on the physical properties of the fill material and estimates of the volume of tailings and water to be contained in the impoundment, the phreatic surface is predicted. The designer then examines a wide range of failure modes (discussed below) to calculate the estimated stresses expressed at hypothetical failure surfaces. The safety factor for each failure mode is then calculated by dividing the estimated resistance of the embankment to stress along the failure surface by the stress load expressed at the failure surface. With this process the designer can look at changes in design parameters and the resulting influence of the safety factor to arrive at the least-cost option consistent with safety objectives (Inyang 1993).

Once impoundment construction has begun, the quality of information available for slope stability analysis improves. The above process may be repeated for each raise of the embankment, replacing estimates of phreatic surface levels and the physical properties of fill materials with measured values collected in the field

(Mittal and Morgenstern 1974). Based on additional safety factor calculations, embankment design may be changed significantly before the structure is completed.

There are numerous methods for performing slope stability analysis. However, a more detailed discussion of these methods is beyond the scope of this paper. Vick (1990) and CANMET (1977), among others, provide much more detailed discussions. The following is a brief discussion of flow nets, used to determine seepage flow characteristics within an embankment.

4.4.1 Flow Net Analysis

In conducting stability analysis, flow nets can be used to estimate seepage direction and volume and pore pressure at points within the embankment (CANMET 1977). A flow net is a graphical solution of Darcy's law to show steady flow through porous media and is often used to show ground water flow. The variables include flow characteristics (either in terms of flow or head), information on the boundaries of the area to be modeled, and information on the hydraulic conductivity within the area. Boundary conditions are the characteristics of flow at the edges of the system being modelled[1].

In a flow net, a grid is formed by the intersection of flow lines (the path that an individual particle of water flows through a region) and equipotential lines (representing contours of head) (Freeze and Cherry 1979). According to Vick (1990), for most types of embankments, flow nets provide conservative estimates of pore pressures within the embankment, with static pore pressure at a point being roughly equal to its depth below the phreatic surface.

In working with seepage and pore pressures, understanding of some basic definitions in terms of hydraulic conductivity or permeability are necessary. Homogeneous means that hydraulic conductivity (K) (or the coefficient of permeability) in the material (natural soil or the embankment) is independent of position. Isotropic means that hydraulic conductivity is independent of direction at the point of measurement. If hydraulic conductivity is dependent on position then the media is heterogenous. If hydraulic conductivity of a media is dependent on direction at the point of measurement then the media is anisotropic.

In generating a flow net, certain assumptions are made to solve the equation, including that the flow is steady state rather than transient (Freeze and Cherry 1979). For this reason, the use of flow nets to determine exact volumes of seepage may not be accurate due to the often transient and unsaturated flow conditions at most tailings impoundments (Vick 1990).

In homogeneous isotropic systems, (systems where hydraulic conductivity is the same throughout the media in terms of location and direction) flow lines and equipotential lines intersect at right angles, providing the graphical solution to Darcy's Law.

[1]Boundary conditions for a homogeneous isotropic media may be zero flow (an impermeable boundary), constant flow (constant head boundary) or a water table (where head approximates atmospheric pressure).

If the media is homogeneous and anisotropic, the cross section (prior to the addition of flow lines) can be converted to an isotropic system by a ratio of the vertical and horizontal conductivities[2]; the construction the flow lines is then conducted perpendicular to the equipotential lines, as with true isotropic systems. After the flow net is constructed, it can be transformed back into the original anisotropic system. (Freeze and Cherry 1979, CANMET 1977) For heterogeneous flow systems, a flow net can be constructed by sketching the different layers of hydraulic conductivity and by refracting flow and equipotential lines as they cross from one layer to another[3]. Also, the same volume that exits one layer must enter the next layer. Typically, layers with higher hydraulic conductivity have relatively horizontal flow lines compared to layers of lower hydraulic conductivity with relatively vertical flow lines. (Freeze and Cherry 1979, CANMET 1977)

Flow nets are generally effective for downstream and centerline dams, which generally mimic homogeneous systems. See Figure 11 for examples of typical flow nets for embankments under various conditions. Due to complex permeability variations (complex heterogeneity) and boundary conditions, flow nets are not always realistic for upstream embankments. Finite-element and other analysis can be used (Vick 1990). For additional information on the construction and use of flow nets, see CANMET 1977, Vick 1990, and Freeze and Cherry 1979.

[2]Convert by the square root of the hydraulic conductivity in the vertical direction by the hydraulic conductivity in the horizontal direction.

[3]The tangent law is used; See Freeze and Cherry 1979.

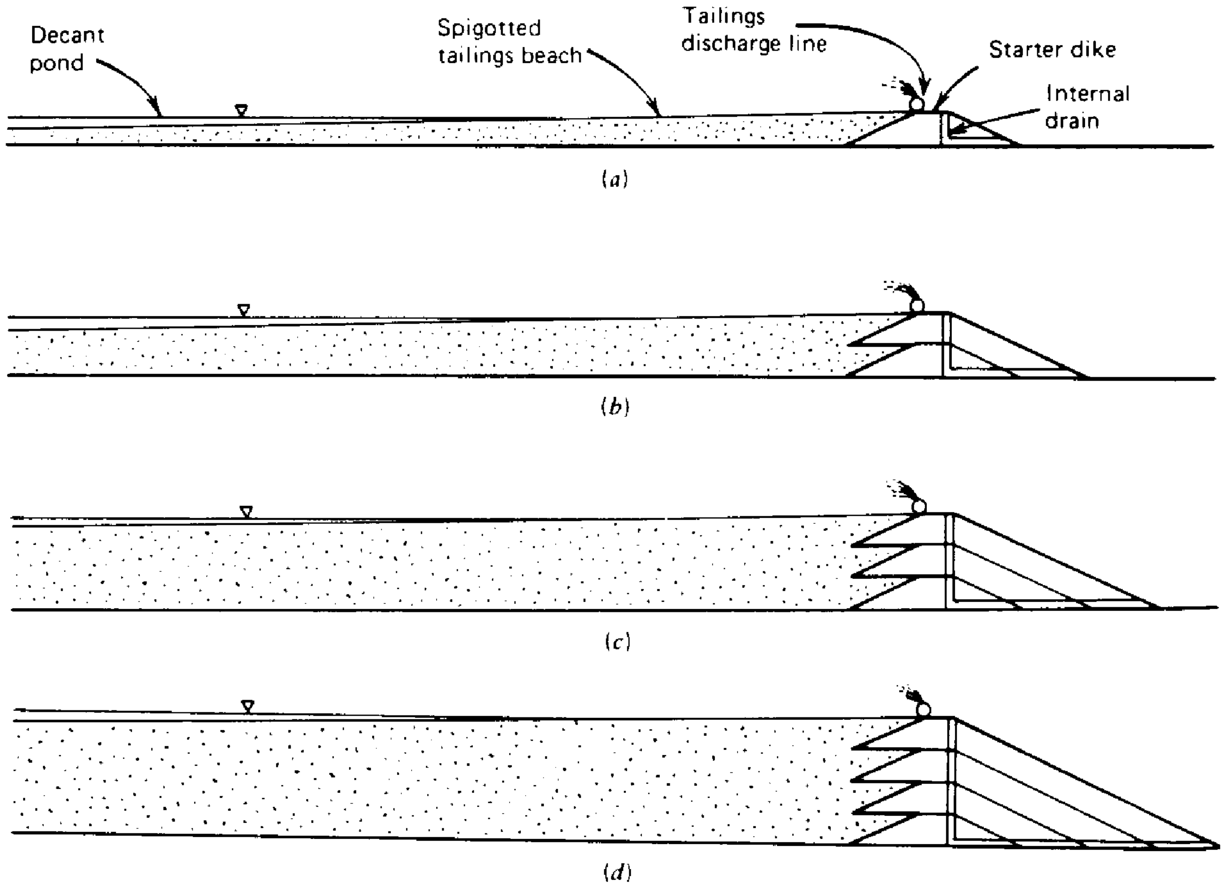


Figure 11. Examples of Tailings Embankment Flow Nets

(Source: CANMET 1977)

4.5 Failure Modes

As noted above, calculation of the safety factor for a tailings embankment requires an analysis of the potential failure surfaces of the embankment. There are a number of common failure modes to which embankments may be vulnerable. These include slope failure from rotational slide, overtopping, foundation failure, erosion, piping, and liquefaction. Each failure mode may result in partial or complete embankment failure.

4.5.1 Rotational Sliding

Rotational sliding, so named because the failure surface appears as a segment of a horizontal cylinder, may result in slope failures ranging from local sloughing of tailings at random areas along the face of an embankment to massive circular arc slides extending over the entire structure. In general, for a stable slope, the shear strength resisting movement along a potential failure surface exceeds the shear stress tending to induce movement. Instability occurs when the shear stress on the failure surface equals the shear strength

(Vick 1990). Specifically, causes of rotational failure may include changes in the water table, changes in the permeability of the foundation materials, disturbances to the embankment caused by vibration or impact loading, settlement of the foundation materials, etc (CANMET 1977).

4.5.2 Foundation Failure

Foundation failures are not uncommon among earthfill structures. Where a weak layer of soil or rock exists at shallow depth in the foundation below the structure, movement along a failure plane will occur if the earthfill loading produces stresses in excess of the shear strength of the soil in the weak layer (CANMET 1977).

4.5.3 Overtopping

One of the most common causes of failure is overtopping by flood waters. Overtopping typically results when the volume of run-on entering an impoundment, from improper diversion of surface water flows or excessive stormwater flow, exceeds the capacity of the impoundment. Because tailings embankments are constructed of highly erodible materials, the friction caused by rapid flow over an unprotected embankment crest may quickly erode a gully in the fill material, allowing sustained release to occur. Additionally, a rapid increase in pore pressure associated with large stormwater inflow may result in the liquefaction of unconsolidated impounded sands and slimes. Sustained high flow over the crest of an embankment can thus result in a major failure of the overall impoundment within minutes (CANMET 1977).

4.5.4 Erosion

In areas of heavy rainfall, some form of protection against erosion is usually required. Tailings embankments may be susceptible to erosion failure in two major areas, embankment abutments and the embankment face. Erosion along the contact line between the embankment and the abutment may result from stormwater flow that concentrates there (CANMET 1977). Typically, this type of failure is preventable with proper stormwater diversion methods and so results from faulty design or maintenance. Erosion of embankment faces may result from rupture in tailings lines installed on the embankment crest. Again, maintenance (and alternate siting of tailings lines) may prevent this type of failure.

4.5.5 Piping

Piping refers to subsurface erosion along a seepage pathway within or beneath an embankment which results in the formation of a low-pressure conduit allowing concentrated flow. Piping may result from seepage exiting the face of an embankment with sufficient velocity to erode the embankment face. The resulting void space promotes progressive erosion extending upstream toward the source of the seepage. In the worst case, the seepage may result in the creation of a direct channel from the tailings pond to the dam face (CANMET 1977). Excessive piping may result in local or general failure of the embankment or the embankment foundation.

4.5.6 Liquefaction

Liquefaction is one of the most common failure modes of cross-valley dams. Because tailings deposits typically comprise unconsolidated, saturated deposits of similarly-sized grains, they are susceptible to temporary suspension in water (Vick 1990). Liquified tailings may behave like a viscous fluid, such that they may pass through narrow openings and flow considerable distances (CANMET 1977). Accordingly, even small dam failures may result in substantial releases of impounded materials if those materials become suspended.

Factors affecting liquefaction potential include:

- *Soil type* - Uniform grain size materials, mostly in the fine sand sizes (the typical gradation of a tailings material), are the most susceptible to liquefaction.

- *Relative density or compactness* - For a given material, the more compact or dense it is the more resistant it will be to liquefaction.

- *Initial confining pressure at the time subjected to dynamic stress* - This offers an opportunity in certain areas to prevent liquefaction by applying overloads to loose deposits.

- *Intensity and duration of the ground shaking* - Liquefaction may occur due to an intensive earthquake, or due to prolonged earth movement.

- *Location of the water table* - A high water able is detrimental. Consequently, a tailings deposit constructed on a pervious foundation or a dam with a phreatic line kept low by providing adequate internal drainage features may have a greatly reduced potential for liquefaction. (Vick 1977)

By incorporating drainage facilities, maintaining a low pond surface, and compacting the fill materials during construction, the density, saturation, and confining pressures can be controlled to reduce the likelihood of liquefaction. If the tailings embankment is constructed of fine sands, compaction of these sands will increase their density and reduce their susceptibility to liquefaction. Compaction to obtain relative densities of 60% or greater provides reasonable protection (CANMET 1977). Therefore, provided embankment materials possess a relative density of 60% or greater, or provided the phreatic surface is maintained at a position well below the embankment surface, the embankment can have a sufficient factor of safety against liquefaction failure. Design calculations generally are needed to verify this for each individual dam.

4.6 Performance Monitoring

Routine monitoring and preventive maintenance are crucial in order to assure good performance of tailings impoundments. Monitoring can consist of visual observation of the tailings embankment, monitoring of piezometers and other instrumentation. Preventive maintenance, based on the early observation of potential "trouble spots," can maintain the stability of the structure, control seepage, and contain costs. Distress signals such as cracking, wet spots on the downstream face, and critical settlement, all indicate deficiencies in the structure, but without proper instrumentation it may be difficult to accurately interpret the extent of the problem. Piezometers, pressure gages, and inclinometers can be used to show developing trends in the behavior of the deposited materials. The observations made from these instruments, combined with disposal operation logs which show dates and locations of deposition, meteorological conditions, etc., can help analyze the situation. (Vick 1990)

Instrumentation should be installed in the embankment or its foundation to monitor changes which may be critical to stability, and in order to help predict unstable conditions. Instruments can be installed to measure pore water pressures, seepage flows, embankment movements, and total pressures.

Pore water pressure in soils may be measured with piezometers. The Casagrande piezometer, a simple and effective piezometer, has a porous ceramic stone element and is designed to measure pressure changes with a minimum lag time. It is installed in a hole drilled into the embankment or its foundation, and water levels are measured by a probe lowered down the hole. Similar types can be installed using porous plastic, porous bronze, perforated steel casing, or steel casing and well points. Hydraulic and electrical piezometers are also available and can be installed at various levels in an embankment. These piezometers are generally more complicated to operate, and their reliability over long periods requires great care in fabrication and installation. When encountered, seepage flow emerging downstream from the embankment, can be collected and directed to a weir for flow measurements. Records of seepage flow will indicate when significant changes occur and permit an evaluation of potential problems from piping.

Simple methods for measuring embankment movements can be utilized. Markers can be installed on the surface aligned in a straight line-of-sight to permit rapid detection of horizontal movement during periodic surveys. Successive measurements between two pegs spaced either side of a crack will indicate any widening and acceleration in separation rate. A more advanced device for measuring horizontal movement is the slope-indicator. For this device, telescoping cylindrical casing is installed in the embankment during construction. The sensing element is lowered down grooves inside the casing and measures the slope of the casing in two directions at right angles. From the measured slopes, the horizontal movements occurring over the length of the casing can be calculated. Surface settling can be measured through the use of leveling or temporary benchmarks.

The frequency of monitoring will depend on previous observations and the critical nature of the parameters. In most instances, frequent observations during and immediately after completing construction phase is important. When records indicate that conditions are relatively stable, frequency of observations can be extended. In some instances, measurements may be needed only after the occurrence of unusual conditions such as heavy surface runoff, peak floods, or seismic activity.

The characteristics of the tailings and the construction method may change substantially over the years taken to construct the dam. These changes can alter the conditions governing the stability of the embankment. Changes may take place in crest levels, water levels, embankment slopes, cross-section geometry, seepage conditions, and material characteristics. A continuous program of inspection and maintenance is necessary from the beginning of deposition throughout the life of the dam. Through careful monitoring, areas of concern may be noted and quickly repaired, thereby preventing failure. In addition to monitoring the stability of the dam, the performance of liners and drainage systems can be evaluated. Monitoring wells are useful in monitoring seepage.

5. WATER CONTROL AND MANAGEMENT

As discussed throughout this paper, the ultimate purpose of a tailings impoundment is to contain tailings in a cost-effective manner that provides for long-term stability of the impoundment and long-term protection of the environment. Water control and management are perhaps the most critical components of tailings impoundment designs and operation. The failure modes discussed previously are all related to water in the impoundment and/or the embankment. Similarly, the environmental impacts of tailings and impoundments are related to water control and management, either directly, as in the cases of ground or surface water contamination, or indirectly, as in the case of airborne transport of dry tailings. Water has been discussed in the previous section in terms of stability; in this section, it is discussed in terms of environmental performance. Most recently, environmental issues have come to the forefront of tailings impoundment design, with special concerns over the quality of effluent and seepage from tailings impoundments, both to ground water and surface water. This concern has lead to both an increase in treatment of especially toxic tailings effluent prior to discharge and more effort toward total containment of the tailings water within the impoundment. The latter effort (i.e., containment) is a challenge that has not been overcome: according to Vick (1990), some methods of seepage control are more effective than others; however, "`Zero discharge,' even with the use of impoundment liners, remains an elusive goal."

5.1 Surface Water

Control of surface water is one of the major factors involved in design and operation of a tailings impoundment. A mass balance approach to water management can be used, with variables categorized into outflows and inflows. Outflows from a tailings impoundment include overflows, evaporation, recycle and re-use, and seepage. Overflows are dependent on the dam's storage capacity and the runoff volume of a storm event in the basin. Evaporation rates are a function of the climate and the surface area of the freewater pond and saturated tailings. Recycling and re-use volumes depend on the operation's capacities and needs. Seepage can exit the dam as ground water or seepage through or under the embankment. This section describes the surface components of water flow into and out of the impoundment. Subsurface flows are described in a later section. Both surface and subsurface components interact in a dynamic fashion and must be considered together in any analysis.

5.1.1 Surface Water Evaluation

Estimation of surface water inflows and outflows using a mass balance approach includes both natural and man-made components. Variables include precipitation (including storm events), evaporation, run-on (including flood events), the liquid component of the tailings as it is discharged to the impoundment, water returned to the impoundment from any downstream seepage return systems, evaporation, infiltration, decanting and recycling tailings water, and any direct discharge (overflow). Ferguson et al. (1985) also include discharge to the free water pond resulting from tailings consolidation.

Precipitation data, topographic maps, streamflow measurements, and snow-depth data are used during impoundment design to prepare hydrographs and frequency curves for use in estimating volumes of precipitation and runon anticipated. Hydrographs, used for ultimate flood designs, determine changes in inflow rates and maximum flow rates. They illustrate stream discharge versus time for storms of various intensities and durations. Hydrographs are composed of interflow, surface water runoff, and baseflow (flow attributed to shallow ground water). Factors affecting hydrograph shape and height are rainfall intensity, distribution and duration; basin size, shape and drainage pattern (e.g. dendritic or trellis); and vegetation patterns.

Peak inflow rates are affected by rainfall intensity and are indicated on a hydrograph as the crest. Rainfall intensity is indicated by the slope of the rising limb. The direct runoff area is the area under the hydrograph minus the baseflow. The baseflow is indicated at the point where the hydrograph changes slope (inflection points).

Frequency curves, used for return-period flood designs, allow the designer to determine discharge rates of a design storm. Snowpack depth is incorporated into dam designs in areas with large snowfalls or fast snowmelts. Avalanche frequencies in the area are considered in the design as appropriate. Rules of thumb are that freshly-fallen snow has a water content of 10 percent while spring and compacted snow have a water content of 30 percent by volume. The importance of containing seasonal rapid snowmelt is worth emphasizing. The Bureau of Mines states that lack of sufficient snowmelt capacity is believed to be one of the major factors responsible for the Summitville leach pad failure, and tailing ponds are similarly vulnerable.

Modelling and analysis can be used estimate the volumes of naturally occurring inflows and outflows, such as precipitation and evaporation. Methods for estimating some of the major naturally occurring inflows and outflows are summarized below; additional inflows and outflows, which have an element of human control, are described in the water controls section.

Storm Events

Runoff volumes can be calculated through precipitation, discharge, and vegetative data of the area. Precipitation data from wet and dry years are used to provide minimum, average, and maximum runoff volumes for determining storage capacity and control structures for the dam. Calculations generally include a time continuum because the dam surface area will increase and the drainage area will decrease as more tailings are deposited into the impoundment. Hydrographs and several computer models, such as HEC (Army Corps of Engineers Hydrologic Engineering Center) and SWMM (Storm Water Management Model), are available for calculating runoff volumes. (Huber 1993)

Large volumes of rainfall and snowmelt in a short period of time can result in erosion of access roads, dike damage, contamination of surface water, and catastrophic failure of a tailings dam. A dam design includes plans to contain or mitigate runon volumes and rates associated with a flood. The type of flood used in a design depends on impoundment size, dam height, and the consequences associated with death, economics, and environmental damage. Designs provide protection from a return-period flood (e.g. 100-year) or an ultimate flood (defined as the maximum volume of runoff from a single event). A flood design involves the determination of rates and volumes associated with inflows and outflows in a dam as a function of time. Because tailings impoundments are intended for permanent disposal (i.e., over 10 or 100 years, the most common return intervals used), it may be appropriate to consider much longer return intervals (and/or extended care).

Infiltration

Infiltration rates are generally low because of the small particle size and low permeabilities in the tailings. Infiltration rates are a function of a soil's moisture content, capillary pressure, unsaturated hydraulic conductivity, and the distance below the surface. There is no runoff or ponding when the infiltration rate is less than the saturated hydraulic conductivity. Runoff or ponding occurs when the infiltration rate is larger than the infiltration capacity and the saturated hydraulic conductivity.

Evaporation

Evaporation is a function of wind velocity, atmospheric pressure, temperature, and areal extent of surface water. In general, it is proportional to the surface area of the free-water pond. Impoundments in arid areas are designed to conserve and recycle water for mining processes during the mine's active life. Evaporation data for certain areas are available from NOAA. Pan evaporation tests can be used to determine evaporation rates if the site is not located in a basin monitored by NOAA. In essence, the pan evaporation test monitors daily water loss in a Class A pan (four feet in diameter and ten inches deep) which is mounted one foot above the ground. A pan coefficient (0.64 to 0.81) is used to adjust pan evaporation rates because they will be higher than normal lake evaporation rates. When the evaporation rates for a basin are known, the designer can determine if surface area dimensions will provide the required evaporation rates. Because net evaporation, like precipitation, is not constant from year to year, it may be beneficial to reduce the calculated evaporation rate by a safety factor to account for annual variability.

5.1.2 Surface Water Controls

Each site requires a slightly different network of surface water controls because of differences in topography, climate, hydrology, geohydrology, etc. Most controls are a combination of storm event, flood event, seepage control, recycling, and dewatering processes. Methods for control can be first used in the design phase by siting the impoundment as far up-valley as possible. One step in minimizing the volume of water in and seeping from the impoundment can be accomplished by minimizing runon from outside sources through diversion of existing streams and run-on. This will in turn reduce size requirements for the impoundment.

The storage capacity of a dam affects the size of runoff control structures, applicability of some control structures, embankment size, and safety factors of a design. In turn, it is affected by the velocity, volume, and frequency of runoff in the basin. In general, the inflow plus the storage available in the dam has to equal the outflow from the dam. The maximum storage occurs when the inflow equals the outflow.

In some cases, storm flows are managed by increasing the freeboard in the impoundment during design; however, this results in additional water in the impoundment available for seepage. Using freeboard may be economical in semi-arid areas where flooding occurs infrequently and the mine requires a large amount of water for processing streams.

The principal methods for controlling runon are catch basins and check dams, and diversion ditches (channels and pipes). Catch basins stop surface water from entering the tailings impoundment area but generally require some method of by-passing the tailings impoundment such as decant systems or diversion ditches. Catch basins may be expensive because of labor and fill material but can be cost-effective for small runoff volumes. Treatment of the water may not be necessary because the water never enters the tailings impoundment itself. Water rights claims and environmental effects are important aspects of this alternative because the frequency and volume of water releases from the catch basin will affect downstream areas.

Decant systems are generally used in conjunction with other forms of surface water control. Major costs associated with the decant systems are pumping, maintenance, and treatment costs. It may be difficult, in areas with large surface water runoff volumes, to provide enough wells for removal of the runoff in a timely manner.

Diversion channels (open and closed) can be used for most dam designs, especially valley-bottom dam designs. Closed channels (pipes) are usually used under cross-valley dams because the dams generally do not permit a side channel for diversion. Water treatment is not an issue with diversion channels if they begin diverting the runoff above the dam. However, the long-term viability of diversion channels must be considered in design.

Spillways generally are designed as temporary structures because they will change (i.e., be moved or increase in length) as raised embankments increase in height. They are constructed of an impervious material able to withstand rapid flow velocities. The spillway also is designed to contain and control hydraulic jumps that occur at the bottom of the spillway. In addition, a spillway design has to consider and plan for water treatment if the surface water runoff passes through the tailings dam.

5.2 Tailings Seepage

As discussed previously, flow nets and other analytical methods can be used to calculate seepage volumes. A less conservative method for estimating seepage is use of a mass balance approach, assessing each of the potential inflows and outflows to determine overall water movement (Ferguson, et al. (1985).

5.2.1 Seepage Flow (Direction and Quantity)

Seepage is the movement of water (contaminated and uncontaminated) through and around the dam and impoundment. Primary factors affecting the volume of seepage present in a system are depth to the ground water table and infiltration capacities of the unsaturated zone and tailings. The quantities and water quality of the seepage affect the types of controls that are incorporated in the dam design. (Vick 1990)

Historically, controlled seepage through embankments has been encouraged to lower the phreatic surface and increase stability. Evaluation of the volume and direction of seepage is conducted using hydraulic principles similar to those used in embankment design. The same variables that are used during the design phase to predict the phreatic surface can be used to estimate the volume of seepage flow. Similarly, variables, such as permeability of the embankment and foundation, that might affect the phreatic surface also affect seepage rates and volumes. However, more exact and extensive data may be required than for calculation of pure pressures for analysis. Flow characteristics of tailings impoundments, their foundations, and underlying soil can be viewed as an inter-related system, with both saturated and unsaturated components.

Seepage evaluation can require information on: (1) components from geologic, hydrologic, and hydrogeologic studies, and (2) physical and chemical characterizations of surface water inflows, seepage, and tailings. Geologic factors affecting seepage are fractured rock, clay lenses, and uplifted geologic formations with large differences in permeability. Hydrologic data is affected by rainfall intensity, soil type, and surface conditions. This data can be used to calculate infiltration rates. Hydrogeologic studies can determine: (1) the critical path and degree of anisotropy of the ground water, (2) the boundary conditions for ground water flow evaluations, (3) the moisture content, permeability, and porosity of the tailings and underlying soil, (4) the thickness of the unsaturated zone and capillary fringe, and (5) the storage capacity, hydraulic conductivity, and transmissivity of the tailings and underlying aquifer. Flow nets and more complex models of seepage flow can be prepared. A mass balanced approach can also be used and is presented by Ferguson et al. (1985). For additional information on the determination of seepage volumes and direction, see Vick (1990), CANMET (1977), and Ritcey (1989).

5.2.2 Seepage Quality

The chemical composition of tailings seepage is important in determining potential environmental impacts. Factors include waste characteristics such as mineralogy of the host rock and milling methods used to produce the tailings, and the interaction of the tailings seepage with the liner (if any) and the subsurface. (Vick 1990)

Contaminant mobility can be increased by physical mining processes such as milling (a small grind results in increased surface area for leaching). Most mining companies manipulate pH and use chelating agents to extract minerals from the ore. These same processes can be applied to the fate and transport of contaminants in tailings. While many heavy metals are hydrophobic with strong adsorption tendencies for soil, the chemical reagents used in mining processes may be present in the tailings material. They are able to desorb the metals, making them mobile in leachate or surface waters.

Contaminated water may be formed from downward migration of impoundment constituents or ground water movement through tailings. Most contaminant transport in ground water systems is from the advection (fluid movement and mixing) of contaminants. Factors affecting the rate of advection include ground water/leachate velocity, chelation, pH, and partition coefficient values. The geochemistry of the aquifer, physicochemical properties of the tailings and seepage will determine the buffering capacity of the soil, types of chemical reactions (precipitation or neutralization) and the rate of adsorption and ion exchange.

A related problem is the production of acid by oxidation of thiosalts, which is a problem for some metal mines in eastern Canada. The bacterial culprit is thiobacillus thiooxidans. Thiosalts may be removed from the mill effluent by biological treatments (Guo and Jank 1980, quoted by Vick 1990).

According to Vick (1990), neutralization, oxidation/reduction, precipitation adsorption, ion exchange, and biological reactions play a major role in the chemical composition of tailings seepage. These are many of the same reactions used in milling operations to free the desired mineral. Seepage quality can be modeled using complex geochemical methods. Vick (1990) and Ritcey (1989), among others, describe the methods in some detail.

5.2.3 Seepage Control

There are two basic options for controlling contaminated water in impoundments: keeping it in the impoundment or capturing it after it exits the impoundment. Seepage controls are typically evaluated in the early phases of impoundment design. The objectives are to maintain embankment stability, decrease water losses, and maintain water-quality at the site. Options for seepage control include installation of liners beneath the entire impoundment (to contain water and to exclude ground water), constructing drains for seepage collection, constructing seepage collection and pumpback (or treatment) systems, sometimes in conjunction with low permeability barriers, construction of low permeability embankments and embankment barriers (i.e., cores and liners), dewatering of tailings prior to deposition, and decreasing hydraulic head by locating the free-water pond away from the embankment. Some of these techniques are described in more detail below.

Liners

Liners have not been incorporated into tailings impoundment designs until the last decade or two. Even now, due to their high cost, mining companies tend to avoid the use of liners under an impoundment. Although liners may be used to seal the upstream face of a tailings dam, most tailings impoundments in use today do not contain a lining system. The two major types of liners used to control flow through tailings dams are synthetic materials, which are very expensive, and constructed liners made of local clays or other readily available materials. Slimes are also sometimes used as low permeability barriers.

Areal coverage needed for the impoundments is a major cost consideration, especially for cross-valley dams. Thicknesses vary depending on the liner type but most thicknesses can be decreased if they are overlain with a drainage system to collect fluids, which reduces the hydraulic head (and stress) on the liner. An underdrain or vents may be necessary to remove sub-grade vapors that might otherwise lift the liner and to prevent ground water infiltration into the tailings. Liners have to be resistant to constituents in the tailings and seepage (such as acids or caustic substances), weathering if exposed to ultraviolet radiation, deformation from loading stresses, and seismicity.

Clays and synthetic liners can be combined to form double and triple liners. To prevent large settlements, clay and synthetic liners are not placed over loose or easily compressed material. Designs usually incorporate covers to mitigate the effects of sunlight, wave, and wind exposure on clay and synthetic liners, and drying on clay liners. The effects of frost action and drying are incorporated as needed into a liner design, especially for dams with sloped bottoms. Leakage can occur through synthetic liners because of shrinkage, faulty seam construction, stress loading, exposure to ultraviolet radiation, or improper planning and construction of the sub-grade. Short-term maintenance plans are generally implemented, because many problems often occur within the first six months of operation.

Clay Liners

Clay can be an inexpensive option for liners, especially in areas with a natural abundance of this material. Clay liners vary in thickness at least two feet, provide permeability of 10^{-6} cm/sec or less, and undergo physical-property tests such as permeability, Atterberg limits, moisture content, compaction, shear, and compression. The Standard Proctor compaction test, the most commonly used test, compacts the soil by a drop hammer in a standard mold. (The soil is compacted in three even lifts, using 25 blows per lift from a 10-lb hammer dropping freely through 18 inches.) From the compaction curve, the water content vs. dry unit weight, and the optimum moisture content can be determined. The optimum moisture content produces the maximum dry unit weight for the material. The primary factors affecting compaction characteristics are soil type and compaction energy.

The density of a clay liner depends on its mineralogy and the method and degree of compaction. Clay can be compacted to a prescribed moisture content and density to provide a permeability of 10^{-6} to 10^{-7} cm/sec or lower. Grain-size distribution curves may be used to determine the amount of fine-grained material in the clay. In general, a high-plasticity clay will be more desirable than a low-plasticity clay because of its lower permeability, but construction and the climate of the site may have an effect on the decision. Chemical tests are undertaken on the clay material to determine if it is resistant to the seepage produced by the tailings dam. Clay liners may be supplemented with other liners (e.g., synthetic) to further reduce potential seepage.

Clay liners can fail when their permeability increases considerably above the design value. According to Van Zyl, et al. (1988), the three major causes of failure are differential settlement of the foundation, causing localized cracking of the clay liner; drying of the clay liner (desiccation), leading to the development of microcracks (that can occur in areas lined with clay too long in advance of the time when wet tailings will cover the liner or if the tailings dry after deposition); and alteration of the liner permeability, due to geochemical reactions between the liner and leach solution.

Synthetic Liners

Synthetic liners are a relatively new development in the control of seepage in tailings impoundments. Of the rigid liners, concrete (rarely used) and gunite may be susceptible to acid and/or sulfate attack, and asphaltic concrete may have questionable weathering and sun-aging characteristics (Kays 1977). Sprayed membranes have demonstrated installation problems which may need to be resolved before being considered as a possible option. Synthetic rubber membranes (butyl rubber, EPDM) may be too costly for tailings impoundments (Vick 1990). Vick provides a discussion on some of the specific characteristics of these materials, their design, and effectiveness. These thermoplastic membranes are the most common liners considered for tailings impoundments.

Estimates of seepage through a liner can be made using Darcy's Law. Non-rigid liners are often grouped into a category called geomembranes. Geomembranes are often used in conjunction with clay liners to form a double or triple liner combination. Seepage losses through geomembranes are estimated on the basis of flow through a hole in the geomembrane. Most synthetic liners are resistant to acids, bases, and salts present in tailing dam seepage. Permeabilities for the liners are generally 10^{-9} to 10^{-14} cm/sec with average thicknesses of 40 to 60 mils (CMA 1991). As noted elsewhere, both the cost and technical feasibility are major factors in selecting synthetic liners, given the large size and uneven terrain usually encountered.

Slimes

Tailings slimes are easy and inexpensive to install as low permeability layers to slow but not stop seepage. To be cost-effective, the slimes must constitute a majority of the whole mill tailings and the coarse and fine sands must be cycloned out of the slimes. In addition, there should be a system in place to guarantee even distribution of the slimes in the tailings pond (using rear, forward, and side spigots). Slimes are often used to line the upstream face of tailings dams (or lifts). Although slimes may offer a low-cost alternative to other materials, they have several disadvantages that are discussed in Vick (1990) and Ritcey (1989). In addition, it is difficult to determine long-term permeabilities of the slimes.

Embankment Barriers

Embankment barriers are installed below the impoundment and include cutoff trenches, slurry walls, and grout curtains. An impervious layer of fill is generally required between them and the tailings. Barriers are installed underneath the upstream portion of a downstream embankment and the central portion of centerline embankments; they are not compatible with upstream embankments. A good water-quality monitoring program is needed when using embankment barriers to ensure that they are completely effective in intercepting flows and also that seepage is not moving downward and contaminating the ground water.

Cutoff trenches, usually 5 to 20 feet in depth, are the most widely used type of embankment barrier for tailings dams, especially in areas with large volumes of natural clays. Dewatering may be necessary during the installation of cutoff trenches when they are installed below the ground water table.

Slurry walls are narrow trenches that are best suited to sites with a level topography and containing saturated or fine-grained soils. They are not compatible with fractured bedrock systems. The slurry walls are installed by excavating a trench to a zone of low permeability material and filling the trench with a soil/bentonite slurry which is then allowed to set to a consistency of clay. Depths average 40 feet and permeabilities obtained can be as low as 10^{-7} cm/sec.

Grout curtains use cement, silicate materials, or acrylic resins as a barrier to seepage movement. They are limited to sites with coarse-grained material (medium sands to gravel or fractured rock with continuous open joints) and can extend to depths of more than 100 feet. Permeabilities obtained can be as low as 10^{-8} cm/sec. However, leaks can occur through curtain joints or by subsequent corrosion of the curtain. (Vick 1990)

Rather than simply intercepting and containing seepage flows, barriers may have gravel (or other pervious material, appropriately filtered) drains immediately upgradient to allow seepage to be removed or directed to embankment underdrains. Barriers and seepage collection systems also may be used downgradient of embankments to prevent further environmental releases.

Pumpback Systems

Pumpback systems consist of seepage ponds and/or seepage collection wells installed downgradient of the impoundment that are outfitted with pumps that send seepage back to the impoundment or for use as process water. Current practices include the use of toe ponds or seepage ponds to collect seepage. In some cases, underdrains or toe drains are designed to flow into the seepage pond. In other cases, however, these systems are installed after construction of the impoundment as a remedial action to collect unanticipated seepage. These units may be used in conjunction with slurry walls, cutoff trenches or grout curtains to minimize downgradient seepage. Depending on effluent quality, the operation of the pumpback system may continue indefinitely.

5.3 Tailings Water Treatment

Tailings ponds can be effective in clarifying water prior to discharge. Many factors influence the effectiveness of the pond to provide sufficient retention time to permit the very fine fractions to settle before reaching the point of effluent discharge or time for unstable contaminants to degrade. Factors affecting settling time are the size of grind, the tendency to slime (particularly with clay type minerals), pH of the water, wave action, depth of the water, and distance between the tailings discharge and the effluent discharge. Although settling velocities of various types and grain sizes of solids can be determined both theoretically and experimentally, many factors influence effectiveness of the decant pool as a treatment device.

The grind required to liberate the valuable mineral is usually under the #200 sieve. Particles in the range of 50 µm with a settling rate of 0.05 in/sec (0.12 cm/sec) can be affected by grind action but will settle in a reasonable time. Particles of 2 µm or less can cause a turbidity problem. Such particles have settling rates of less than 0.01 in/sec (0.025 cm/sec) in still water and, under conditions prevalent in most tailings ponds, require several days to settle due to the turbulence caused by wave action.

Observations of existing ponds has led to general rules for clarification. The pool should provide 10 to 25 acres of pond area for each 1,000 tons of tailings solids transported each day and should provide 5 days retention time. An average of 15 acres per 1,000 tons is usually considered adequate (CANMET 1977).

6. CASE STUDY: STILLWATER MINING COMPANY TAILINGS IMPOUNDMENT

In the early 1980s, Stillwater Mining Company was planning for the development of a platinum and palladium mine approximately 77 miles southwest of Billings, Montana. The State of Montana Regulations require a mine to submit an application for hard rock mining and to obtain a permit for hard rock mining before construction of the mine and mine facilities may begin (exploration activities may continue during the permitting process).

The design for engineering report for the Stillwater tailings impoundment was submitted to the Montana Department of State Lands in February 1987. Its purpose was to present comprehensive information on all the activities that had been conducted at the site in relation to the design of the future tailings impoundment and to present the design to accommodate the engineering criteria developed as a result of the site evaluation, the tailings characteristics, the environmental regulations and future operations. The report included a scope of work that indicated the various tasks that had been completed in the conduct of the study. These tasks were listed as follows:

- Prepare design basis memoranda of the project design criteria,
- Supervise soil drilling, test pit excavations, and field density testing.
- Prepare and administer laboratory test programs for soils and tailings.
- Perform static and pseudo-static stability analyses and estimate the seismically-induced deformations of the dam due to the Maximum Credible Earthquake event.
- Perform hydrological studies to determine design flood runoff to the impoundment and water profile curves on adjacent natural waterways resulting from designated flood events.
- Perform reclamation studies to design a tailings drainage system.
- Select appropriate impoundment liner materials.
- Estimate construction material quantities and prepare construction sequencing curves showing required embankment crest elevation and tailings elevation versus time.

- Prepare inspection, maintenance, and contingency plans.
- Prepare design drawings of the initial, final, and reclaimed impoundment stages.
- Prepare an engineering report.
- Prepare plans and technical specifications sufficient for construction permitting.

6.1 Site Evaluation, Field Exploration and Laboratory Tests

6.1.1 Site Evaluation

The consultants responsible for all aspects of the tailings impoundment design performed their first reconnaissance of the site in August 1983. The purpose of this visit was to observe the foundation of the proposed tailings disposal area, determine if evidence of potential landslides and faulting existed at the site or in the vicinity of the site and to search for materials that could be used in the construction of the impoundment. The results of this reconnaissance, and previously collected information from a past drilling effort, indicated that the foundation beneath the proposed site was composed of pervious materials, gravels and boulders in a silty sand matrix. Prominent unweathered granite outcrops were noted as abutments to the tailings impoundment dam. Landslide materials were noted above the tailings impoundment area but were determined to be stable based on the natural slope and the lack of evidence of instability (ground cracking and leaning trees). Faulting and shearing were noted in the granite outcrops immediately west of the proposed impoundment, the geologist conducting the reconnaissance indicated that the fault was not active and will not have the potential for cracking of the tailings pond lining.

6.1.2 Field Exploration

A seismic refraction survey conducted in the impoundment area in 1983 determined the depth of bedrock to range from 31 to 226 feet below ground surface in a trough-shaped valley.

Test pits excavated up to 22 feet below ground surface in 1983 and 1985 explored ground conditions in the pond and dam foundation areas. In-place field density tests were conducted in 14 of the pits, nine in the location of the proposed dam foundation. The upper one to two feet of the test pits consisted of brown silty and sandy soils and below this soil horizon the material in the pit was largely composed of sand, gravel, cobbles and boulders with only 2 to 17 percent silty fines. Building rubble (left from a previous mining venture), abandoned pipelines and other non-native materials were uncovered during the excavation of the pits. The average dry density of the soil in the bottom of the pits was determined to be 135 pounds per cubic foot and the average dry density was determined to be 130 pounds per cubic foot. The results of the seismic refraction surveys indicated that soil densities increased below the bottom of the test pits.

Eight monitoring wells drilled in the impoundment area between 1979 and 1983 provided baseline ground water information and foundation conditions. The ground water surface ranged from 40 to 100 feet below the ground surface, but bedrock in the western portion of the proposed impoundment was found to form a ground water boundary and wells located west of this area were dry. Five soil borings ranging from 54 to 74 feet deep were drilled into the foundation area. Standard Penetration Test (ASTM D-1586) was used during the drilling, but the results were used only to qualitatively evaluate the density of the sands and gravels. Representative soil samples removed during the drilling were sent for laboratory evaluation.

6.1.3 Laboratory Tests

Laboratory tests of the borrow materials to be used in the proposed embankment and the foundation soils included grain size analyses (both sieve and hydrometer), Atterberg limits, natural moisture contents and specific gravity. Atterberg limits tests indicated that the fines display little to no plasticity. Natural moisture content was determined to range between 1 and 7 percent. Triaxial compression tests were also performed on borrow materials to be used in embankment design. The resulting strength parameters were used in preliminary stability analyses. Consolidated-undrained triaxial compression tests with pore pressure measurements were performed on recompacted samples of embankment borrow materials and foundation materials.

In the triaxial compression tests, foundation soil samples recompacted to the average foundation dry density determined in the field (130 pcf) were determined to have an effective angle of internal friction of 35 degrees and an effective cohesion of zero.

Laboratory compaction test results showed that the maximum dry density of the impoundment sands and gravels (embankment materials) range from 148 pcf to 159 pcf with optimum moisture contents ranging from 5 to 8 percent. The high density of the materials is attributed to their high specific gravity (3.0 to 3.2).

In the triaxial compression tests, the impoundment soil samples were compacted to 95 percent of the maximum dry density determined by ASTM D-698 (140 pcf). The effective angle of internal friction was determined to be between 39 and 41 degrees with an effective cohesion of zero.

Laboratory tests were also undertaken for tailings produced from a pilot grind on the mine site ore. Only fines were tested (cyclone overflow) since coarse tailings were to be deposited underground. Gradation, Atterberg limits and specific gravity were determined for the sample as well as sedimentation tests to determine the settled tailings density. Consolidation tests were conducted to estimate the variation of tailings density with depth and time-rate settlement characteristics.

Mine waste rock was also proposed for use in the construction of the dam embankments, however, no results of field or laboratory testing were presented in the engineering report. Results of visual observations noted that the rock was moderately well graded from fine rock dust to 24 inches, with the greatest proportion of materials in the 3 to 6 inch range. The rock was described as moderately hard with angular sharp edges. Debris (pipes, wood, plastic tarps and wire mesh) was noted mixed in with the waste rock.

6.2 Office Evaluations

The hydrology evaluations and stability analyses required for tailings dam design can be accomplished using results of the field and laboratory tests as well as maps and published data and information.

6.2.1 Hydrology Evaluation

The Stillwater River flows approximately south to north just east of the tailings impoundment site. A small tributary of the Stillwater River, Mountain View Creek, lies just south of the tailings impoundment. The toe dike was designed to be located 200 to 300 feet west of the Stillwater River and 50 feet north of Mountain View Creek.

The watersheds for both the Stillwater and Mountain View Creeks were estimated as well as the tailings impoundment and tailings impoundment catchment areas. These were presented in the engineering report as follows:

Watershed	Drainage Area	Average Basin Elevation
Tailings Impoundment Catchment	68 acres	5500 feet
Final Tailings Impoundment	35 acres	
Mountain View Creek	1.48 square miles	7300 feet
Stillwater River above Mountain View Creek Confluence	191 square miles	9000 feet

Flow records from the gaging station nearest the mine site with a long period of record (located 25 miles downstream of the site) shows that the maximum recorded flow was 12,000 cfs. The drainage area at this location is 975 square miles.

The flood storage volumes for the impoundment were determined to size the impoundment to prevent overtopping. The design flood for the impoundment is based on size and downstream hazard potential classifications as found in the U.S. Army Corps of Engineers "Recommended Guidelines for Safety Inspection of Dams". Guidelines recommend that the design flood for this impoundment should range from one-half the probable maximum flood (PMF) to the full PMF. The one-half PMF was chosen as the design flood for the impoundment at intermediate heights and the full PMF was chosen for the impoundment at stages which exceed a height of 100 feet.

The PMF and one-half PMF estimates were determined for the Tailings Impoundment Catchment Area, the Mountain View Creek Watershed and the Stillwater River Watershed above the confluence with Mountain View Creek. The Army Corp of Engineers' Hydrologic Engineering Center (HEC) computer programs, used to determine flood hydrographs (HEC-1) and water surface profiles (HEC-2), were employed in the estimation effort.

Other basic data for use in the PMF study were pulled from a number of sources. The probable maximum precipitation (PMP) for Six-hour local and 72-hour general storms were developed from the "Hydrometeorological Report No. 55, Probable Maximum Precipitation Estimates - United States, Between the Continental Divide and the 103rd Meridian". The PMP for 72-hour storms assumed unlimited snowpack available for snowmelt since the maximized storms occur primarily from the end of May through June (spring melt season). Snowmelt estimates were based on the Army Corp of Engineers' "Runoff from Snowmelt" since actual data on local snowpack and snowmelt were not available. Temperatures and windspeeds during the PMP were calculated following the procedures in the "hydrometeorologic Report No. 43, Probable Maximum Precipitation, Northwest States". Unit hydrographs, infiltration and retention losses were developed from the Soil Conservation Service procedures.

The results of the HEC-1 computer program determined the following results of the design floods, as shown in Table 2.

Table 2. Stillwater Mining Company Calculated Design Floods

Design Storm	Tailings Impoundment	Mountain View Creek	Stillwater River above Confluence with Mountain View Creek	Stillwater River below Confluence with Mountain View Creek
PMF (72-hr. PMP plus snowmelt) volume	312 acre-feet			
1/2 PMF (72-hr. PMP plus snowmelt) volume	156 acre-feet			
PMF (6-hr. local storm PMP) peak discharge		11,230 cfs		
1/2 PMF (6-hr. local storm PMP) peak discharge		5,615 cfs		
PMF (72-hr. PMP plus snowmelt) volume		8,241 cfs	329,980 cfs	330,828 cfs
1/2 PMF (72-hr. PMP plus snowmelt) volume		4,121 cfs	164,990 cfs	165,414 cfs

The HEC-2 water surface profiles computer program was used to determine the estimated maximum water surface elevations and flow velocities for the PMF and 1/2 PMF peak discharges at the stretch of the Stillwater River opposite the tailings impoundment. The river sections (cross sections and longitudinal sections) were assumed to be stable, with no scour or bank sloughing. This is of a conservative assumption since scour is likely to occur during a flood of PMF magnitude and the scour would widen and deepen the channel. The computed surface water elevations resulting from the PMF on the Stillwater River were shown to locally exceed the design toe dike by 15 feet, however, this left 5 feet to the top of the toe dike. The 1/2

PMF exceeded the bottom elevation of the toe dike by about 4 feet and the distance left to the top of the toe dike was 16 feet. The toe dike is beyond the limits of the computed 100-year and 500-year flood plains.

Velocity calculations indicated that erosion would occur under PMF and 1/2 PMF conditions on both the Stillwater River and the Mountain View Creek. The 1/2 PMF storm was not considered to be of sufficient extent to cause total failure of the dam. The PMF storm was considered to create sufficient erosion to cause total failure of the dam.

6.3 Tailings Impoundment Design

At the Stillwater Mine, whole tailings were to be separated by cycloning into the coarse and fine fractions; coarse fractions were to be deposited underground and fine fractions were to be placed in the lined tailings impoundment.

The engineering plans for the tailings impoundment indicate that whole tailings on occasion may be deposited in the tailings impoundment. A total tailings production rate of 500 dry tons per day during the first 4 years (approximately half that to be disposed in the impoundment as fine tailings) were estimated for tailings design. From year 5 forward a total tailings production rate of 1000 dry tons/day (approximately half that to be disposed in the impoundment as fine tailings) were estimated for tailings design. Tailings production was estimated to occur 330 days per year, 24 hours a day. The tailings were assumed to have a solids content of 30 percent and the fine fraction was assumed to have a solids content of 18 percent.

The tailings impoundment design, a side hill modification, calls for the embankment to be raised in four stages throughout the life of the mine. This layout and the final dam crest elevation were based on the preliminary studies and a mine life of 20 years. The maximum height of the dam will be 130 feet and the crest width was designed to be 20 feet to accommodate vehicle traffic and a tailings slurry pipeline. The upstream slopes of the dam were designed at 1.6:1 and the downstream slopes at 2:1 as determined through static and dynamic stability analyses.

Impoundment excavation will occurs in stages one and two to provide construction materials for the embankment and to increase the storage capacity of the impoundment. Each new stage of the embankment will be added in the downstream direction.

The embankment stage and estimated stage life statistics are listed below as based on a 1987 startup date.

Stage Number	Dam Crest Elevation	Approximate Year Dam Stage Construction Completed	Approximate Year Stage Filled
1	5045	1986	1992
2	5077	1991	2002
3	5096	2001	2007

4	5102	2006	2009

The impoundment was designed to store the design flood volume. The design freeboard (3 feet while containing the design flood volume) was determined from the flood storage volume and operational considerations.

The impoundment was to be monitored for settlement using survey monuments located along the dam crest. Piezometers were to be installed in the dam foundation to monitor for seepage.

The design calls for the installation of a synthetic liner to minimize the migration of effluent from the impoundment to ground water. The installation of the liner was planned in stages to coincide with the embankment raises. This plan not only reduces cost but also prevents potential damage to portions of the liner that would have been exposed for many years. The liner was selected based on economy, chemical resistance, resistance to weather, constructability and strength and durability. Hypalon and HDPE liners were being tested at the time of the engineering report. Based on initial tests (simulations of the tailings pond environment), it appeared as though the HDPE liner experienced no changes to its material properties while the Hypalon liner was experiencing some changes in material properties. Installation procedures for the liner required the removal of all objects (rocks, clods, debris, sharp objects, etc) that could potentially damage the liner. As-built figures have not been obtained.

In order to complete evaluation of the effectiveness of lining the tailings impoundment, additional information is needed. However, this tailings impoundment example shows that the mining industry is investigating options for lining tailings impoundments and that in some cases, liners may be a feasible alternative. This case study exemplifies the amount of study necessary to assess the feasibility of using a synthetic liner. Additional studies (which were not obtained prior to preparation of this report) may provide an analysis of the water balance and how it has been affected by the synthetic liner. Final cost analysis (also not obtained) will help to provide a measure of the feasibility of lining impoundments with synthetic liners. This impoundment design has been approved by the State of Montana and the impoundment is currently operating as planned, providing an example showing that lining of impoundments can be a feasible option to minimize seepage and environmental impact.

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Human and Ecological Risk Assessment of Coal Combustion Wastes

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Human and Ecological Risk Assessment of Coal Combustion Wastes

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U.S. Environmental Protection Agency
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List of Acronyms

Acronym	**Definition**
3MRA	multimedia, multiple exposure pathway, multiple receptor risk assessment
ADD	average daily dose
Ag	silver
Al	aluminum
As	arsenic
ATSDR	Agency for Toxic Substances and Disease Registry
B	boron
Ba	barium
BCF	bioconcentration factors
Be	beryllium
CAIR	Clean Air Interstate Rule
CalEPA	California EPA
CAMR	Clean Air Mercury Rule
CCW	coal combustion waste
Cd	cadmium
Co	cobalt
Cr	chromium
CSCL	chemical stressor concentration limit
CSF	cancer slope factor
Cu	copper
DAF	dilution attenuation factor
DBGS	depth below ground surface
DOE	U.S. Department of Energy
DWAK	Drinking Water Action Level
EFH	Exposure Factors Handbook
EIA	Energy Information Agency
EPA	U.S. Environmental Protection Agency
EPACMTP	EPA's Composite Model for Leachate Migration with Transformation Products
EPRI	Electric Power Research Institute
F	fluoride
FBC	fluidized-bed combustion
Fe	iron
FGD	flue gas desulfurization
GIS	geographic information system
HBN	health-based number
HDPE	high-density polyethylene
HEAST	Health Effects Assessment Summary Tables
HELP	Hydrologic Evaluation of Landfill Performance
Hg	mercury
HGDB	Hydrogeologic Database
HHRAP	Human Health Risk Assessment Protocol
HQ	hazard quotient

Acronym	**Definition**
ID	identification
IEM	Indirect Exposure Methodology
IRIS	Integrated Risk Information System
IWEM	Industrial Waste Evaluation Model
LADD	lifetime average daily dose
LDS	leak detection system
LF	landfill
LOAEL	lowest observed adverse exposure level
MCL	maximum concentration limit
Mn	manganese
MINTEQA2	a geochemical assessment model for environmental systems
Mo	molybdenum
MRL	minimal risk level
MSW	municipal solid waste
Ni	nickel
NOAEL	no observed adverse exposure level
NPDES	National Pollutant Discharge Elimination System
ORD	Office of Research and Development (EPA)
Pb	lead
PCS	Permit Compliance System
pH	a measure of hydrogen ion activity
RCRA	Resource Conservation and Recovery Act
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RME	reasonable maximum exposure
SAB	Science Advisory Board (EPA)
Sb	antimony
SD	standard deviation
Se	selenium
SI	surface impoundment
Sr	strontium
SW	solid waste
SWTSS	surface water total suspended solids
TCLP	toxicity characteristic leaching procedure
Tl	thallium
TL3	trophic level 3
TL4	trophic level 4
TSS	total suspended solids
UF	uncertainty factor
USGS	U.S. Geological Survey
V	vanadium
WMU	waste management unit
Zn	zinc

Human and Ecological Risk Assessment of Coal Combustion Wastes – Executive Summary

The Executive Summary of EPA's *Human and Ecological Risk Assessment of Coal Combustion Wastes* is organized into four parts. First, it presents **Background** for the regulation and study of coal combustion wastes. Next, it discusses the **Risk Assessment Methodology** used to evaluate these wastes' potential impact on human health and the environment. The Executive Summary continues with the presentation of the report's **Results and Characterization**. Finally, it discusses the overall **Conclusions** of the report.

Background

The U.S. Environmental Protection Agency (EPA) is evaluating management options for solid wastes from coal combustion: fly ash, bottom ash, boiler slag, flue gas desulphurization (FGD) residues, and fluidized bed combustion (FBC) wastes. In this report, these five types of coal combustion wastes are referred to as coal combustion waste (CCW). All coal-fired electric utility plants in the United States generate at least one of these wastes, and most generate more than one. For example, most electric utility plants generate fly ash and either bottom ash or boiler slag.[1] Some plants also generate FGD residues.[2] Coal-fired electric utility plants that use FBC technology generate both bottom ash (bed ash) and fly ash.

Depending on the coal-fired power plant boiler and air pollution control technologies employed at the power plants, these five types of CCW might be initially generated either as primarily dry or primarily wet material. Typically, the dry materials are disposed of in landfills, while the wet materials are disposed of, at least initially, in surface impoundments (the settled solids can be removed periodically and disposed of in landfills). Landfills and surface impoundments are referred to as waste management units (WMUs).

Coal-fired power plants typically conduct coal preparation activities before burning the coal in their boilers. Wastes from these coal preparation activities (such as coal handling by conveyor systems, coal washing for removing mineral matter, and coal "sizing"—for example, reducing particle sizes of coal for firing in a pulverized coal boiler) are not part of the Bevill exclusion under the federal Resource Conservation and Recovery Act. However, in the past, some U.S. coal-fired power plants have managed CCW together with these coal preparation wastes, or "coal refuse," in the same landfills and surface impoundments. Because the chemical characteristics of the coal refuse can affect the amount and behavior of chemical constituents in the CCW,[3] EPA designed this analysis specifically to estimate risks from CCW management that is conducted separately from coal refuse management, as well as to estimate risks from CCW that is comanaged with coal refuse.

This report describes the results of a national-scale analysis of groundwater impacts of managing CCW in five separate scenarios:

- CCW managed alone in landfills
- CCW managed alone in surface impoundments
- CCW comanaged with coal refuse in landfills

[1] U.S. EPA (1999a), Figure 3-2.
[2] U.S. EPA (1999a), Figure 3-3.
[3] U.S. EPA (1999a), page 3-18.

- CCW comanaged with coal refuse in surface impoundments
- FBC waste managed in landfills.

This risk assessment was designed and implemented to identify and quantify human health and ecological risks that may result from groundwater contamination from current management practices for high-volume CCWs. The risk assessment uses mathematical models to represent either a landfill or a surface impoundment, and to represent the movement of chemical constituents from the CCW placed into a landfill or surface impoundment through the environment, up to an exposure point where the chemical constituent comes into contact with a person (such as in a glass of drinking water from a well) or an aquatic organism (such as a fish swimming in surface water that has become contaminated by groundwater that discharges into the stream near a CCW landfill). In this analysis, EPA evaluated human health exposures that occur by the groundwater-to-drinking-water pathway, human health exposures that occur by fish consumption, ecological exposures of aquatic organisms in direct contact with contaminated surface water or sediment, and ecological exposures of organisms that eat contaminated food items from those contaminated nearby surface water bodies.

Because the infiltration from a landfill or surface impoundment can significantly influence how much, and how quickly, leachate flows out of a waste management unit, the models also account for three types of liner scenarios: unlined, clay-lined, and composite-lined. An unlined waste management unit has native soils as the bottom and sides; a clay-lined unit has a certain amount of clay present to slow the flow of leachate; and a composite-lined unit is constructed from various layers, including human-made materials, which are assumed to retard the leachate flow to a significantly greater extent than a clay liner.

The risk assessment provides a distribution of estimated risks for each of the five scenarios and three liner types. EPA modeled CCW waste management units that were located across the United States, in locations that represent a subset of the coal-fired power plants that were in use in the mid-1990s. The models used to represent the movement of chemical constituents from a landfill or surface impoundment through the environment rely on data such as weather patterns, soil types, and subsurface geology, which influence the speed and direction in which the chemical constituents move. Thus, the environmental setting, or geographic location, of a landfill or surface impoundment can influence the resulting estimated risk. By conducting the analysis at a national scale, EPA estimated risks at locations across the United States.

Risk Assessment Methodology

To estimate the risks posed by the onsite management of CCW, the risk assessment determined the release of CCW constituents from landfills and surface impoundments, estimated the concentrations of these constituents in environmental media, and estimated the risks that these concentrations pose to human and ecological receptors. To evaluate the significance of these risks, they were compared with a risk range or single criterion as follows:

- For constituents that cause cancer (carcinogens), the typical cancer risk evaluated was a range from 1 excess lifetime cancer case per 1,000,000 exposed individuals (i.e., 10^{-6} excess cancer risk) to 1 case per 10,000 exposed individuals (i.e., 10^{-4} excess lifetime cancer risk).[4]

[4] This is the typical cancer risk range used by the Office of Solid Waste and Emergency Response - (10^{-6} to 10^{-4}).

- For constituents that cause adverse, noncancer health effects (noncarcinogens), the criterion is a hazard quotient (HQ)[5] of greater than 1
- For constituents that cause adverse ecological effects, the criterion is an HQ of greater than 1.

In support of this risk assessment, EPA assembled a constituent database that includes leachate and porewater waste concentrations for 41 CCW constituents taken from more than 140 CCW disposal sites around the country. The CCW risk assessment subjected these waste and leachate constituent concentrations to a risk assessment methodology that implemented the following steps to assess the human and ecological risks posed by CCW:

- **Hazard Identification,** which collected existing human health and ecological benchmarks for the 41 CCW constituents to identify the 25 chemicals with benchmarks for constituent screening
- **Constituent Screening,** which compared very conservative estimates of exposure concentrations (e.g., whole waste concentrations, leachate concentrations) to health-based concentration benchmarks to quickly and simply eliminate constituents and exposure pathways that did not require further analysis
- **Full-Scale Analysis,** which used a Monte Carlo probabilistic analysis to characterize the risks to human health and ecological receptors from onsite disposal of CCW constituents that posed the greatest potential risks in the screening analysis.

To select the constituents for full-scale modeling, the screening analysis compared very conservative estimates of exposure concentrations (e.g., leachate concentrations) to health-based concentration benchmarks to quickly and simply identify constituents that do not appear to pose human or ecological health concerns, so that these constituents could be eliminated from further analysis. For example, leachate concentrations were compared directly to drinking water standards, which is equivalent to assuming that human receptors are drinking leachate.

During both the screening and probabilistic modeling stages, two exposure scenarios were evaluated for humans:

- Contaminated groundwater being transported to drinking water wells from a CCW landfill or surface impoundment
- Contaminated groundwater discharging into a surface waterbody where people catch and eat fish.

Constituents addressed in the full-scale analysis were those that posed the greatest potential risks to human or ecological health. The full-scale analysis was designed to characterize waste management scenarios based on two WMUs (landfills and surface impoundments), three waste types (CCW, CCW codisposed with coal refuse, and FBC waste), and three liner types (unlined, clay-lined, and composite-lined). Because FBC waste is not known to be disposed of in surface impoundments, this left 15 possible disposal options to model. These options provide a good representation of CCW disposal practices and waste chemistry conditions that affect the release of CCW constituents from WMUs.

The full-scale analysis was implemented using a probabilistic approach that produces a distribution of risks or hazards for each receptor by allowing the values of some of the parameters in the analysis to vary. This approach is ideal for this risk assessment because there are so many CCW facilities across the United States, and the approach

5 The HQ is the ratio of the average daily exposure level to a protective exposure level corresponding to the maximum level at which no appreciable effects are likely to occur.

captures the variability in both waste management practices and environmental settings (e.g., hydrogeology, climate, hydrology). This probabilistic approach was implemented through the following steps:

1. Characterize the CCW constituents and waste chemistry, along with the WMUs in which each waste stream may be managed (i.e., the size and linear status of CCW landfills and surface impoundments).
2. Characterize the environmental settings for the sites where CCW landfills and surface impoundments are located (i.e., locations of coal-fired power plants).
3. Identify how contaminants are released from a WMU through leaching and transported to human and ecological receptors by groundwater and surface water.
4. Predict the fate, transport, and concentration of constituents in groundwater and surface water once they are released to groundwater from the WMUs and travel to receptors at each site.
5. Quantify the potential exposure of human and ecological receptors to the contaminant in the environment.
6. Estimate the potential risk to each receptor from the exposure and characterize this risk in terms of exposure pathways and health effects.

Based on this approach, EPA characterized the potential risks associated with the waste disposal scenarios and exposure pathways, including the uncertainties associated with the results.

Results and Characterization

The CCW risk assessment presented results at a typical exposure (50th percentile) as well as a high-end exposure (90th percentile). CCW risk assessment results at the 90th percentile suggest that managing CCW in unlined or clay-lined WMUs result in risks greater than the risk criteria of an HQ greater than 1 for noncancer effects to both human and ecological receptors (for humans drinking groundwater, 90th percentile HQs up to 3 for antimony, 7 for boron, 9 for lead, 8 for molybdenum, 20 for nitrate, and 4 for thallium; for ecological receptors, 90th percentile HQs up to 2,000 for boron, 300 for lead, 100 for arsenic, 30 for cadmium, and 12 for selenium). With respect to arsenic in CCW, the 90th percentile results suggest that managing CCW in unlined or clay-lined WMUs results in human excess cancer risks within or above a range of 1 in 1 million to 1 in 10,000 (i.e., ranging from 6 in 100,000 to 1 in 50 excess cancer risk). Clay-lined units tended to have lower risks than unlined units, but still had 90th percentile arsenic III excess cancer risks ranging from 6 in 100,000 to 7 in 1,000.However, it was the composite-lined units that effectively reduced risks from all pathways and constituents, below1 in 100,000 excess cancer risk or an HQ of one.

The tables that follow present selected risk results only for chemicals that exceed an excess cancer risk of 1 in 100,000 (arsenic only) or an HQ of 1.

As shown in **Table ES-1**, arsenic was the constituent with the highest risk for landfills. Clay-lined landfills presented 90th percentile arsenic III cancer risks as high as 1 in 5,000 and thallium HQs as high as 2. When landfills were unlined, they additionally presented arsenic III cancer risks as high as 1 in 2,000 and a maximum thallium HQ of 3. In addition to arsenic and thallium, clay-lined FBC landfills also presented 90th percentile risks above an HQ of 1 for antimony. However, unlined FBC landfills differed in that they only exceeded a 1 in 100,000 excess cancer risk for arsenic and did not exceed an HQ of 1 for any of the noncarcinogens modeled.[6] At the 50th percentile (see **Table ES-2**) arsenic

[6] Unlined FBC units showed less risk as modeled.

III from CCW codisposed with coal refuse exceeded an excess cancer risk of 10^{-5}, with cancer risks of 1 in 50,000.

As shown in **Table ES-3**, arsenic and cobalt were the constituents with the highest risks for surface impoundments. Clay-lined surface impoundments presented 90th percentile excess cancer risks above 1 in 10,000 for arsenic and exceed the HQ criterion of 1 for boron, cadmium, cobalt, molybdenum, and nitrate. Here, arsenic excess cancer risks were as high as 1 in 500, and cobalt had HQs as high as 200. When surface impoundments were unlined, they also showed risk above the HQ criterion for lead and selenium. Here, arsenic excess cancer risks were as high as 1 in 50, and cobalt had HQs as high as 500. As seen in **Table ES-4**, the 50th percentile surface impoundment results exceeded a 1 in 100,000 cancer risk for arsenic and only cobalt exceeded an HQ of 1. Here, unlined units had arsenic excess cancer risks as high as 6 in 10,000 while clay-lined units had arsenic excess cancer risks as high as 1 in 5,000. Cobalt HQs were as high as 20 and 6 for unlined and clay-lined surface impoundments, respectively.

For the groundwater-to-drinking-water pathway, composite liners, as modeled in this assessment, effectively reduced risks from all constituents to below a 10^{-5} cancer risk or HQ of 1 for both landfills and surface impoundments at the 90th and 50th percentiles.

For the groundwater-to-drinking-water pathway, arrival times of the peak concentrations at a receptor well are much longer for landfills (hundreds or thousands of years) than for surface impoundments (most less than 100 years).

For humans exposed via the groundwater-to-surface-water (fish consumption) pathway, unlined and clay-lined surface impoundments posed risks above the HQ criterion and an excess cancer risk of 1 in 100,000 at the 90th percentile (see **Table ES-5**). For CCW managed alone in surface impoundments, these exceedences came from selenium (HQs of 3 and 2 for unlined and clay-lined units, respectively), while for CCW comanaged with coal refuse, these exceedences came from arsenic (3 in 100,000 and 2 in 100,000 excess cancer risks for unlined and clay-lined units, respectively). All 50th percentile surface impoundment risks are below an HQ of 1 and an excess cancer risk of 1 in 100,000. No constituents pose risks above these levels for landfills (including FBC landfills) at the 90th or 50th percentile.

Waste type has a much larger effect when managed in surface impoundments than when managed in landfills. In the case of surface impoundments, some constituents presented higher risks from CCW managed alone (boron, molybdenum, nitrate, and selenium). However, others presented higher risks when CCW is comanaged with coal refuse (arsenic, cadmium, cobalt, and lead).

The higher risks for surface impoundments than landfills are likely due to higher waste leachate concentrations and the higher hydraulic head from the impounded liquid waste. This is consistent with damage cases reporting wet handling as a factor that can increase risks from CCW management.

Table ES-1. Selected[a] 90th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Drinking-Water Pathway

Chemical	90th Percentile HQ or Cancer Risk Value[b]		
	Unlined Units	**Clay-Lined Units**	**Composite-Lined Units**
Conventional CCW – 79 landfills			
Cancer			
Arsenic III	4E-04	2E-04	0
Arsenic V	2E-04	3E-05	0
Noncancer			
Antimony	2	0.8	0
Molybdenum	2	0.8	0
Thallium	3	2	0
Codisposed CCW and Coal Refuse – 41 landfills			
Cancer			
Arsenic III	5E-04	2E-04	0
Arsenic V	4E-04	6E-05	0
Noncancer			
Molybdenum	2	0.6	0
Thallium	2	1	0
FBC Waste – 7 landfills			
Cancer			
Arsenic III	3E-05	6E-05	0
Arsenic V	2E-05	2E-05	0
Noncancer			
Antimony	0.8	3	0
Thallium	1	4	0

[a] Values are presented only for chemicals that exceed an excess cancer risk of 1 in 100,000 (arsenic only) or an HQ of 1.

[b] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000-year period of the analysis.

Table ES-2. Selected[a] 50th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Drinking-Water Pathway

Chemical	50th Percentile HQ or Cancer Risk Value[b]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Codisposed CCW and Coal Refuse – 41 landfills			
Cancer			
Arsenic III	2E-05	6E-06	0

[a] Values are presented only for chemicals that exceed an excess cancer risk of 1 in 100,000 (arsenic only) or an HQ of 1.

[b] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000-year period of the analysis.

Table ES-3. Selected[a] 90th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Drinking-Water Pathway

Chemical	90th Percentile HQ or Cancer Risk Value[b]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 44 surface impoundments			
Cancer			
Arsenic III	2E-03	9E-04	2E-07
Arsenic V	7E-04	2E-04	0
Noncancer			
Boron	7	4	5E-03
Lead (MCL)[c]	3	0.7	1E-21
Molybdenum	8	5	7E-03
Nitrate/nitrite (MCL)[c]	20	10	9E-04
Selenium VI	2	1	1E-03
Codisposed CCW and Coal Refuse – 72 surface impoundments			
Cancer			
Arsenic III	2E-02	7E-03	4E-06
Arsenic V	2E-02	2E-03	3E-09
Noncancer			
Cadmium	9	3	5E-05
Cobalt	500	200	3E-06
Lead (MCL)[c]	9	1	1E-19
Molybdenum	3	2	4E-03

[a] Values are presented only for chemicals that exceed an excess cancer risk of 1 in 100,000 (arsenic only) or an HQ of 1.

[b] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000-year period of the analysis.

[c] Values are ratios of exposure concentration to MCL.

Table ES-4. Selected[a] 50th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Drinking-Water Pathway

Chemical	50th Percentile HQ or Cancer Risk Value[b]		
	Unlined Units	Clay-Lined Units	Composite–Lined Units
Conventional CCW – 44 surface impoundments			
Cancer			
Arsenic III	1E-04	6E-05	0
Arsenic V	2E-05	4E-06	0
Codisposed CCW and Coal Refuse – 72 surface impoundments			
Cancer			
Arsenic III	6E-04	2E-04	0
Arsenic V	3E-04	4E-05	0
Noncancer			
Cobalt	20	6	0

[a] Values are presented only for chemicals that exceed an excess cancer risk of 1 in 100,000 (arsenic only) or an HQ of 1.

[b] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000-year period of the analysis.

Table ES-5. Selected[a] 90th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Surface-Water Pathway

Chemical	90th Percentile HQ or Cancer Risk Value[b]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 44 surface impoundments			
Noncancer			
Selenium VI	3	2	2E-06
Codisposed CCW and Coal Refuse – 72 surface impoundments			
Cancer			
Arsenic III	3E-05	2E-05	1E-14
Arsenic V	2E-05	8E-06	6E-19

[a] Values are presented only for chemicals that exceed an excess cancer risk of 1 in 100,000 (arsenic only) or an HQ of 1.

[b] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000-year period of the analysis.

For ecological receptors exposed via surface water, risks for landfills exceeded an HQ of 1 for boron and lead at the 90th percentile, but 50th percentile HQs were well below 1. For surface impoundments, 90th percentile risks for several constituents exceeded the risk criteria, with boron showing the highest risks (HQ = 2,000). Only boron exceeded an HQ of 1 at the 50th percentile (HQ = 7). Exceedances for boron and selenium are consistent with reported ecological damage cases, which include impacts to waterbodies through the groundwater-to-surface-water pathway.

For ecological receptors exposed via sediment, 90th percentile risks for lead, arsenic, and cadmium exceeded the risk criteria for both landfills and surface impoundments because these constituents strongly sorb to sediments in the waterbody. The 50th percentile risks were generally an order of magnitude or more below the risk criteria.

Sensitivity analysis results indicate that for more than 70 percent of the scenarios evaluated, the risk assessment model was most sensitive to parameters related to the contaminant source and groundwater flow and transport, including WMU infiltration rate, leachate concentration, and aquifer hydraulic conductivity and gradient. For the groundwater-to-surface water pathway, another sensitive parameter is the flow rate of the waterbody into which the contaminated groundwater is discharging. For strongly sorbing contaminants (such as lead and cadmium), variables related to sorption and travel time are also important (adsorption coefficient, depth to groundwater, and receptor well distance).

Although the best available data and techniques were used, there were several uncertainties associated with the CCW risk assessment. The major types of uncertainty were as follows:

- **Scenario Uncertainty** includes the assumptions and modeling decisions that are made to represent an exposure scenario.
- **Model Uncertainty** is associated with all models used in a risk assessment because mathematical expressions are simplifications of reality that approximate real-world conditions and processes.
- **Parameter Uncertainty** occurs when there is a lack of data about the values used in the equations, data available are not representative of the instance being modeled, or parameter values have not been measured precisely because of limitations in technology.

Scenario uncertainty has been minimized by basing the risk assessment on conditions around existing U.S. coal-fired power plants around the United States. Uncertainty in environmental setting parameters has been incorporated into the risk assessment by varying these inputs within reasonable ranges when the exact value is not known. Uncertainty in human exposure factors (such as exposure duration, body weight, and intake rates) has also been addressed through the use of national distributions.

Some uncertainties not addressed explicitly in the risk assessment have been addressed through comparisons with other studies and data sources. These include the appropriateness of the leachate data used for landfills, concentrations of mercury in current CCW, and the potential impacts of future mercury regulations.

Other uncertainties are not as easily addressed as the ones above. These include issues such as receptor well distance, liner conditions, ecological benchmarks, ecological receptors at risk, and synergistic risks. Detailed discussion of all the risk assessment uncertainties is presented in **Section 4.4** of the report.

Conclusions

Given the results and characterization above, composite liners, as modeled in this risk assessment, effectively reduced risks from all pathways and constituents below the risk criteria for both landfills and surface impoundments. The CCW risk assessment suggests that the management of CCW in unlined landfills and unlined surface impoundments may present risks to human health and the environment. Selenium in certain types of WMUs managing certain types of CCW may present a risk of clinical selenosis to highly exposed groundwater users or fish consumers, or a risk of adverse effects to highly exposed aquatic receptors. Arsenic in certain types of WMUs managing certain types of CCW may present lifetime cancer risks above EPA's range of concern to highly exposed groundwater users. Estimated risks from clay-lined units are lower than the risks of unlined units, but are still above the risk criteria used for this analysis. In addition, surface impoundments typically showed higher risks than landfills, regardless of liner type. Finally, for surface impoundments, codisposal of CCW with coal refuse results in significantly higher risks from arsenic and certain other constituents than CCW disposed alone, while for other constituents, managing CCWs alone results in higher estimated risks than codisposed CCW.

These risk results are in many cases consistent with damage cases compiled by EPA (U.S. EPA, 2000, 2003e, 2007) and others (Lang and Schlictmann, 2004; Zillmer and Fauble, 2004; Carlson and Adriano, 1993; Rowe et al., 2002; Hopkins et al., 2006).[7] For example, the full-scale modeling of selenium released from unlined surface impoundments into groundwater suggests that certain fish consumers may be exposed to relatively high levels of selenium, consistent with fish consumption advisories at some of the proven damage case sites. These results suggest that with a higher prevalence of composite liners in new CCW disposal facilities, along with practices to prevent codisposal of coal refuse with CCW, future national risks from onsite CCW disposal are likely to be lower than those presented in this risk assessment (which is based on 1995 CCW WMUs).

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[7] See **Sections 4.1.5** and **4.2.5** for a more complete discussion of CCW damage cases and risk assessment results.

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1.0 Introduction

1.1 Background

The U.S. Environmental Protection Agency (EPA) has evaluated the human health and environmental risks associated with coal combustion waste (CCW) management practices, including disposal in landfills and surface impoundments. In May 2000, EPA determined that regulation as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act (RCRA) was not warranted for certain CCWs, but that regulation as nonhazardous wastes under RCRA Subtitle D was appropriate. However, EPA did not specify regulatory options at that time. This risk assessment was designed and implemented to help EPA identify and quantify human health and ecological risks that may be associated with current management practices for high-volume CCWs. These wastes are fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) sludge, along with wastes from fluidized-bed combustion (FBC) units and CCWs codisposed with coal refuse. This risk assessment will help EPA develop CCW management options for these high-volume waste streams. Details on EPA's CCW work can be found at http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/index.htm.

Note that the full-scale risk assessment described in this report was primarily conducted in 2003, meaning that the data collection efforts to support the risk assessment were based on the best information available to EPA at that time. As a result, more recent Agency efforts to characterize CCW wastes and management practices, such as the joint EPA and U.S. Department of Energy (DOE) survey of CCW waste management units (WMUs) (U.S. DOE, 2006) and EPA's recent study of CCW chemistries and leaching behavior (U.S. EPA, 2006c, 2008c), were not considered in the main analysis phase of this risk assessment. However, these more recent efforts are discussed as part of the risk characterization, and EPA is currently evaluating how to best incorporate and consider the results and findings of these studies in future efforts to address CCW management practices.

The Agency has revised this risk analysis document to address comments on the analytical methodology, data, and assumptions used in the risk assessment from an independent scientific peer review by experts outside EPA. Public comments (available in docket number EPA-HQ-RCRA-2006-0796[1]) were made available to the peer reviewers for their consideration during the review process. The peer review focused on technical aspects of the analysis, including the construction and implementation of the Monte Carlo analysis, the selection of models to estimate the release of constituents found in CCW from landfills and surface impoundments and their subsequent fate and transport in the environment, and the characterization of risks resulting from potential exposures to human and ecological receptors. EPA's responses to the peer-review comments, including descriptions of the revisions incorporated in this document to address those comments, are available in a separate response-to-comments document (U.S. EPA, 2009d).

[1] Available at http://www.regulations.gov.

1.2 Purpose and Scope of the Risk Assessment

The purpose of this risk assessment was to identify CCW constituents, waste types, exposure pathways, and receptors that may produce risks to human and ecological health, and to provide information about those scenarios that EPA could use to develop management options for CCW management.

The scope of this risk assessment was utility CCWs managed onsite at utility power plants. EPA's *Report to Congress: Wastes from the Combustion of Fossil Fuels* (U.S. EPA, 1999a) reports that there are 440 coal-fired utility power plants in the United States. Although these plants are concentrated in the East, they are found in nearly every state, with facility settings ranging from urban to rural. The large volumes of waste generated by these plants are typically managed onsite in landfills and surface impoundments. This risk assessment was designed to develop national human and ecological risk estimates that are representative of onsite CCW management settings throughout the United States.

1.3 Overview of Risk Assessment Methodology

To estimate the risks posed by the onsite management of CCW, this risk assessment estimated the release of CCW constituents from landfills and surface impoundments, the concentrations of these constituents in groundwater and surface water near coal-fired utility power plants, and the risks that these concentrations pose to human and ecological receptors.

1.3.1 Contaminant Sources

The size, design, and locations of the onsite CCW landfills and surface impoundments modeled in this risk assessment were based on data from a national survey of utility CCW disposal conducted by the Electric Power Research Institute (EPRI) in 1995 (EPRI, 1997). Data from this survey on facility area, volume, and liner characteristics were used in the CCW risk assessment because they were the most recent and complete data set available at the time the risk assessment was conducted (2003). However, as shown in **Table 1-1**, the EPA/DOE study conducted since then (U.S. DOE, 2006) shows a much higher proportion of lined facilities than do the 1995 EPRI data (see further discussion in **Section 4.4.1**).

Table 1-1. Liner Prevalence in EPRI and DOE Surveys

Liner Type	Landfills	Surface Impoundments
1995 EPRI Survey[a] – 181 facilities		
Unlined	40%	68%
Lined (compacted clay or composite [clay and synthetic])	60%	32%
2004 DOE Survey[b] – 56 facilities		
Unlined	3%	0%
Lined (compacted clay or composite [clay and synthetic])	97%	100%

[a] EPRI (1997)
[b] U.S. DOE (2006)

1.3.2 Exposure Pathways

The releases, and hence media concentrations and risk estimates in this report, were based on leaching to groundwater and groundwater transport to nearby wells and surface water bodies. This analysis did not address direct releases to surface water, which are permitted under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act. Thus, the estimated media concentrations and risks do not take into account contributions from NPDES-permitted releases, including discharges due to flooding or heavy rainfall. Uncertainties associated with this decision are described in **Section 4.4.1** of this report.

EPA recognizes that there are exposure pathways in addition to the groundwater pathways addressed in this report that could be of concern to human health and ecological receptors, including fugitive dust eroded and transported by wind from uncovered CCW landfills, and erosion and transport of CCW constituents from uncovered landfills onto adjacent land and eventually into downslope waterbodies. These “aboveground” pathways were addressed in the 1998 risk assessment, and in 2002, EPA conducted a draft screening analysis (U.S. EPA, 2002a) to evaluate risks from these pathways.

1.3.3 Risk Levels

To evaluate the significance of the estimated risks from the pathways assessed in this assessment, EPA compared the risk estimates to a risk range (for carcinogens) or to a specific risk criterion (for noncarcinogens) that are protective of human health and the environment:

- An estimate of the excess lifetime cancer risk for individuals exposed to carcinogenic (cancer-causing) contaminants ranging from 1 chance in 1,000,000 (10^{-6} excess cancer risk) to 1 chance in 10,000 (10^{-4} excess cancer risk). For decisions made to screen out certain constituents from further consideration, a 1 in 100,000 (10^{-5}) excess lifetime cancer risk was used.[2]

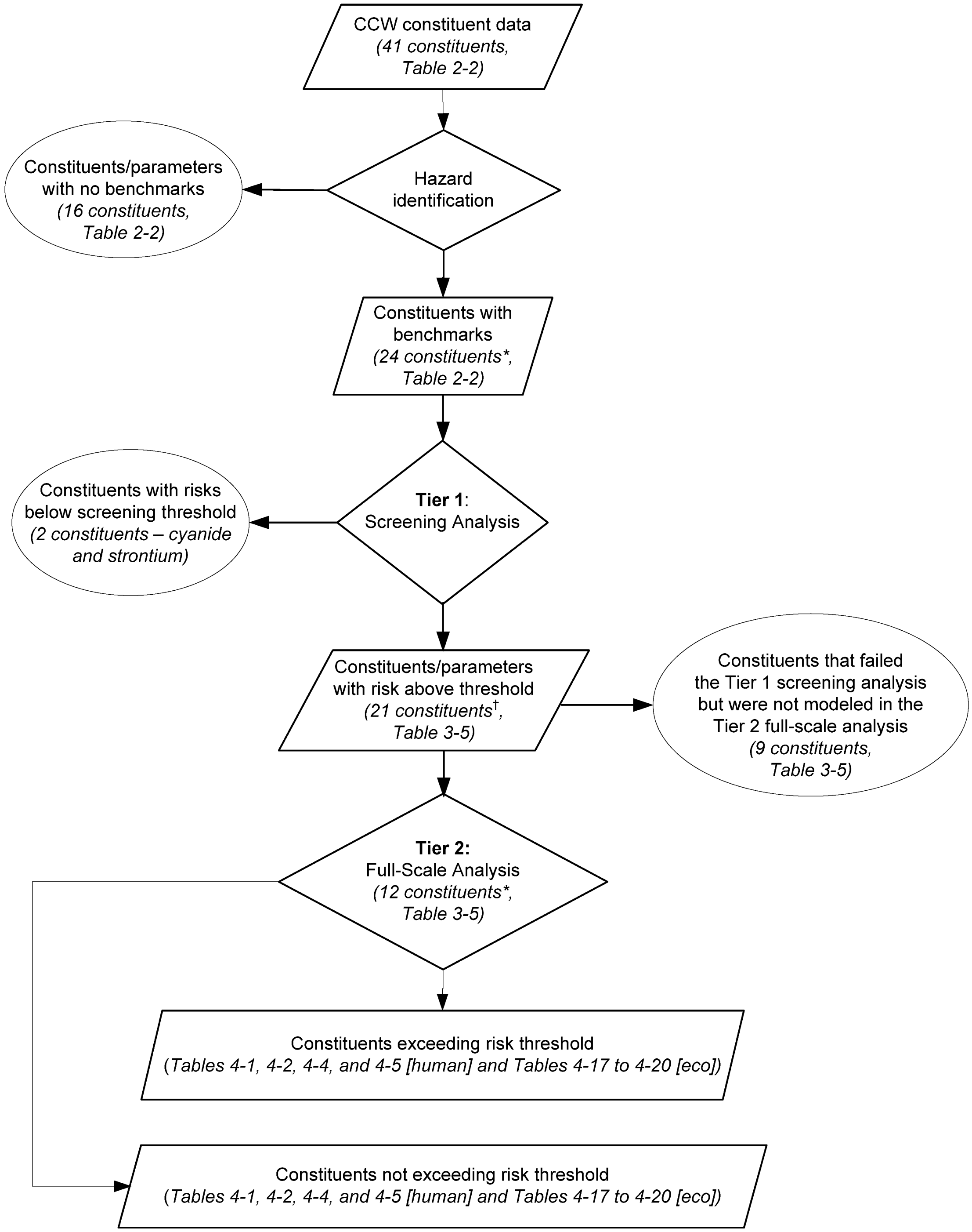
- A measure of safe intake levels to predicted intake levels, a hazard quotient (HQ) greater than 1 for constituents that can produce noncancer human health effects (an HQ of 1 is defined as the ratio of a potential exposure to a constituent to the highest exposure level at which no adverse health effects are likely to occur)

- An HQ greater than 1 for constituents with adverse effects to ecological receptors.

1.3.4 Methodology

In 1998, EPA conducted a risk assessment for fossil fuel combustion wastes (which include CCWs) to support the May 2000 RCRA regulatory determination (U.S. EPA, 1998a,b). Since then, EPA has added to the waste constituent database that was used in that effort, expanding the number of leachate and total waste analyses for 41 CCW constituents. The CCW risk assessment subjected these waste and leachate constituent concentrations to the tiered risk assessment methodology illustrated in **Figure 1-1**.

[2] The typical cancer risk range used by the Office of Solid Waste and Emergency Response is 10^{-4} to 10^{-6}.



* Does not include ammonia. Although ammonia was detected in CCW, data were insufficient to address it in the screening analysis or the full-scale analysis.

† Does not include mercury. Although mercury was considered in the screening analysis and modeled in the full-scale analysis, the results were not meaningful due to the high proportion of non-detect measurements.

Note: The risk threshold used for cancer risks was 1 in 100,000.

Figure 1-1. Overview of coal combustion waste risk assessment.

This methodology implemented the following steps to assess the human and ecological risk of CCWs:

- **Hazard Identification**, which collected existing human health and ecological benchmarks for the CCW constituents. Only constituents with benchmarks moved on to the next step, constituent screening.
- **Constituent Screening**, which compared very conservative estimates of exposure concentrations (e.g., using leachate concentrations) to health-based concentration benchmarks to quickly and simply identify constituents with risks below the screening criteria.
- **Full-Scale Analysis**, which characterized at a national level the human health and ecological risks for constituents in CCW disposed onsite in landfills and surface impoundments using a site-based probabilistic Monte Carlo risk analysis.

This document focuses on the full-scale Monte Carlo analysis, but includes a discussion of the hazard identification and screening analysis (in U.S. EPA, 2002a) that led to the full-scale assessment.

1.3.5 Waste Management Scenarios Addressed

The full-scale analysis was designed to characterize waste management scenarios based on two waste management options (disposal of CCW onsite in landfills and in surface impoundments) and three waste types, as follows:

- **Conventional CCW**, which includes fly ash, bottom ash, boiler slag, and FGD sludge
- **Codisposed CCWs and coal refuse,**[3] which are more acidic than conventional CCWs due to sulfide minerals in the mill rejects
- **FBC wastes**, which include fly ash and the fluidized bed ash, and which tend to be more alkaline than conventional CCW because of the limestone mixed in during fluidized bed combustion.

Conventional CCW and codisposed CCW and coal refuse are typically disposed of in landfills and surface impoundments that can be lined with clay or composite liners. FBC wastes are only disposed of in landfills in the United States; therefore, surface impoundment disposal was not modeled for FBC waste.

These three waste types, two waste management options, and three liner conditions (unlined, clay lined, composite lined) modeled in this analysis provide a good representation of CCW disposal practices and waste chemistry conditions that affect the release of CCW constituents from WMUs.

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[3] Coal refuse is the waste coal produced from coal handling, crushing, and sizing operations, and tends to have a high sulfur content and low pH from high amounts of sulfide minerals (like pyrite). In the CCW constituent database, codisposed coal refuse includes "combined ash and coal gob," "combined ash and coal refuse," and "combined bottom ash and pyrites."

1.3.6 Modeling Approach

The full-scale analysis was implemented using a site-based probabilistic approach that produces a distribution of risks or hazard for each receptor by allowing the values of some of the parameters in the analysis to vary. Input parameters were varied in the analysis using data collected at or around CCW disposal facilities or, when site-based data were not available, from distributions representing the variability of parameters across the United States. This approach was ideal for this risk assessment because there are many CCW facilities across the United States, and site-based data collection can capture both the variability in waste management practices at these facilities and the differences in their environmental settings (e.g., hydrogeology, climate, hydrology).

This probabilistic approach was implemented through seven primary steps:

Problem Formulation

1. Characterize the CCW constituents and waste chemistry, along with the size and liner status of the WMUs in which each waste stream may be managed

2. Characterize the environmental settings for the sites where CCW landfills and surface impoundments are located

3. Identify scenarios under which contaminants are released from a WMU and transported to a human receptor

Analysis

4. Screen risks to select CCW constituents for full-scale analysis

5. Predict the fate and transport of constituents in the environment once they are released from the WMUs at each site

6. Quantify the exposure of human and ecological receptors to the contaminant in the environment and the risk associated with this exposure

Risk Characterization

7. Estimate the risk to receptors from the exposure and characterize this risk in terms of exposure pathways, health effects, and uncertainties

8. Identify the waste disposal scenarios and environmental conditions that pose risks of potential concern to human health or the environment. Evaluate risks at the 50th and 90th percentiles.

1.4 Document Organization

This document is organized into the following sections:

- **Section 2, Problem Formulation,** describes how the framework for the full-scale analysis was developed, including identification of the waste constituents, exposure pathways, and receptors of concern; selection and characterization of waste management practices and sites to model; and development of the conceptual site models for the modeling effort.
- **Section 3, Analysis,** describes the probabilistic modeling framework and the models and methods used to (1) screen CCW constituents for the full-scale analysis, (2) estimate constituent releases from CCW landfills and surface impoundments (source models), (3) model constituent concentrations in the environmental media of concern (groundwater and surface water), (4) calculate exposure, and (5) estimate risk to human and ecological receptors.
- **Section 4, Risk Characterization,** characterizes the human health and environmental risks posed by CCW, including (1) discussion of the methods used to account for variability and uncertainty and (2) identification of the scenarios and conditions modeled that resulted in higher and lower risks. Results are presented as national estimates for CCW landfills and CCW surface impoundments, as well as by waste type and liner status. This section characterizes the risks posed by CCW constituents and pathways under the conditions modeled, including factors (such as liners or facility environmental setting) that result in higher or lower risk levels. Finally, the risk characterization evaluates the risk results in light of more recent research on CCW waste management practices and the environmental behavior of CCW constituents.

The first three appendices provide detailed information on how wastes, WMUs, and settings were characterized for the risk assessment. **Appendix A** describes the chemical characteristics of CCW, including the CCW leachate concentration distributions used to represent disposal conditions in landfills and surface impoundments. **Appendix B** describes how EPA characterized the CCW landfills and surface impoundments, including locations, surface area, capacities, geometry, and liner status. **Appendix C** presents the methodologies and data used to characterize the environmental setting at each CCW site identified in Appendix B, including delineating the site layout and determining the environmental setting (e.g., meteorology, climate, soils, aquifers, and waterbodies).

The next five appendices provide detailed information on the specific models and data used to calculate risk, including the nonlinear sorption isotherms (**Appendix D**), the surface water fate and transport and intake equations (**Appendix E**), the exposure factors (**Appendix F**), benchmarks for human health (**Appendix G**), and benchmarks for ecological risk (**Appendix H**).

The next three appendices provide background and results for the screening analysis, including calculation of health-based numbers (HBNs, **Appendix I**), chemical-specific inputs used in the screening analysis (**Appendix J**), and the screening analysis results (**Appendix K**).

Finally, **Appendix L** provides figures showing, for selected CCW constituents, cumulative percentiles of the time it took for the peak concentration to reach a receptor well for each source type.

2.0 Problem Formulation

The CCW risk assessment was intended to evaluate, at a national level, risk to individuals who live near WMUs used for CCW disposal. This section describes how the conceptual framework for the full-scale risk assessment was developed, including

- Constituent selection to identify the CCW constituents, exposure pathways, and receptors to address in this analysis (**Section 2.1.1**)
- Location and characterization of the CCW landfills and surface impoundments to be modeled as the sources of CCW contaminants in the full-scale site-based analysis (**Section 2.1.2**)
- The conceptual site model used to represent CCW disposal facilities (**Section 2.2**)
- The general modeling approach and scope, including constituent screening (**Section 2.3**), and full-scale modeling (**Section 2.4**) to estimate exposure point concentrations, assess exposures, and calculate risks to human and environmental receptors.

2.1 Source Characterization

The main technical aspects of the CCW risk assessment were completed in 2003, and the waste management scenarios modeled in this assessment were based on the best data on waste compositions, industry operations, and waste management practices that were available at that time. These data sources included a 1995 industry survey on CCW management practices (the EPRI comanagement survey [EPRI, 1997]) and data collected from a variety of sources before the 2003 risk assessment (e.g., EPA's CCW constituent database). Since 2003, DOE and EPA have completed a survey to characterize CCW waste disposal practices from 1994 to 2004, with a focus on new facilities or facility expansions completed within that same time frame (U.S. DOE, 2006). In addition, EPA studies of CCW composition and leaching behavior are ongoing (U.S. EPA, 2006c, 2008c). Although these newer data were not available when this risk assessment was conducted, they are discussed in the risk characterization (**Section 4**) as an uncertainty with respect to how well the risk assessment represents CCW leachate composition and current WMU liner conditions.

This risk assessment provides a national characterization of waste management scenarios for wastes generated by coal-fired utility power plants. The sources modeled in these scenarios are onsite landfills and surface impoundments, which are the primary means by which CCW is managed in the United States. The characterization of these sources, in terms of their physical dimensions, operating parameters, location, environmental settings, and waste characteristics, is fundamental to the construction of scenarios for modeling. This section describes how the coal combustion waste streams and management practices were characterized (based on the above data sources) and screened to develop the waste disposal scenarios modeled in the full-scale analysis.

2.1.1 Identification of Waste Types, Constituents, and Exposure Pathways

To identify the CCW constituents and exposure pathways to be addressed in this risk assessment, we relied on a database of CCW analyses that EPA had assembled over the past several years to characterize whole waste and waste leachate from CCW disposal sites across the country (see **Appendix A**). The 2003 CCW constituent database includes all of the CCW characterization data used by EPA in its previous risk assessments, supplemented with additional data collected from public comments, data from EPA Regions and state regulatory agencies, industry submittals, and literature searches up to 2003.

The CCW constituent database represents a significant improvement in the quantity and scope of waste characterization data available from the 1998 EPA risk assessment of CCWs (U.S. EPA, 1998a,b). For example, the constituent data set used for the previous risk assessments (U.S. EPA, 1999a) covered approximately 50 CCW generation and/or disposal sites, while the 2002 CCW constituent database covers approximately 140 waste disposal sites.[1] The 2002 database also has broader coverage of the major ion concentrations of CCW leachate (e.g., calcium, sulfate, pH), that can influence CCW impacts on human health and the environment.

2.1.1.1 Waste Types

Table 2-1 shows the waste types included in the 2002 CCW constituent database, along with counts of the number of sites with wastes of each type with constituent measurements in landfill leachate, surface impoundment porewater, and whole waste.

Comments received by EPA on the previous CCW risk assessment pointed out that the analysis did not adequately consider the impacts of CCW leachate on the geochemistry and mobility of metal constituents in the subsurface. Commenters stated that given the large size of the WMUs and the generally alkaline nature of CCW leachate, it is likely that the leachate affects the geochemistry of the soil and aquifers underlying CCW disposal facilities, which can impact the migration of metals in the subsurface. To address this concern, EPA statistically evaluated major ion porewater data from the CCW constituent database for the waste streams shown in Table 2-1. Based on this analysis and prevalent comanagement practices, EPA grouped the waste streams into three statistically distinct categories: conventional CCW (fly ash, bottom ash, slag, and FGD sludge), which has moderate to high pH; codisposed CCW and coal refuse, which tends to have low pH; and FBC waste, which tends to have high pH. As shown in Table 2-1, each of these waste types included several waste streams that are usually codisposed in landfills or surface impoundments. Note that some sites in the CCW database have more than one waste stream, so the site counts for the different waste streams in a waste type category sum to more than the total site count for that waste type.

[1] Although EPA believes that the 140 waste disposal sites do represent the national variability in CCW characteristics, they are not the same sites as in the EPRI survey. During full-scale modeling, data from the CCW constituent database were assigned to each EPRI site based on the waste types reported in the EPRI survey data.

Table 2-1. Waste Streams in CCW Constituent Database

Waste Type Waste Stream	Landfills		Surface Impoundments
	Landfill Leachate	Total Waste[b]	Pore Water
Conventional CCW	***97***	***62***	***13***
Ash (not otherwise specified)	43	30	0
Fly ash	61	33	2
Bottom ash and slag	24	23	3
Combined fly and bottom ash	7	4	4
FGD sludge	4	5	6
Codisposed Ash & Coal Refuse	***9***	***1***	***5***
FBC Waste	***58***	***54***	***0***
Ash (not otherwise specified)	18	10	0
Fly ash	33	32	0
Bottom and bed ash	26	25	0
Combined fly & bottom ash	20	22	0

[a] For waste types (shaded rows) the table gives the number of sites; for waste streams (unshaded rows), the table gives the number of samples.
[b] Whole waste concentration data.

Along with the type of WMU (landfill or surface impoundment), the three waste types in Table 2-1 defined the basic modeling scenarios to be addressed in the full-scale analysis. To characterize these waste types, the CCW constituent database was queried by waste type to develop the waste concentration data for the constituents and the major ion and pH conditions used to develop waste-type-specific metal sorption isotherms (see **Appendix D** for a more extensive discussion of the development of CCW waste chemistries and metal sorption isotherms).

2.1.1.2 CCW Constituents of Potential Concern

The CCW constituent database contains data on more than 40 constituents. During the hazard identification step of the CCW risk assessment, constituents of potential concern were identified from this list of constituents by searching EPA and other established sources for human health and ecological benchmarks (e.g., Agency for Toxic Substances and Disease Registry [ATSDR]; see **Section 3.1** and **Appendices G** and **H** for a full list of sources). **Table 2-2** shows the results of that search for each constituent. Benchmarks were found for 24 chemicals in the constituent database. The 16 constituents without human health or ecological benchmarks were not addressed further in the risk analysis.[2]

[2] The CCW constituents without human health benchmarks are limited to common elements, ions, and compounds (e.g., iron, magnesium, phosphate, silicon, sulfate, sulfide, calcium, pH, potassium, sodium, carbon, sulfur). These measurements were used to determine overall CCW chemistries modeled in the risk assessment (see Section 3). Although some of these chemicals or parameters (e.g., pH, sulfate, phosphate, chloride) can pose an ecological hazard if concentrations are high enough, they were not addressed in this risk assessment.

Table 2-2. Toxicity Assessment of CCW Constituents

Constituent	CAS ID	HHB[a]	EcoB[b]
Metals			
Aluminum	7429-90-5	✔	✔
Antimony	7440-36-0	✔	✔
Arsenic	7440-38-2	✔[c]	✔
Barium	7440-39-3	✔	✔
Beryllium	7440-41-7	✔[d]	✔
Boron	7440-42-8	✔	✔
Cadmium	7440-43-9	✔[d]	✔
Chromium	7440-47-3	✔[c]	✔
Cobalt	7440-48-4	✔	✔
Copper	7440-50-8	✔	✔
Iron	7439-89-6		
Lead	7439-92-1	✔[e]	✔
Magnesium	7439-95-4		
Manganese	7439-96-5	✔	
Mercury	7439-97-6	✔	✔
Molybdenum	7439-98-7	✔	✔
Nickel	7440-02-0	✔	✔
Selenium	7782-49-2	✔	✔
Silver	7440-22-4	✔	✔
Strontium	7440-24-6	✔	
Thallium	7440-28-0	✔	✔
Vanadium	7440-62-2	✔	✔
Zinc	7440-66-6	✔	✔
Inorganic Anions			
Chloride	16887-00-6		
Cyanide	57-12-5	✔	
Fluoride	16984-48-8	✔	
Nitrate/nitrite	14797-55-8/14797-65-0	✔	
Phosphate	14265-44-2		
Silicon	7631-86-9		
Sulfate	14808-79-8		
Sulfide	18496-25-8		
Inorganic Cations			
Ammonia	7664-41-7	✔	
Calcium	7440-70-2		
pH	12408-02-5		
Potassium	7440-09-7		
Sodium	7440-23-5		
Nonmetallic Elements			
Carbon	7440-44-0		
Sulfur	7704-34-9		

(continued)

Toxicity Assessment of CCW Constituents (continued)

Constituent	CAS ID	HHB[a]	EcoB[b]
Measurements			
Total Dissolved Solids	none		
Total Organic Carbon	none		
Dissolved Organic Carbon	none		

[a] HHB = human health effect benchmark
[b] EcoB = ecological benchmark
[c] Known carcinogen (for chromium VI, inhalation only); although arsenic can act as both a carcinogen and a noncarcinogen, the cancer risk exceeds the noncancer risk at any concentration, so the more protective cancer benchmark for human health was used throughout this assessment.
[d] Probable carcinogen
[e] Safe Drinking Water Act Action Level only

2.1.2 Waste Management Scenarios

The full-scale CCW risk assessment modeled landfills and surface impoundments managing wastes onsite at coal-fired utility power plants. Because EPA selected a site-based modeling approach for the full-scale analysis, it was necessary to locate these disposal sites across the country to provide the spatial foundation for this analysis. It was also necessary to characterize CCW WMUs to define the scope for source modeling.

Two primary sources of data on these were used to characterize this population:

- 1998 Energy Information Agency (EIA) data on coal-fired power plants, which identifies approximately 300 coal-fired power plants with onsite waste management
- The 1995 EPRI waste comanagement survey (EPRI, 1997), which contains detailed WMU data (i.e., area, capacity, liner status, and waste type) for 177 of those facilities.

Because of the completeness of the WMU data from the EPRI survey, the EPRI data were used to establish the plant locations and WMU data for the full-scale modeling effort for conventional CCW[3] and CCW codisposed with coal refuse, as well as to help define protective waste management settings for the screening analysis.

Note that although there is overlap, the 140-site CCW constituent database described in Appendix A and the EPRI survey used to characterize CCW landfills and surface impoundments were assembled under separate efforts and represent different populations of disposal sites. As described in Section 3.1.3, these data sets were sampled independently during the Monte Carlo analysis, and constituent data were not assigned to particular sites except by waste type.

Although there is a good amount of FBC data in the constituent database (58 sites; see Table 2-1), there were only 3 FBC landfill sites in the EPRI database and 4 additional sites added by EPA, for a total of 7 FBC sites with data on onsite WMUs. Because EPA believes that this

[3] Fly ash, bottom ash, boiler slag, and FGD sludge.

small sample is not sufficient to represent the universe of FBC disposal units and, if included in the overall analysis, could bias the Monte Carlo results towards the environmental conditions around these few landfill units, FBC wastes were addressed separately from the more conventional CCW types in the full-scale analysis and are not included with the conventional and codisposal CCW management scenarios in the overall results. **Section 4.1.3** compares the risk results for each of these waste types, including FBC.

Table 2-3 shows how the plants were distributed across the waste type/WMU scenarios modeled in the full-scale analysis. The distribution across the waste type/WMU scenarios, the geographic distribution of these facilities, and the size and liner status of the WMUs were assumed to be representative of all onsite CCW landfills and surface impoundments in the continental United States as of 1995. As mentioned previously, DOE and EPA have conducted a newer survey on CCW disposal facilities (U.S. DOE, 2006), but the scope of this survey was not as comprehensive as the EPRI survey (e.g., WMU areas and capacity data were not collected). Newer information (U.S. DOE, 2007a,b) suggest that there now may be up to approximately 500 coal-fired electric utility power plants in the United States, the majority of which would be expected to conduct some waste management activities in onsite landfills or surface impoundments (U.S. EPA, 2010).

Table 2-3. Coal Combustion Plants with Onsite CCW WMUs Modeled in the Full-Scale Assessment

Waste Type and Liner Status	Number of Plants in 1995 EPRI Survey[a] with Onsite:		
	Landfills	Surface Impoundments	Either WMU Type[b]
Conventional CCW[c]	71	38	103
unlined	*38*	*24*	*60*
clay-lined	*28*	*10*	*38*
composite-lined	*10*	*5*	*15*
Codisposed CCW and coal refuse	38	65	100
unlined	*20*	*52*	*69*
clay-lined	*10*	*11*	*21*
composite-lined	*9*	*2*	*11*
FBC waste[d]	7	-	7
unlined	*3*		*3*
clay-lined	*3*		*3*
composite-lined	*1*		*1*
All waste types	108	96	181

[a] EPRI (1997); note that some coal combustion plants have one or more onsite WMUs.
[b] Number of coal combustion plants with onsite landfill(s), surface impoundment(s), or both.
[c] Fly ash, bottom ash, boiler slag, and FGD sludge.
[d] Includes 3 EPRI Survey FBC landfills plus 4 additional FBC landfills added by EPA. FBC was treated separately in the full-scale assessment because of the small number of FBC sites.

2.2 Conceptual Model

The waste stream/WMU combinations discussed above provided the waste management scenarios evaluated in the risk assessment. The full-scale assessment used the EPRI survey data to place these scenarios at actual onsite CCW disposal sites across the country. These sites were used as the basis for a national-scale site-based Monte Carlo assessment of risks posed by the onsite disposal of CCW at utility power plants across the United States. **Figure 2-1** maps the CCW disposal sites modeled in this analysis against long-term average precipitation levels for the country.

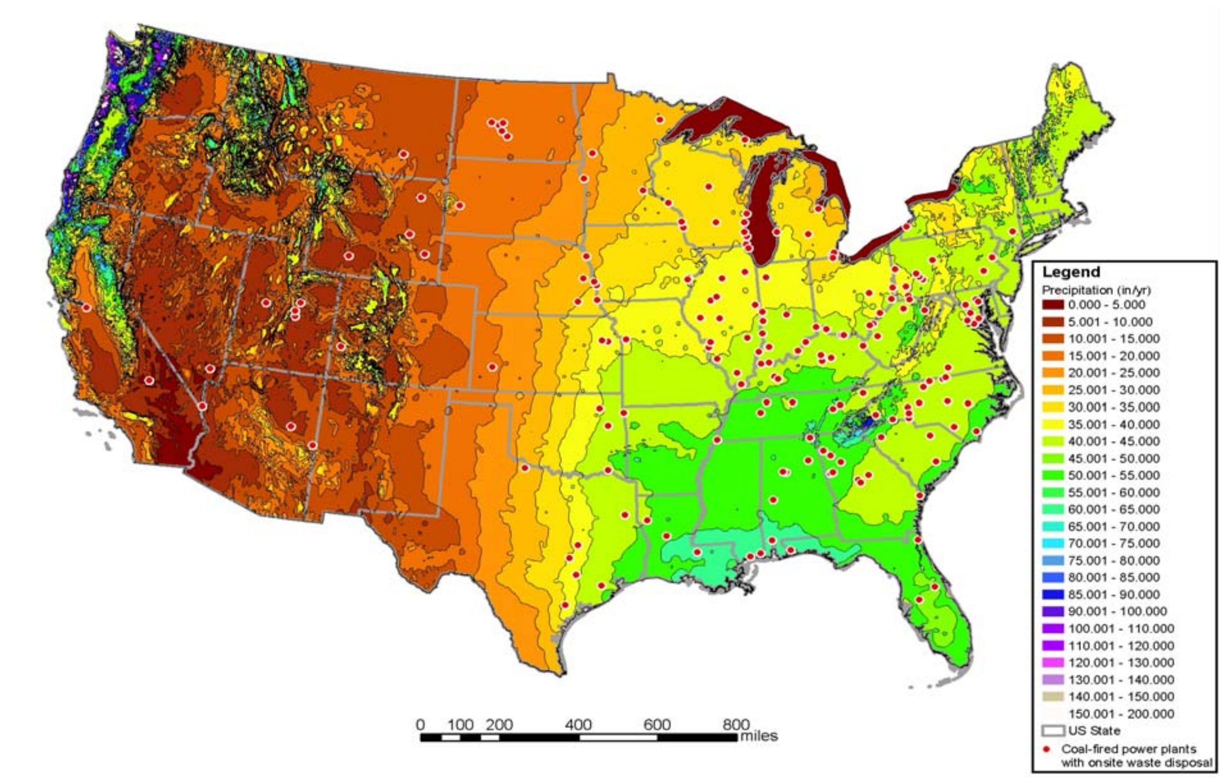

Figure 2-1. Coal combustion plants with onsite waste disposal modeled in CCW risk assessment.

2.2.1 Conceptual Site Model

Figure 2-2 depicts the conceptual site model for CCW disposal that was the basis for the national CCW risk assessment, including contaminant sources, exposure pathways, and receptors. The CCW conceptual site model includes the following exposure pathways:

Human Health:

- Groundwater to drinking water (drinking water ingestion)
- Groundwater to surface water (fish consumption)

Ecological Risk:

- Groundwater to surface water and subsequent direct contact with contaminated surface water and sediments
- Groundwater to surface water and subsequent ingestion of contaminated aquatic food items.

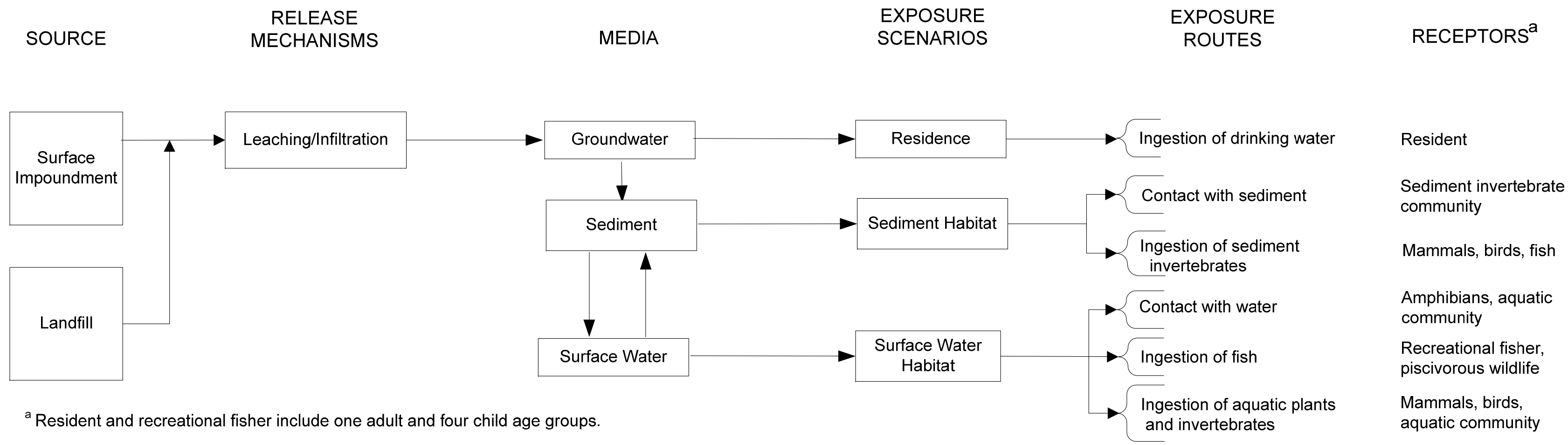

Figure 2-2. Conceptual site model of CCW risk assessment.

As shown in Figure 2-2, EPA focused full-scale modeling on groundwater-to-drinking-water and groundwater-to-surface-water exposure pathways for the national risk assessment. This groundwater pathway analysis evaluated exposures through drinking water ingestion and surface water contamination from groundwater discharge. For the groundwater-to-surface-water pathway, the analysis assumed that human exposure occurs through the consumption of contaminated fish and that ecological exposure occurs through direct contact with contaminated surface water and sediment or from the consumption of aquatic organisms.

2.2.2 Conceptual Site Layouts

This risk assessment was based on site layouts that are conceptual rather than site-specific. Although EPA had plant locations and some site-specific data on WMUs, we did not have the exact locations of each WMU or the residential wells surrounding each facility. Therefore, EPA had to develop conceptual layouts to place receptors around each WMU.

The conceptual site layouts capture possible relationships between a WMU and human and ecological receptors by locating, with respect to the WMU boundary, the geographic features (i.e., receptor wells, waterbodies) that are important for determining human and ecological exposures to chemicals released from CCW landfills and surface impoundments.

Two site layouts were used in the full-scale analysis to model the land use scenarios of most concern for CCW disposal facilities:

- Residential groundwater ingestion scenario
- Recreational fisher and aquatic ecological risk scenario.

These two conceptual site layouts are shown in the following two subsections, including WMU boundaries, waterbodies, and residential wells modeled in this analysis. In the conceptual site layouts, the WMU is represented as a square source. The size of the source was determined by the surface area of the WMU (CCW WMU areas were collected from the EPRI comanagement survey, as described in **Appendix B**). The WMU was assumed to be located at the property line of the facility to which it belongs.

Adjacent to the WMU is a buffer area within which there was assumed to be no human activity that would present human risk (i.e., there are no residences or waterbodies in the buffer). The buffer area lies between the WMU boundary and the residential well or waterbody, and represents the distance to well or waterbody discharge point modeled by the groundwater model. Each site layout must also be oriented in terms of direction.

2.2.2.1 Residential Groundwater-to-Drinking-Water Scenario

The residential groundwater-to-drinking-water scenario, shown in **Figure 2-3**, calculated exposure through residential use of well water as drinking water. In the Monte Carlo analysis, the receptor well was randomly placed up to 1 mile downgradient from the edge of the WMU (this radial well distance is labeled R_{rw} in Figure 2-3), based on a nationwide distribution of nearest downgradient residential wells from Subtitle D municipal landfills (U.S. EPA, 1988a; this distribution is provided in **Appendix C**). EPA assumed that this distribution was relevant to onsite CCW landfills and surface impoundments at coal-fired utility power plants, but does not have data on typical distances (or the distributions of distances) of domestic drinking water wells from CCW disposal facilities. (The potential impact on the results of this assumption is discussed as an uncertainty in **Section 4.4.3.3**).

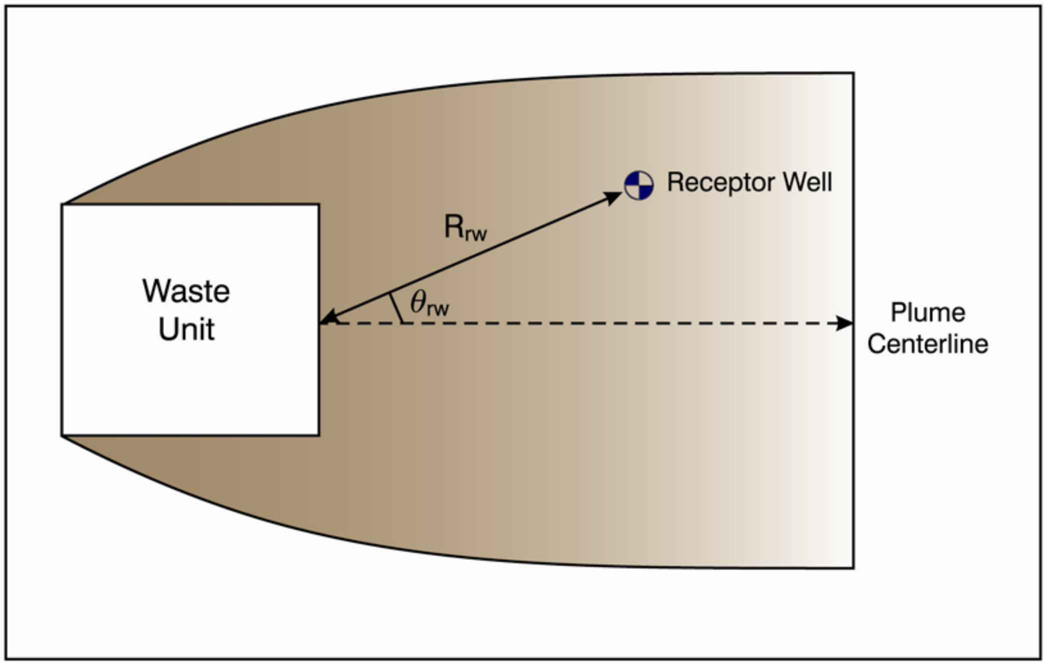

Figure 2-3. Conceptual site layout for residential groundwater ingestion scenario.

The angle off the contaminant plume centerline (θ_{rw} in Figure 2-3) was based on a uniform distribution ranging from 0 to 90°. The depth of the well below the water table was set within the groundwater model based on assumptions that are generally typical of average conditions for surficial aquifers across the United States. These limits are discussed in **Section 3.6.3**. In this assessment, receptors were always located within the lateral extent of the plume.

The soil and aquifer characteristics needed for the groundwater model were based on available data on soil and groundwater conditions collected around the 181 modeled sites, as described in **Appendix C**.

2.2.2.2 Recreational Fisher and Ecological Risk Scenario

The recreational fisher[4] scenario, shown in **Figure 2-4**, was used to estimate risks to recreational fishers (and their children) who live near the CCW landfills and surface impoundments and catch and consume fish from a waterbody located adjacent to the buffer and contaminated by CCW constituents through the groundwater to surface water pathway. The

[4] Only recreational fishers were considered as the reasonable maximum exposed individuals. Subsistence receptors who eat fish were not modeled, but could be expected to have higher risks than the recreational fishers for whom we present results.

potential for cumulative exposure from both contaminated fish and groundwater was not considered in the CCW risk assessment. One reason is that the exposures are likely to occur over different timeframes because of differences in transit time of the contaminant plume to wells versus surface waterbodies. As described in **Section 3.6.3**, for each model run in the Monte Carlo analysis, the distances to the downgradient well and surface water were independently sampled from national distributions presented in Appendix C, Tables C-1 (wells) and C-2 (surface waterbodies). Also, these exposures may involve different receptors because a resident exposed via groundwater may not be a recreational fisher. Thus, adding risks across pathways would not likely change the results.

The waterbody was assumed to be a stream or lake located downgradient from the WMU, beginning where the buffer area ends (see Figure 2-4), and was also used as the most impacted aquatic system for the ecological risk assessment. Waterbody characteristics were determined based on a combination of site-specific, regional, or national data (as described in **Appendix C**), except for the length of the stream impacted by the plume, which was determined by the width of the plume as it intersects the waterbody.

The downgradient distance to the surface water body was determined from a national distribution developed by measuring this distance (using scaled U.S. Geological Survey [USGS] maps and aerial photographs obtained from the Terraserver Web site [http://terraserver.usa.com/geographic.aspx]) at 59 CCW landfill and surface impoundment sites randomly selected from a larger data set of 204 CCW WMUs, including those modeled in this risk assessment. **Appendix C** presents that distribution and further details on how the distribution was developed and the sample of 59 facilities used to develop the distribution.

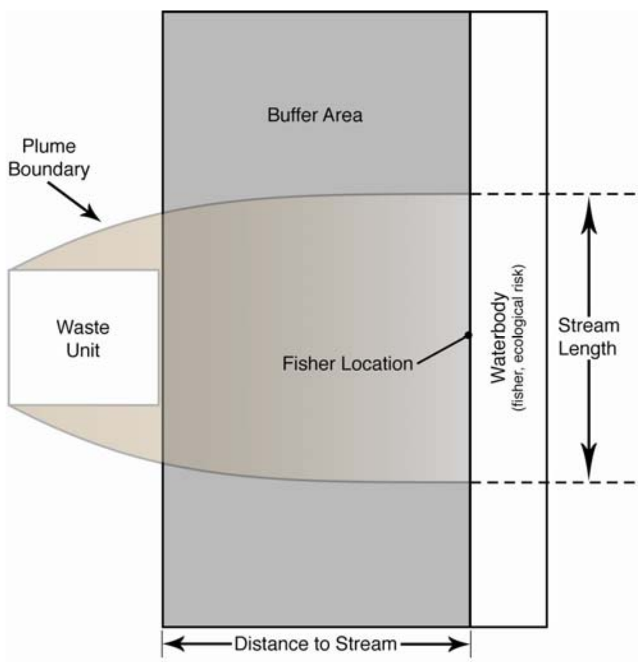

Figure 2-4. Conceptual site layout for residential fisher and aquatic ecological risk scenario.

2.3 Screening Analysis

To assist in selecting constituents for full-scale modeling, a screening analysis was conducted in 2002 (U.S. EPA, 2002a) that compared very conservative estimates of exposure concentrations (e.g., leachate concentrations) to health-based concentration benchmarks to quickly and simply identify constituents with risks that clearly do not exceed the risk criteria so that these could be eliminated from further analysis. For example, for the groundwater-to-drinking-water pathway, leachate concentrations were compared directly to drinking water standards, which is equivalent to assuming that human receptors are drinking leachate.[5] Similarly conservative estimates were used for ecological receptors (e.g., fish swimming directly in leachate). EPA made use of those screening results in this risk assessment, which was conducted in 2003 and documented in the August 6, 2007, draft report and its subsequent revisions, including the current document. **Section 3.2** provides further detail on how the CCW screening analysis was conducted to develop the list of CCW constituents modeled in the full-scale analysis.

2.4 Full-Scale Risk Assessment

Although the screening analysis identified the potential for risk for a subset of the constituents reported in CCW, the conservative assumptions used precluded an accurate quantitative estimate of these risks. The screening results were not intended to, and do not, characterize the risks that we expect would actually occur, because the purpose is not to characterize risks but rather to identify those constituent/pathway/receptor combinations that are unlikely to be problematic versus those that are most likely to be problematic. To gain a better understanding of the risks that may be posed by the constituents identified as likely to be problematic, EPA conducted a full-scale probabilistic (Monte Carlo) risk assessment to estimate the national distribution of the risks to human health and the environment posed by CCW disposal, and to provide the information needed to assess future management options for these wastes in the context of their risks to human health and the environment. The full-scale CCW Monte Carlo risk assessment was designed to characterize the national CCW risk profile in terms of WMU type, waste type, and constituent, and to use distributions in a probabilistic modeling framework to incorporate variability and uncertainty into the analysis.

The full-scale modeling approach used data about waste management practices and environmental conditions at 181 utility CCW disposal sites across the United States.[6] These sites were assumed to represent the universe of CCW onsite waste disposal sites at the time of the EPRI survey (1995) and defined the national framework for the risk assessment. One question related to this risk assessment is how CCW facilities may have changed since the 1995 EPRI survey. Although the DOE/EPA survey did not include all of the data needed to conduct a risk assessment (WMU area and capacity data were not collected), liner conditions were addressed, and by comparing the DOE/EPA survey results to the EPRI data, it is possible to assess how

[5] Note that RCRA waste disposal risk assessments do not address direct discharges from impoundments to surface waters because they are regulated as permitted point source discharges under the Clean Water Act by EPA's Office of Water.

[6] These 181 sites include177 sites from the EPRI survey and 4 additional CCW sites added by EPA to better represent FBC waste disposal facilities; see Section 2.1.2.

liner conditions have changed as CCW facilities were built or expanded since 1995. The 56 WMUs surveyed in the U.S. DOE (2006) study were commissioned between 1994 and 2004. Although the actual number of WMUs that were established in that timeframe cannot be verified, based on proxy data (i.e., CCW available for disposal in those states with identified new WMUs and coal-fired power plant generating capacity), the sample coverage was estimated to be at least 61 to 63 percent of the total population of the newly commissioned WMUs.[7] With the exception of one landfill, the newly constructed facilities are all lined, with either clay, synthetic, or composite liners. The single unlined landfill identified in the recent DOE report receives bottom ash, which is characterized as an inert waste by the state, and therefore, a liner is not required. There has been a marked trend away from unlined WMUs in favor of lined units, with a distinct preference for synthetic or composite liners. A comparison of the 26 coal combustion plants in both the EPRI survey and the DOE/EPA survey (U.S. DOE, 2006) showed that although most of those facilities (17 of 26) were using unlined WMUs in 1995, all 26 are now placing wastes in new or expanded landfills or surface impoundments that are lined with clay, synthetic, or composite liners. However, it is likely that the older unlined units were closed with wastes in place, and that these wastes therefore still pose a threat through groundwater pathways. In addition, the available data cannot be used to determine the number of unlined units that continue to operate in the United States. See further discussion of the uncertainty posed by the use of the EPRI liner data in **Section 4.4.1**.

The full-scale assessment was conducted using several modeling components: (1) EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP; U.S. EPA, 1997a) groundwater model, (2) a simple steady-state surface water and aquatic food web model, and (3) a multipathway exposure and risk modeling system.

2.4.1 Data Collection

For the sites representing each WMU and waste type combination selected for analysis, the Monte Carlo analysis began with input files that contain, for each Monte Carlo realization, the following variables collected at and around each of the 181 modeled sites:

- WMU area, depth, and capacity
- WMU liner status (no liner, clay liner, composite liner)
- Waste type (conventional CCW, CCW codisposed with coal refuse, FBC wastes)
- Soil texture (for vadose zone properties and infiltration rates)
- Soil pH and organic carbon
- Aquifer type
- Groundwater temperature
- Climate center (for infiltration rates)
- USGS Hydrologic Region (for surface water quality data)
- Surface water type and flow conditions.

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7 For additional details as to how these estimates were derived, the reader is referred to the DOE study, pages S-2 to S-3 of the Summary Section and Section 3.1.2.

Data sources and collection methods for these variables may be found in **Appendices B** and **C**.

CCW constituent data in the CCW constituent database were used as a national empirical distribution of the concentrations of the constituents of concern in CCW landfill leachate and surface impoundment porewater. Like the WMU database, the CCW constituent data include WMU type and waste type, which enabled constituent concentrations to be assigned to the 181 CCW sites by waste type and WMU type. The CCW constituent database was also used to assign (by waste type) the high, medium, and low leachate pH and ionic strength conditions needed to select the appropriate subsurface sorption isotherms for each model run (see **Appendix D**).

Because site-specific data were not readily available, national distributions were used to populate the following variables by model run:

- Distance to nearest drinking water well
- Distance to nearest surface waterbody
- Aquifer depth, thickness, gradient, and hydraulic conductivity (based on site-specific hydrogeologic setting)
- Soil hydrologic properties (based on site-specific soil type).

The data sources used to develop national distributions for these variables are described in **Appendix C**. Human exposure factors, such as exposure duration and drinking water and fish consumption rates, were also based on national distributions, which are provided in **Appendix F**.

2.4.2 Model Implementation

As a first step in the modeling process, the groundwater model (EPACMTP) read the site-based data files to estimate the following for each model run:

- Drinking water well peak concentration
- Time to drinking water peak concentration
- Peak surface water contaminant flux
- Time to peak surface water contaminant flux.

The groundwater model was run until contaminant concentrations at the receptor point returned to zero after the concentration peak or for the maximum simulation time of 10,000 years, whichever came first.

Groundwater model results were passed to the multimedia modeling system to estimate surface water and sediment concentrations and to calculate human and ecological exposure and risk. Additional inputs sent to the model at this stage included

- Site-based surface waterbody type, dimensions, flows, pH, and total suspended solids (TSS) concentration
- Chemical-specific fish bioconcentration factors (BCFs)
- Human exposure factors (from national distributions)
- Human and ecological health benchmarks.

For human health, the multimedia modeling system calculated risk from drinking water ingestion and fish consumption for each realization. For ecological risk, the model used surface water and sediment concentrations along with ecological benchmarks to estimate the risks to ecological receptors.

2.4.3 Exposure Assessment

Table 2-4 lists the human and ecological receptors considered in the CCW risk assessment, along with the specific exposure pathways that apply to each receptor. All of the receptors that EPA considered were assumed to live offsite, at a location near the WMU.

Table 2-4. Receptors and Exposure Pathways Addressed in the Full-Scale CCW Assessment

Receptor	Ingestion of Drinking Water	Fish Consumption	Direct Contact with Surface Water and Sediment	Ingestion of Aquatic Organisms
Human Receptors				
Adult resident	✔			
Child resident	✔			
Adult recreational fisher		✔		
Child recreational fisher		✔		
Ecological Receptors				
Aquatic and sediment organisms			✔	
Mammals and birds				✔

For human receptors, the exposure assessment estimated the dose to an individual receptor by combining modeled CCW constituent concentrations in drinking water or fish with intake rates for adult and child receptors. The full-scale CCW risk assessment considered exposures due to chemicals leaching from WMUs and contaminating groundwater. The groundwater exposures include drinking water ingestion and consumption of recreationally caught contaminated fish from surface waterbodies affected by contaminated groundwater. For the groundwater-to-drinking-water pathway, it was assumed that well water was the only source of drinking water (although some households may drink bottled or treated water or may drink water outside the home, e.g., at work or at school).

For ecological receptors, exposure assumptions were incorporated into the development of ecological benchmarks (see **Appendix H**), which were surface water and sediment concentrations corresponding to an HQ of 1.

The time period for the exposure assessment was defined by the peak concentration in the media of concern and the exposure duration. For human receptors, annual average media concentrations were averaged over the randomly selected exposure duration around the peak concentration for each run. To protect against chronic effects to ecological receptors, EPA considered the exposure duration over a significant portion of the receptor's lifetime, and we believe that one year is the appropriate period of time for that. To be protective, we used the highest (peak) annual average concentration to estimate ecological exposure and risk.

2.4.4 Risk Estimation

Risk was estimated using several risk endpoints as particular measures of human health risk or ecological hazard. A risk endpoint is a specific type of risk estimate (e.g., an individual's excess cancer risk) that is used as the metric for a given risk category. The CCW risk assessment evaluated cancer and noncancer endpoints for humans and noncancer endpoints for ecological receptors. For human risk, the availability of toxicological benchmarks for cancer and noncancer effects determined which endpoints were evaluated for each constituent.

EPA used two risk endpoints to characterize risk for the human receptors and a single risk endpoint, total HQ, to characterize risk for ecological receptors. These endpoints are discussed in **Section 3.9**; in addition, uncertainty related to these endpoints is discussed in **Sections 4.4.2** (exposures to multiple constituents) and **4.4.3.4** (benchmark uncertainties).

From the distribution of risks for each risk endpoint generated by the Monte Carlo analysis, the 50th and 90th percentile risks were selected and compared to a risk range of 1 in 1,000,000 to 1 in 10,000 excess cancers and a hazard quotient greater than 1 for noncarcinogenic effects. A hazard quotient greater than 1 was also used for the ecological risk criterion in the full-scale risk assessment.

3.0 Analysis

The CCW risk analysis evaluated risks from CCWs disposed of in landfills and surface impoundments located onsite at coal-fired utility power plants across the United States based primarily on data collected in 1995 by EPRI (1997).[1] Chemical constituents found in CCW can be released from these WMUs into the surrounding environment by releases through leachate to the subsurface underlying the WMU. Leachate forms in both landfills and surface impoundments, migrates from the WMU through soil to groundwater, and is transported in groundwater to drinking water wells (groundwater-to-drinking-water pathway) and into surface waterbodies near the WMU (groundwater-to-surface-water pathway).

To select the constituents for full-scale modeling, the screening analysis compared very conservative estimates of exposure concentrations (e.g., leachate concentrations) to health-based concentration benchmarks to quickly, simply, and safely identify constituents with risks that clearly do not exceed the risk criteria so that these could be eliminated from further analysis. For example, leachate concentrations were compared directly to drinking water standards, which is equivalent to assuming that human receptors are drinking leachate.

For the full-scale analysis, EPA used computer-based models and sets of equations to estimate the risk to human health and the environment from current CCW disposal practices.[2] These models included

- **Source** models that simulate the release of CCW constituents in leachate from landfills and surface impoundments[3]
- **Fate and transport** models that estimate contaminant concentrations in environmental media such as groundwater and surface water
- **Exposure** models that estimate daily contaminant doses for humans and ecological receptors exposed to CCW constituents in environmental media that were not screened out
- **Risk** models that calculate risks to humans and ecological receptors.

This section describes the data, models, and equations used for CCW constituent screening, as well as those used to calculate exposure point concentrations and risk in the full-

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1 The selection and characterization of these CCW WMUs are described in more detail in Appendix B.

2 As discussed in **Section 2**, the 1995 EPRI survey data was assumed to represent current CCW management practices. However, new data from a more recent DOE/EPA survey suggest that liners may be more prevalent in new and expanded units built since 1994. **Section 4** discusses implications of this uncertainty on the risk assessment results.

3 EPA used source-term models integrated into EPACMTP to estimate environmental releases of constituents in leachate from landfills and surface impoundments.

scale analysis. **Section 3.1** describes the health benchmarks used to develop human and ecological risk estimates for screening and full-scale analysis. **Section 3.2** describes the screening analysis, along with how the screening results were used to select constituents for the full-scale analysis. **Section 3.3** provides the overall structure for the full-scale analysis, including the spatial and temporal framework and the probabilistic (Monte Carlo) framework for the model runs. **Sections 3.4** and **3.5** describe the landfill and surface impoundment source models used to predict environmental releases of constituents from CCW. **Sections 3.6** and **3.7** describe the fate and transport modeling used to predict contaminant concentrations in groundwater and surface water. **Section 3.8** describes the human exposure calculations and **Section 3.9** describes how risks were calculated for human and ecological receptors.

Supporting detail can be found in the following appendices:

- **Appendix A, CCW Constituent Data**, provides the CCW constituent concentrations used and describes how they were collected and processed for both the screening and full-scale analyses
- **Appendix B, Waste Management Unit Data**, describes the location and characteristics of each landfill and surface impoundment modeled and describes how the source model input parameter values were collected for the full-scale analysis
- **Appendix C, Site Data**, describes how environmental data around each CCW waste disposal site were collected to provide inputs for the groundwater and surface water modeling
- **Appendix D, MINTEQA2 Nonlinear Sorption Isotherms**, describes the development and application of the CCW-specific MINTEQ metal sorption isotherms used to model fate and transport in soils and groundwater
- **Appendix E, Surface Water, Fish Concentration, and Contaminant Intake Equations**, documents the algorithms used to calculate surface water concentrations, fish concentrations, and drinking water and fish intake rates
- **Appendix F, Human Exposure Factors**, documents the human exposure parameters and equations used for calculating the environmental exposure from CCW disposal
- **Appendix G, Human Health Benchmarks**, describes how the human toxicity benchmarks were selected and developed for CCW constituents
- **Appendix H, Ecological Benchmarks**, describes how the ecological toxicity benchmarks were selected and developed for CCW constituents
- **Appendix I, Calculation of HBNs,** describes how health-based numbers were calculated for the screening analysis
- **Appendix J, Chemical-Specific Inputs Used in the Screening Analysis,** describes additional chemical-specific data used in the screening analysis

- **Appendix K, Screening Analysis Results,** provides the results of the screening analysis for human and ecological receptors.

- **Appendix L, Time of Travel to Receptor Well,** provides figures showing, for selected CCW constituents, cumulative percentiles of the time it took for the peak concentration to reach a receptor well for each source type.

3.1 Toxicity Assessment

The assessment of human risks from disposal of a waste stream like CCW begins by assessing, for constituents in the waste, the ability of each chemical to cause an adverse human health effect, which depends on the toxicity of the chemical, the chemical's route of exposure to an individual (ingestion, inhalation, or direct contact), the duration of exposure, and the dose received (the amount that a human ingests or inhales). Similar principles apply to ecological receptors, although exposure duration is much shorter than for human receptors because humans generally live longer than ecological receptors. For a risk assessment, the toxicity of a constituent is defined by a human health or ecological benchmark for each route of exposure. A benchmark is a quantitative value used to predict a chemical's possible toxicity and ability to induce an adverse effect at certain levels of exposure. Because different chemicals cause different health effects at different doses, benchmarks are chemical-specific.

Appropriate human health and ecological benchmarks for the constituents of potential concern in CCW wastes were collected for use in the screening assessment and in the full-scale risk assessment. Although these assessments were conducted in 2002 and 2003, the benchmarks and risks presented in this 2009 report were updated to reflect current toxicity data.[4] The data sources and collection methodology for these benchmarks are described briefly in **Sections 3.1.1** (human health benchmarks) and **3.1.2** (ecological benchmarks), and in more detail in **Appendix G** (human health benchmarks) and **Appendix H** (ecological benchmarks).

3.1.1 Human Health Benchmarks

Human health benchmarks for chronic oral exposures were needed for the full-scale analysis. These health benchmarks were derived from toxicity data based on animal studies or human epidemiological studies. Each benchmark represents a dose-response estimate that relates the likelihood and severity of adverse health effects to exposure and dose. This section presents the noncancer and cancer benchmarks used to evaluate human health effects that may result from exposure to the constituents modeled.

Chronic human health benchmarks were used to evaluate potential noncancer and cancer risks. These include reference doses (RfDs) to evaluate noncancer risk from oral exposures and oral cancer slope factors (CSFs) to evaluate cancer risk from oral exposures. The benchmarks are chemical-specific and do not vary between age groups.

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[4] Because the risk calculations are linear and occur at the end of the analysis, all screening and full-scale results can be simply scaled to accommodate any changes in human health and ecological benchmarks.

- The **RfD** is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. The RfD provides a reference point to gauge the potential effects (U.S. EPA, 2002c). At exposures increasingly greater than the RfD, the potential for adverse health effects may increase, although this potential cannot be quantified. Lifetime exposure above the RfD does not imply that an adverse health effect would necessarily occur.

- The **CSF** is an upper-bound estimate (approximating a 95 percent confidence limit) of the increased human cancer risk from a lifetime exposure to an agent. Because this is an upper-bound estimate, true risk is likely lower. This estimate is usually expressed in units of proportion (of a population) affected per milligram of agent per kilogram body weight per day (mg/kg-d). Unlike RfDs, CSFs do not represent "safe" exposure levels; rather, they relate levels of exposure with a probability of effect or risk.

Human health benchmarks are available from several sources. Health benchmarks developed by EPA were used whenever they were available. Sources of human health benchmarks were used in the following order of preference:

- Integrated Risk Information System (IRIS) (U.S. EPA, 2002c)
- Superfund Technical Support Center Provisional Benchmarks
- Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1997f)
- Various other EPA health benchmark sources
- ATSDR minimal risk levels (MRLs) (ATSDR, 2002).

These sources and the selection hierarchy are described in more detail in **Appendix G**.

The chronic human health benchmarks used in the screening and full-scale analysis are summarized in **Table 3-1**. For most constituents, human health benchmarks were available from IRIS. Benchmarks for a few constituents were obtained from ATSDR. For chemicals for which purely health-based benchmarks were not available (lead), a drinking water action level was used (U.S. EPA, 2002d).

Table 3-1. Human Health Benchmarks Used in the CCW Risk Assessment

Constituent	Type of Benchmark[a]	Value	Units	Source[b]
Cancer Benchmark				
Arsenic	CSF	1.5E+00	$(mg/kg\text{-}d)^{-1}$	IRIS
Noncancer Benchmarks				
Aluminum	RfD	1.0E+00	mg/kg-d	PPRTV
Antimony	RfD	4.0E-04	mg/kg-d	IRIS
Arsenic	RfD	3.0E-04	mg/kg-d	IRIS
Barium	RfD	2.0E-01	mg/kg-d	IRIS
Beryllium	RfD	2.0E-03	mg/kg-d	IRIS

(continued)

Human Health Benchmarks Used in the CCW Risk Assessment (continued)

Constituent	Type of Benchmark[a]	Value	Units	Source[b]
Boron	RfD	2.0E-01	mg/kg-d	IRIS
Cadmium	RfD (water)[c]	5.0E-04	mg/kg-d	IRIS
	RfD (food)[d]	1.0E-03	mg/kg-d	IRIS
Chromium III	RfD	1.5E-00	mg/kg-d	IRIS
Chromium VI	RfD	3.0E-03	mg/kg-d	IRIS
Cobalt	RfD	3.0E-04	mg/kg-d	PPRTV
Copper	RfD	1.0E-02	mg/kg-d	ATSDR
Cyanide	RfD	2.0E-02	mg/kg-d	IRIS
Fluoride	RfD	6.0E-02	mg/kg-d	IRIS
Lead	MCL	1.5E-02	mg/L	DWAL
Manganese	RfD (food)	1.4E-01	mg/kg-d	IRIS
	RfD (water, soil)	4.7E-02	mg/kg-d	IRIS
Mercury (divalent)	RfD (food, water, soil)	3.0E-04	mg/kg-d	HEAST
	RfD (fish)	1.0E-04	mg/kg-d	IRIS
Molybdenum	RfD	5.0E-03	mg/kg-d	IRIS
Nickel	RfD	2.0E-02	mg/kg-d	IRIS
Nitrate	MCL	1.0E+01	mg/L	DWAL
	RfD	1.6E+00	mg/kg-d	IRIS
Nitrite	RfD	1.0E-01	mg/kg-d	IRIS
Selenium	RfD	5.0E-03	mg/kg-d	IRIS
Silver	RfD	5.0E-03	mg/kg-d	IRIS
Strontium	RfD	6.0E-01	mg/kg-d	IRIS
Thallium	RfD	8.0E-05	mg/kg-d	IRIS
Vanadium	RfD	7.0E-03	mg/kg-d	HEAST
Zinc	RfD	3.0E-01	mg/kg-d	IRIS

[a] MCL = maximum concentration limit
[b] References:
ATSDR: Minimal Risk Levels, ATSDR (2009)
DWAL: Drinking Water Action Level, U.S. EPA (2002d)
HEAST: U.S. EPA (1997f)
IRIS: U.S. EPA (2009a)
PPRTV: Provisional peer-reviewed toxicity value (U.S. EPA, 2006a, 2006b, 2008a)
[c] Used for drinking water ingestion.
[d] Used for fish ingestion.

Cadmium has two RfDs, one for exposures via water and one for exposures via food. The RfD for water was used for drinking water ingestion and the RfD for food was used for fish consumption.

3.1.2 Ecological Benchmarks

The ecological risk assessment addressed two routes of exposure for ecological receptors, direct contact with contaminated media and ingestion of contaminated food items. For each constituent for which ecological effect data were available, HQs were calculated using chemical-specific media concentrations assumed to be protective of ecological receptors of concern. To calculate ecological HQs, these media concentrations (also known as chemical stressor concentration limits [CSCLs]) were divided by the estimated media concentrations. The CSCLs are media-specific environmental quality criteria intended to represent a protective threshold value for adverse effects to various ecological receptors in aquatic ecosystems (surface water and sediment). The CSCLs were developed to be protective of the assessment endpoints chosen for this assessment. An HQ greater than 1 indicates that the predicted concentration exceeds the CSCL, and therefore, the potential for adverse ecological effects exists. In this regard, the use of CSCLs to calculate an ecological HQ is analogous to the use of the reference concentration (RfC) for human health where the air concentration is compared to the health-based concentration (the RfC), and an HQ greater than 1 is considered to indicate the potential for adverse health effects.

Table 3-2 shows the receptor types assessed for each exposure route (direct contact and ingestion) in each environmental medium addressed by the full-scale CCW risk assessment.

Table 3-2. Ecological Receptors Assessed by Exposure Route and Medium (Surface Water or Sediment)

Receptor Type	Surface Water (water column)	Surface Water Sediment
Direct Contact Exposure		
Aquatic Community	✔	
Sediment Community		✔
Amphibians	✔	
Aquatic Plants and Algae	✔	
Terrestrial Plants		
Ingestion Exposure		
Mammals	✔	
Birds	✔	

Ecological receptors that live in close contact with contaminated media are considered to be potentially at risk. For the screening and full-scale analysis, these receptors are exposed through direct contact with contaminants in surface water and sediment. The benchmarks for receptor communities (aquatic or sediment communities) are not truly *community-level* concentration limits in that they do not consider predator-prey interactions. Rather, they are based on the theory that protection of 95 percent of the species in the community will provide a sufficient level of protection for the community (see, for example, Stephan et al., 1985, for additional detail). **Appendix H** summarizes the benchmark derivation methods for each receptor assessed for the direct contact route of exposure.

For surface water and sediments, the ingestion route of exposure addresses the exposure of terrestrial mammals and birds through ingestion of aquatic plants and prey. Thus, the benchmarks for ingestion exposure represent media concentrations that, based on certain assumptions about receptor diet and foraging behavior, are expected to be protective of populations of mammals and birds feeding and foraging in contaminated areas.

For birds and mammals, the derivation of ingestion benchmarks required the selection of appropriate ecotoxicological data based on a hierarchy of sources. The assessment endpoint chosen for birds and mammals was population viability and therefore, the ingestion benchmarks were based on study data for physiological effects that are relevant to populations. These data included measures of reproductive fitness, developmental success, survival, and other toxicological effects that could have an impact on the population rather than just the health of an individual animal. Choosing these measures of effect provided the basis to evaluate the potential for adverse effects at the population level by inference; this analysis did not evaluate the effects on population dynamics in the sense that a reduction in the population was predicted over time in response to exposure to constituents released from CCW. Population-level modeling was beyond the scope of this risk assessment.

Once an appropriate ingestion exposure study was identified, a benchmark was calculated. **Appendix H** describes the basic technical approach used to convert avian or mammalian benchmarks (in daily doses) to the CSCLs (in units of concentration) used to assess ecological risks for contaminated surface water and sediment. The methods reflect exposure through the ingestion of contaminated plants, prey, and various media, and include parameters on accumulation (e.g., BCFs), uptake (e.g., consumption rates), and dietary preferences.

Where multiple ecological benchmarks were available for a pathway of interest, the benchmark that produced the lowest (most sensitive) CSCL for each chemical in each medium was used. For example, several types of receptors (the aquatic community, amphibians, aquatic plants, mammals, birds) can be exposed to contaminants in surface water. The surface water criterion for a given constituent represents the lowest CSCL for these receptors, and thus gives the highest (most protective) HQ. The CSCLs used to assess ecological endpoints in the full-scale analysis and the associated receptor are summarized in **Table 3-3**. Additional details on the CCW ecological benchmarks and CSCLs and their development can be found in **Appendix H** and in U.S. EPA (1998a).

Table 3-3. Ecological Risk Criteria Used for Surface Water and Sediment

Constituent	Medium[a]	Exposure Route	CSCL	Units	Receptor
Aluminum	Surface Water	Direct contact	0.09	mg/L	Aquatic biota
Arsenic total	Sediment	Ingestion	0.51	mg/kg	Spotted sandpiper
Arsenic III	Surface Water	Direct contact	0.15	mg/L	Aquatic biota
Arsenic IV	Surface Water	Direct contact	8.10E-03	mg/L	Aquatic biota
Barium	Sediment	Ingestion	190	mg/kg	Spotted sandpiper
	Surface Water	Direct contact	4.00E-03	mg/L	Aquatic biota
Boron	Surface Water	Direct contact	1.60E-03	mg/L	Aquatic biota

(continued)

Ecological Risk Criteria Used for Surface Water and Sediment (continued)

Constituent	Medium[a]	Exposure Route	CSCL	Units	Receptor
Cadmium	Sediment	Direct contact	0.68	mg/kg	Sediment biota
	Surface Water	Direct contact	2.50E-03	mg/L	Aquatic biota
Cobalt	Surface Water	Direct contact	0.02	mg/L	Aquatic biota
Lead	Sediment	Ingestion	0.22	mg/kg	Spotted sandpiper
	Surface Water[b]	Ingestion	3.00E-04	mg/L	River otter
Selenium total	Surface Water	Direct contact	5.00E-03	mg/L	Aquatic biota
Selenium IV	Surface Water	Direct contact	0.03	mg/L	Aquatic biota
Selenium VI	Surface Water	Direct contact	9.5E-03	mg/L	Aquatic biota

Source: U.S. EPA (1998a)
[a] If a medium (surface water or sediment) is not listed, there were insufficient data to develop a benchmark for it.
[b] Includes ingestion of fish.

3.2 Constituent Screening

The screening risk analysis was designed to select the CCW constituents for full-scale exposure modeling. The groundwater pathway screening evaluated exposure through drinking and surface water contamination[5] from groundwater. The analysis considered risks to both human and ecological receptors. Waste constituents that passed the screen (i.e., were below target risk/hazard criteria) were assumed to pose *de minimis* risks and were not addressed in the full-scale modeling.

3.2.1 Waste Constituent Concentrations

The CCW screening analysis addressed metals and inorganic compounds identified as described in **Section 2.1.1.2**. Waste concentrations were available for most of these constituents from the CCW constituent database described in **Section 2.1.1** and **Appendix A**. The CCW constituent database includes waste analysis data for CCW leachate, surface impoundment and landfill porewater, and whole waste samples, and was used in the screening analysis as follows:

- Analyte concentrations (in mg/L) porewater sampled from surface impoundment sediments represent surface impoundment leachate affecting the groundwater pathways

- To represent landfill leachate, the different types of landfill leachate and porewater data in the CCW constituent database were selected based on a hierarchy developed to best represent CCW landfill waste concentrations at a wide variety of sites and waste disposal conditions.

To allow screening decisions to be made by waste constituent, waste stream, and exposure pathway, CCW data were processed to produce a single concentration per analyte and waste

[5] For the groundwater-to-surface-water pathway, the analysis assumed that human exposure occurs through the consumption of contaminated fish. Ecological exposure occurs through direct contact to contaminated surface water and sediment and consumption of aquatic organisms.

stream (surface impoundment porewater and landfill leachate) for comparison with health-based numbers (HBNs) and CSCLs. Data processing to create these analyte concentrations involved two steps:

- **Calculation of average constituent concentrations by site for landfill leachate, surface impoundment porewater, and total ash concentrations.** Site averaging avoids potential bias toward sites with many analyses per analyte. During site averaging, separate waste disposal scenarios at a site (e.g., non-FBC and FBC ash; FGD sludge and ash) were treated as separate "sites" and averaged independently. Nondetects were averaged at one-half the reported detection limit.[6]

- **Selection of screening concentrations from site-averaged values.** For the screening calculations, the analysis used the 90th percentile of the site-averaged concentrations across all sites for landfill leachate and surface impoundment porewater.

Appendix A describes the CCW constituent database and how the waste constituent concentrations were selected and processed for the screening analysis and full-scale risk assessment.

3.2.2 Media-Specific Exposure Concentrations for Screening

The screening analysis required media concentrations for groundwater, surface water, and sediment to compare with the HBNs and CSCLs. As a simple first screen of risk, the analysis used waste concentrations as protective estimates of offsite groundwater and surface water concentrations.

For groundwater-to-drinking-water exposures, the analysis used the 90th percentile waste porewater[7] and leachate concentrations to represent groundwater contamination from the surface impoundment and landfill, respectively. No dilution or attenuation was assumed between the WMU and the drinking water well because the large size range of CCW units precluded the use of a dilution attenuation factor (DAF)[8] for a nearby well. Similarly, surface water concentrations were assumed to be equivalent to waste leachate and porewater concentrations.

3.2.3 Screening Methodology

The CCW screening approach compared protective health-based concentrations in each medium of concern with estimated offsite media concentrations of CCW constituents described in **Section 3.2.2**. Both human and ecological receptors were addressed. HBNs are media concentrations developed to protect human health, and CSCLs are media concentrations developed to protect ecological receptors. HBNs were calculated based on the target risk criteria

[6] Appendix A contains figures showing how site-averaged 90th percentile concentrations and 90th percentile concentrations taken across all analyses (nonaveraged concentrations) compare with HBNs for surface impoundment porewater, toxicity characteristic leaching procedure (TCLP) leachate, and whole waste concentrations.

[7] Although the 95th percentile was used in 1998, the 90th percentile was used in this analysis as a reasonably conservative value considering the protective screening analysis assumptions and the larger 2002 constituent data set.

[8] A DAF is the waste concentration divided by the media concentration at the point of exposure.

for the screening analysis: an HQ of 1 (for noncarcinogens) or an excess cancer risk level of 10^{-5}. CSCLs were calculated based on an HQ of 1. A full description of the development of the HBNs can be found in **Appendix I**. Development of the CSCLs used for screening based on ecological risks is provided in **Appendix H**.

Screening involved developing these HBNs and CSCLs, as well as developing the waste constituent or media concentrations to be used in the comparison and estimating the risk associated with these concentrations. Pathways and waste streams evaluated in the analysis include those summarized in **Table 3-4**, along with the basic assumptions and methods used to evaluate each pathway in the screening analysis.

Table 3-4. Exposure Pathways Evaluated In CCW Constituent Screening

Exposure Pathway	Methodology
Groundwater-to-drinking-water	Compared drinking water HBNs to landfill leachate and surface impoundment porewater concentrations
Groundwater-to-surface-water (fish consumption; ecological)	Compared surface water HBNs and CSCLs to landfill leachate and surface impoundment porewater concentrations
Direct exposure to surface impoundment CCW (ecological only)	Compared surface water CSCLs to CCW surface impoundment constituent concentrations from the 1998 CCW risk assessment

3.2.3.1 HBN Calculations

HBNs represent media concentrations that are protective of human health from exposure pathways that are relevant to that particular medium. The exposure scenarios assumed for CCW management (see **Section 2.2**) defined the media of concern for the analysis. Human exposure scenarios included the following:

- Drinking of groundwater contaminated by leachate from CCW landfills and surface impoundments
- Consumption of fish by recreational fishers fishing in streams and lakes contaminated by CCW leachate through the groundwater-to-surface-water pathway

The CCW screening analysis used HBNs calculated for groundwater and surface water exposure. The CCW HBNs represent reasonable maximum exposure (RME) scenarios for an offsite receptor:

- Groundwater HBNs are protective for residential drinking water exposure from a domestic well immediately downgradient from a CCW landfill or surface impoundment
- Surface water HBNs are protective for fish caught (and consumed) by a recreational fisher from a river, lake, or stream adjacent to a CCW landfill or surface impoundment.

Key features and assumptions of the HBN calculations included the following:

- HBNs were calculated based on a target cancer risk of 10^{-5} or target HQ of 1

- The analysis considered exposures for three child receptor cohorts and one adult receptor cohort; exposure for these cohorts was assumed to start at ages 3, 8, 15, and 20, respectively
- Chemical properties (bio-uptake and bioaccumulation factors) were collected from best available literature values (see **Appendix J**)
- Human exposure factors (e.g., body weight, exposure duration, exposure frequency, consumption rates) were set at central tendency values.

Appendix I describes the methodology used to develop the CCW HBNs and provides the HBNs used in the screening analysis.

3.2.3.2 CSCL Calculations

The CCW ecological screening analysis paralleled the human health screening analysis and addressed two routes of exposure for ecological receptors: direct contact with contaminated media and ingestion of contaminated food items. Ecological exposure scenarios occurring near CCW landfills or surface impoundments and addressing these exposure routes included the following:

- Direct contact with surface water contaminated by CCW leachate through the groundwater-to-surface-water pathway
- Ingestion of aquatic organisms in streams and lakes contaminated by CCW leachate through the groundwater-to-surface-water pathway.

CSCLs for the contaminated media in each of these exposure scenarios were calculated as described in **Section 3.1.2** and **Appendix H** (the same CSCLs were used for both screening and the full-scale analysis). As with the HBNs, CSCLs were compared directly to concentrations of constituents found in CCW and CCW leachate and porewater, or to protective offsite media concentrations to estimate risk for screening.

3.2.4 Screening Results

The screening analysis conducted in 2002 (U.S. EPA, 2002a) was used in this risk assessment to help narrow the list of constituents to be addressed in the full scale analysis for the groundwater-to-drinking-water and groundwater-to-surface-water pathways. Detailed human and ecological screening results for these pathways are provided in **Appendix K**. The groundwater-to-drinking-water and groundwater-to-surface-water pathways (human fish consumption and ecological risks) did show risks above the screening criteria for several CCW constituents in the screening analysis. **Table 3-5** lists the 21 constituents that had 90th percentile screening analysis groundwater pathway risks greater than a cancer risk of 1 in 100,000 or a noncancer risk with an HQ greater than 1 for human health and 10 for ecological risk.[9]

[9] An HQ of 10 was used for screening ecological risks to account for conservatism of ecological benchmarks and exposure estimates used in the screening analysis (see Section 4.4.3.4).

Table 3-5. Screening Analysis Results: Selection and Prioritization of CCW Constituents for Further Analysis[a]

Constituent	Human Health – Drinking Water		Human Health – Surface Water[b]		Ecological Risk - Surface Water	
	LF HQ (*Cancer Risk*)	SI HQ (*Cancer Risk*)	LF HQ (*Cancer Risk*)	SI HQ (*Cancer Risk*)	LF HQ	SI HQ
Constituents Modeled in Full-scale Assessment						
Carcinogen						
Arsenic[c]	*(*$1.4x10^{-3}$*)*	*(*$1.8x10^{-2}$*)*	*(*$2.2x10^{-4}$*)*	*(*$1.7x10^{-5}$*)*	49	640
Noncarcinogens						
Boron	4.0	28	-	-	6,600	47,000
Cadmium	3.4	8.9	1.4	3.7	20	52
Lead	16	12	-	-	790	590
Selenium	1.2	2.4	4.7	9.5	35	71
Thallium	21	19	6.3	5.7	-	-
Aluminum	-	-	-	-	120	270
Antimony	22	5.5	-	-	-	-
Barium	-	-	-	-	400	75
Cobalt	-	11	-	-	-	270
Molybdenum	4.2	6.8	-	-	-	-
Nitrate/ Nitrite	- /1.2	60/1.2	-	-	-	-
Constituents Not Modeled in Full-scale Assessment[d]						
Noncarcinogens						
Chromium VI	2.3	4.2	-	-	18	33
Fluoride	1.8	5.2	-	-	-	-
Manganese	1	5.6	-	-	-	-
Vanadium	2.2	2.3	-	-	23	24
Beryllium	-	-	-	-	24	-
Copper	-	-	-	-	16	31
Nickel	-	1.3	-	-	-	14
Silver	-	-	-	-	110	14
Zinc	-	-	-	-	16	-

HQ = screening hazard quotient.
LF = landfill.
SI = surface impoundment.

[a] A dash in a cell indicates that the screening HQ was less than 1 (or 10 for ecological risk), so the risk did not exceed the screening criteria for the indicated pathway.

[b] Fish consumption pathway.

[c] Although arsenic can act as both a carcinogen and a noncarcinogen, the cancer risk exceeds the noncancer risk at any concentration, so the more protective cancer benchmark for human health was used throughout this assessment.

[d] These constituents were addressed using risk attenuation factors developed from full-scale results from modeled constituents (see **Section 4.1.5**).

Note that although mercury was originally addressed in both the 2002 screening and 2003 full-scale analyses, results were removed from the 2007 draft and this version of the risk assessment report because subsequent evaluation found that the very high proportion of mercury nondetects in the CCW constituent database, along with the use of one-half the detection limit for the nondetect measurements, led to the results being driven by the detection limit, rather than the actual (but unknown) levels in CCW leachate and porewater. Therefore, the results were not meaningful in terms of the actual risks mercury in CCW poses to human and ecological health. Similarly, a large number of nondetects (or a very small number of measurements) prevented accurate screening or full-scale analysis for antimony, thallium, and cobalt in surface impoundments. These uncertainties are discussed in **Section 4.4.3.1**.

Full-scale modeling was not conducted for all 21 constituents that had 90th percentile risks above the screening criteria for the groundwater pathways. Instead, those 21 constituents were ranked and divided into two groups to focus the full-scale analysis on the CCW constituents that were likely to pose relatively higher risks to human and ecological receptors. The ranking was based on the magnitude of the HQs and the number of HQs exceeding the screening criteria, and was used to select chemicals for full-scale modeling. Constituents with at least one human health HQ greater than 6 or with ecological HQs greater than 100 for both landfills and surface impoundments were modeled. Arsenic, with cancer risks greater than 1 in 1,000, exceeded the cancer risk criterion by a factor of 100 and was also modeled in the full-scale analysis. Constituents with no human health HQs greater than 6 and only one or no ecological HQs greater than 100 were not modeled, but were addressed in a separate analysis using results from the modeled constituents.

Table 3-5 shows the 21 constituents and which of these constituents exceeded the screening criteria and thus were modeled in the full-scale analysis. As shown, 12 constituents were subjected to the full-scale probabilistic risk assessment described in this document. Another 9 constituents exceeded the screening criteria and were addressed using risk factors developed from comparing the screening and full-scale results for the modeled constituents, as described in **Section 4.1.5** of this document.

3.3 Full-Scale Modeling Approach

This section describes the framework, general assumptions, and constraints for the full-scale probabilistic analysis. **Section 3.3.1** describes the temporal and spatial framework. **Section 3.3.2** describes the probabilistic framework, and **Section 3.3.3** describes how the assessment was implemented within the probabilistic framework.

3.3.1 Spatial and Temporal Framework

The spatial framework for the analysis was determined by the geographic distribution of CCW facilities modeled and by the site layout assumed as the conceptual site model for risk assessment. As described in **Section 2.1.2**, the geographic distribution of landfills and surface impoundments managing wastes onsite at coal-fired utility power plants was determined from the 177 sites in the 1995 EPRI survey of the onsite management of CCW (EPRI, 1997). The assessment assumes that these 177 sites and their locations were representative of the approximately 300 coal-fired power plants identified by EIA data as having onsite waste management of conventional CCW and CCW codisposed with coal refuse throughout the United States. For FBC wastes, these 177 sites include only 3 FBC landfills. EPA was able to add 4 additional FBC landfill sites to better represent FBC waste management, for an overall total of 181 sites in this analysis.

The conceptual site layouts applied to each of the sites are described and pictured in **Section 2.2.2**. Two site layouts were used to define the relationship between a landfill or surface impoundment and (1) a drinking water well (for human risk via the groundwater-to-drinking-water pathway) and (2) a surface water body (for human and ecological risk via the groundwater-to-surface-water pathway). In each case, the receptor point (well or waterbody) was assumed to lie within the boundaries of the groundwater contaminant plume. The distance from the edge of the WMU to the well or waterbody was varied for each model run based on national distributions, with well distance taken from a national distribution for Subtitle D municipal landfills (U.S. EPA, 1988a) and distance to surface water taken from a set of measured distances for CCW landfills and surface impoundments developed for this assessment. **Appendix C** presents additional details on these distributions.

The temporal framework was mainly defined by the time of travel from the modeled WMU to the well or waterbody, which can be up to one mile away from the edge of the unit, and the exposure duration over which risks were calculated. The subsurface migration of some CCW constituents (e.g., lead) may be very slow; therefore, it may take a long time for the contaminant plume to reach the receptor well or nearest waterbody, and the maximum concentration may not occur until a very long time after the WMU ceases operations. This time delay may be on the order of thousands of years. To avoid excessive model run time while not missing significant risk at the receptor point, the groundwater model was run until the observed groundwater concentration of a contaminant at the receptor point dropped below a minimum concentration (10^{-16} mg/L) or until the model had been run for a time period of 10,000 years. The minimum concentration used for all fate and transport simulations (10^{-16} mg/L) was at least a million times below any risk- or health-based criteria.

For the groundwater-to-drinking-water pathway (human health risk), risks were calculated based on a maximum time-averaged concentration around the peak concentration at each receptor well. The exposure duration (which varies from 1 to 50 years)[10] was applied around the peak drinking well concentration to obtain the maximum time-averaged concentration.

For the groundwater-to-surface-water pathway, the groundwater model produced surface water contaminant loads (based on groundwater concentration and flow) for a stream that penetrates the aquifer. Because the surface water model is a steady-state model, there is no temporal component to it and the receptor is exposed to the same concentration over the entire exposure duration. For human health risk, the loadings from groundwater to surface water were averaged over the exposure duration, bracketing the time of the peak groundwater concentration.

[10] Distributions of exposure duration and other exposure variables were obtained from the *Exposure Factors Handbook* (U.S. EPA, 1997c,d,e) as described in **Section 3.8.2** and **Appendix F**.

The exposure duration for sensitive ecological receptors was generally a year or less; therefore, for ecological risk, a single peak annual average surface water concentration was used.

For all scenarios, if the groundwater model predicted that the maximum groundwater concentration had not yet occurred after 10,000 years, the actual groundwater concentration at 10,000 years was used in the exposure calculations instead of a maximum time-weighted average concentration around the peak.

3.3.2 Probabilistic Approach

The full-scale analysis evaluated risk in a probabilistic manner and was based on a Monte Carlo simulation that produced a distribution of exposures and risks. The general Monte Carlo approach is shown in **Figure 3-1**. The foundation of the Monte Carlo simulation was the source data derived from the EPRI survey. These were combined with data from the national CCW constituent database to conduct a Monte Carlo simulation of 10,000 iterations per waste type/WMU type/constituent combination.

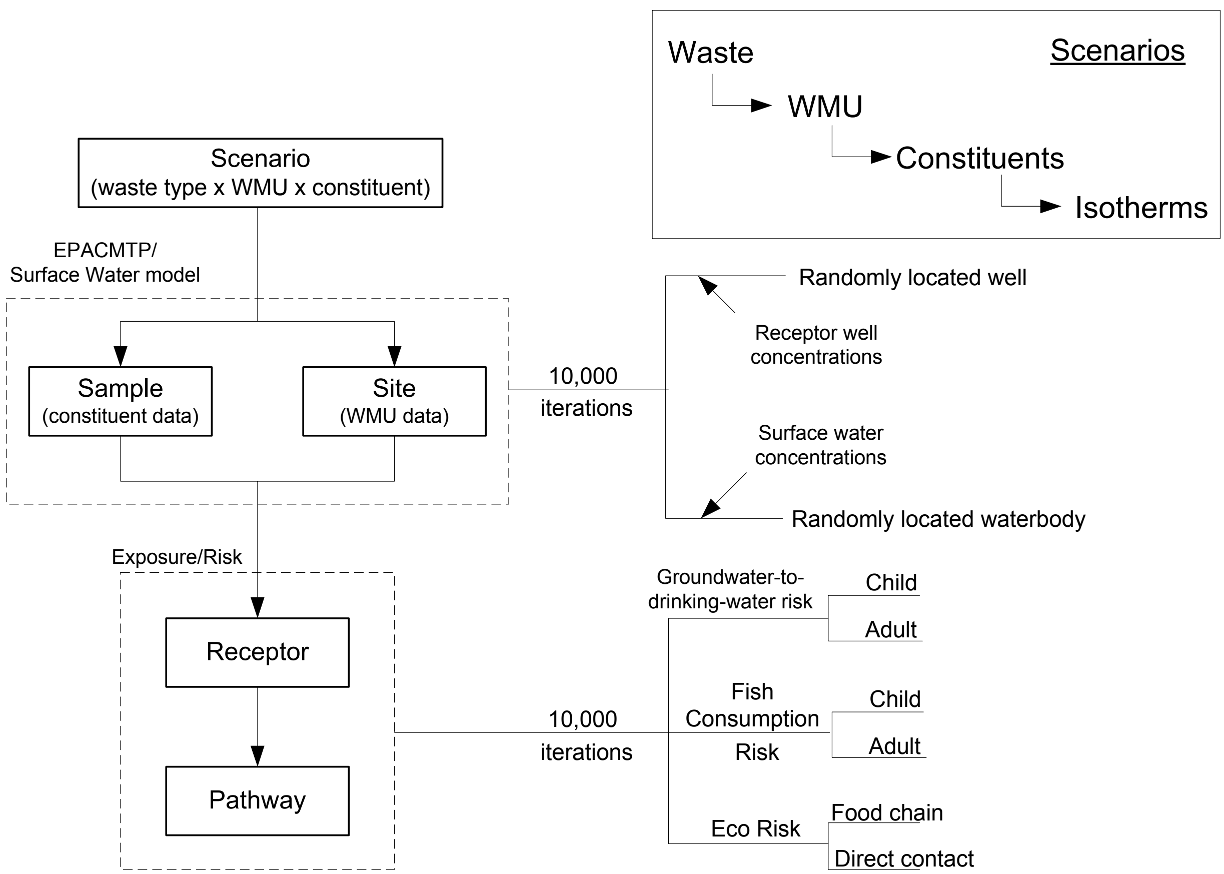

Figure 3-1. Overview of the Monte Carlo approach.

The detailed looping structure for the Monte Carlo analysis is shown in **Figure 3-2**. For each waste type/WMU combination, two separate loops were run. The first loop (shown with dashed lines in Figure 3-2) prepared a set of input files containing 10,000 sets of WMU and site data (as described in **Section 3.3.3**). The second loop (shown with solid lines in Figure 3-2) used those input files to run 10,000 iterations of the source, fate and transport, exposure, and risk models for each constituent.

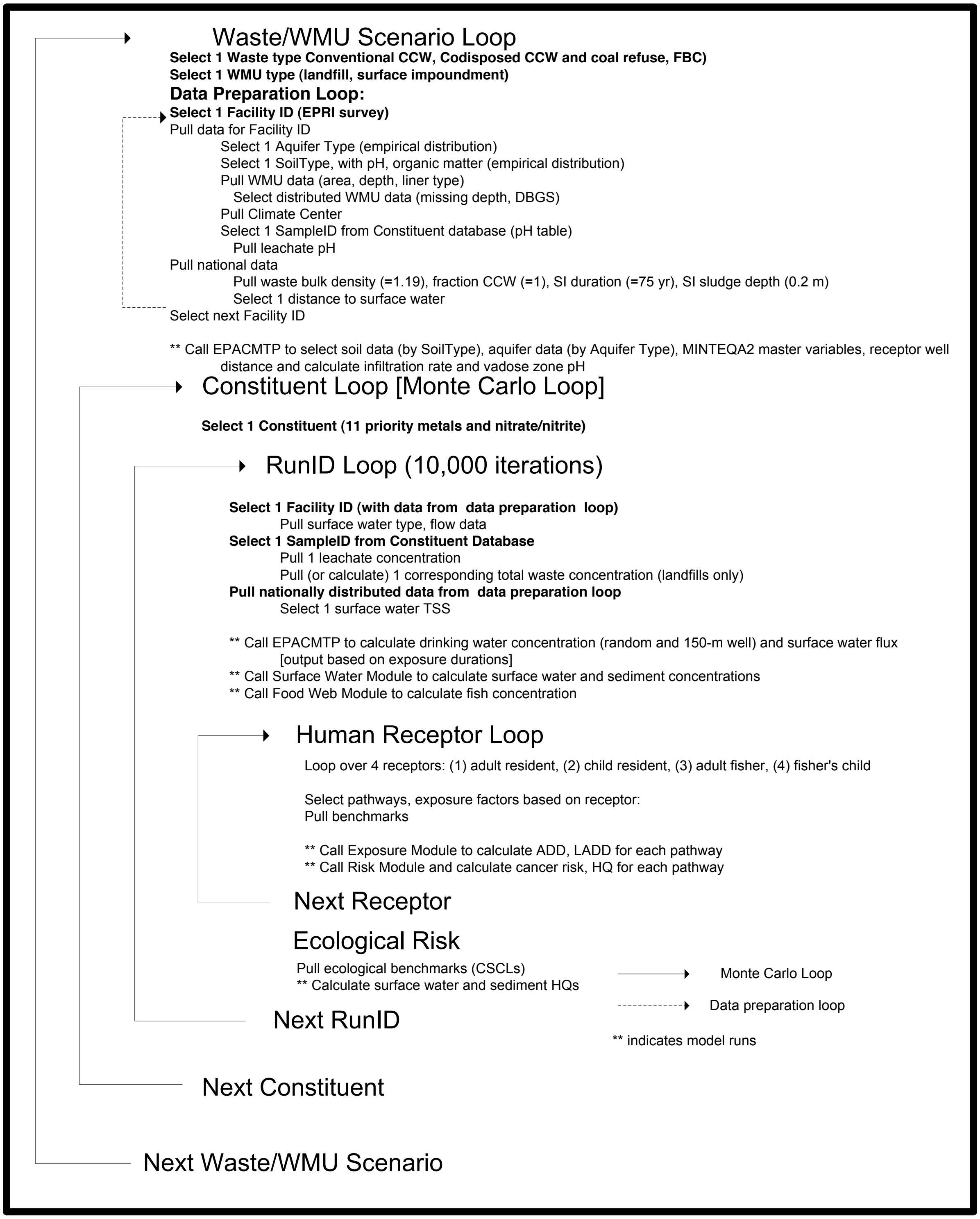

Figure 3-2. Monte Carlo looping structure.

3.3.3 Implementation of Probabilistic Approach

Table 3-6 lists the five waste disposal scenarios addressed in the full-scale analysis. FBC waste landfills were modeled and treated as a separate scenario in the analysis because of the limited number (7) of FBC landfill sites. Each waste disposal scenario modeled in the full-scale assessment included unlined, clay-lined, and composite-lined WMUs. Additional detail on these scenarios can be found in **Section 2.1** and **Appendix A**.

Table 3-6. CCW Waste Management Scenarios Modeled in Full-Scale Assessment

WMU Type	Waste Type
Conventional CCW and CCW Codisposed with Coal Refuse (main analysis)	
Landfill	Conventional CCW (fly ash, bottom ash, boiler slag, FGD sludge)
Landfill	Codisposed CCW and coal refuse
Surface impoundment	Conventional CCW
Surface impoundment	Codisposed CCW and coal refuse
FBC Waste (separate analysis)	
Landfill	FBC waste (fly ash and bottom [bed] ash)

To capture the national variation in waste management practices for the Monte Carlo analysis, an input database was created with approximately 10,000 iterations for each of the waste type/WMU combinations. This input database provided the source data for 10,000 iterations of the source modeling and the fate and transport modeling. **Figure 3-3** provides an overview of the process used to compile these data, which were organized into source data files. As shown in Figure 3-3, seven tasks, some parallel and some sequential, were required to construct these data files, one file for each waste management scenario.

Constructing the source data files for use in the probabilistic analysis involved first developing a 10,000-record data file for each waste type-WMU scenario. This was accomplished by selecting from the EPRI survey data the landfills and surface impoundments that manage each type of waste. Within a scenario, a list of the EPRI plants with that WMU type and waste type was repeated to produce around 10,000 records. For each record, site-based, regional, and national inputs were randomly selected from distributions developed to characterize the regional or national variability in these inputs. Each record in the source data files was identified by a model run identification number (RunID).

The EPRI survey provided most of the WMU data needed, including area, capacity, liner type, and waste type. Additional data were collected to characterize the height and depth below ground surface of typical CCW landfills and surface impoundments (see **Appendix B**).

The environmental setting in which waste disposal occurs was characterized based on the location of the 181 power plants used in the full-scale analysis. These locations were used to characterize climate, soils, aquifers, and surface water bodies at each site as follows (see **Appendix C** for details):

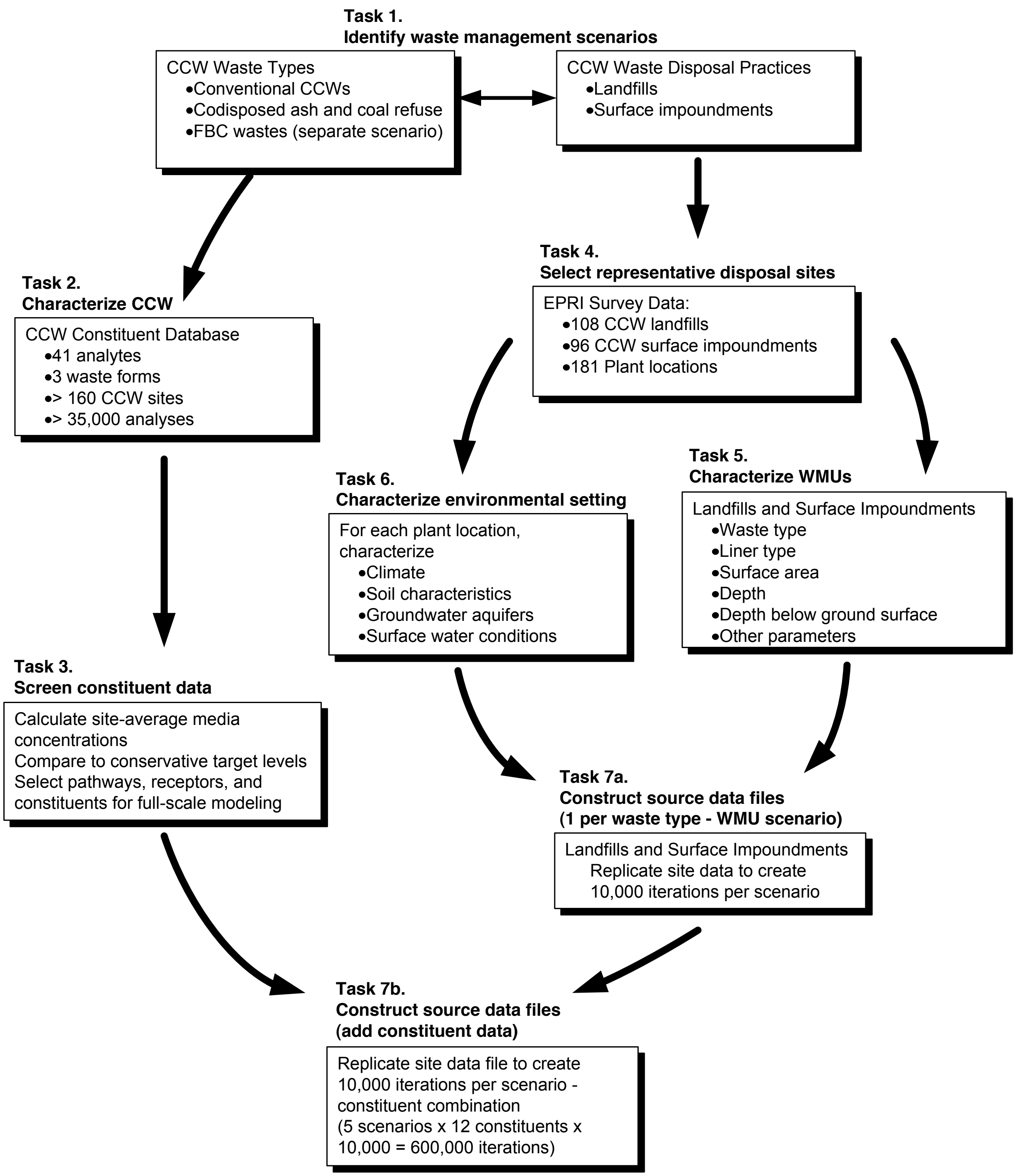

Figure 3-3. Process used to construct the Monte Carlo input database.

- Climatic data, including precipitation and infiltration rates, were collected by assigning each site to a nearby HELP climate center (see **Section 3.4.2.1** for a discussion of the HELP landfill infiltration model).

- Soil and aquifer type were collected within a 5-km radius of each site location to account for locational uncertainty for the WMUs (site location are often facility centroids or front gate locations).
- Surface water type and flows were collected using a geographic information system (GIS) to identify the nearest stream and by matching plants to the Permit Compliance System (PCS) database to get the stream segment for each plant's NPDES discharge point.

These site-based data were supplemented with regional data on surface water quality and with national distributions of receptor distances (i.e., distance to drinking water well and distance to nearest surface waterbody). **Appendix C** describes the site-based approach and data sources used for these site-specific, regional, and national-scale data collection efforts.

The five 10,000-record scenario-specific source data files were then combined with the CCW constituent data for each constituent in the appropriate waste type to develop the final source data files for each scenario. With 12 constituents modeled for most scenarios, this resulted in over 600,000 records in the final input data set.

3.4 Landfill Model

Releases from landfills were modeled using a landfill source-term model contained in EPACMTP. EPA has used EPACMTP and its predecessor models for almost 20 years to conduct groundwater risk assessments in support of regulations for land disposal of hazardous and nonhazardous wastes. In that context, EPACMTP has undergone numerous peer reviews, including multiple reviews by EPA's Science Advisory Board (SAB). Each of these reviews has supported and approved the use of this model for developing national regulations and guidance, including verification that the model and model code are scientifically sound and properly executed. Some of the more important reviews include

- A 1989 review by SAB of the component saturated zone (groundwater) model used in EPACMTP
- A 1993 review by EPA's Office of Research and Development (ORD) of EPACMTP for potential Hazardous Waste Identification Rule applications, which resulted in a number of improvements in the computational modules of EPACMTP
- A 1994 consultation with SAB on the use of EPACMTP for determination of dilution-attenuation factors for EPA's *Soil Screening Guidance*
- A 1994 review by expert modelers Dr. Fred Molz (Auburn University) and Mr. Chris Neville (SS Papadopoulos & Associates), who verified that the mathematical formulation of the model and the code verification testing are scientifically sound
- The peer-reviewed publication of EPACMTP in the *Journal of Contaminant Hydrology* (Kool et al., 1994)

- An in-depth review by SAB related to the use of EPACMTP in the proposed/draft 1995 Hazardous Waste Identification Rule (U.S. EPA, 1995)
- A 1999 peer review by leading modelers of the implementation of EPACMTP in EPA's multimedia, multiple exposure pathway, multiple receptor risk assessment (3MRA) model (U.S. EPA, 1999c)
- A 2003 SAB review of the 3MRA implementation of EPACMTP (SAB, 2004).

An overview and statement of assumptions for the landfill model is presented here, followed by a listing of inputs to the landfill source-term model and a brief discussion of the output generated by the model.

3.4.1 Conceptual Model

The landfill model treats a landfill as a permanent WMU with a rectangular footprint and a uniform depth (see **Figure 3-4**). If only the area is known (which is the case for the CCW landfills), the landfill source-term model assumes a square footprint. The model assumes that the landfill is filled with waste during the unit's operational life and that upon closure of the landfill, the waste is left in place and a final soil cover is installed.

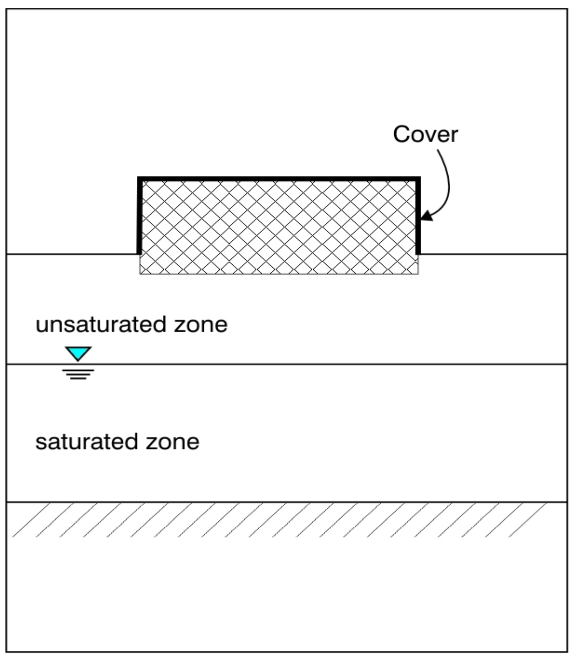

Figure 3-4. Conceptualization of a landfill in the landfill source-term model.

Three liner scenarios were modeled: a no-liner (unlined) scenario, a compacted clay liner, and a composite liner that combines a high-density polyethylene (HDPE) membrane with either geosynthetic or natural clays.

In the unlined scenario, waste is placed directly on local soils, either on grade or excavated to some design depth and without a leachate collection system. After the landfill has been filled to capacity, a 2-foot native soil cover (the minimum required by Subtitle D regulations) is installed and assumed to support vegetation.

In the clay liner scenario, waste is placed directly on a 3-foot compacted clay liner, which is installed on the local soils, either on grade or excavated to some design depth and without a leachate collection system. After the landfill has been filled to capacity, a 3-foot clay cover is installed and covered with 1 foot of loam to support vegetation and drainage. The hydraulic conductivity of both the liner and cover clays is assumed to be $1x10^{-7}$ cm/sec, the typical design specification for compacted clay liners (U.S. EPA, 1988c).

In the composite liner scenario, wastes are placed on a liner system that consists of a 60 mil HDPE membrane with either an underlying geosynthetic clay liner or a 3-foot compacted clay liner. A leachate collection system is also assumed to exist between the waste and the liner system. After the landfill has been filled to capacity, a 3-foot clay cover is assumed to be installed and covered with 1 foot of loam to support vegetation and drainage (U.S. EPA, 2002b).

As described in **Section 3.4.3** (and **Appendix B**), one of these three liner types was assigned to each CCW landfill or surface impoundment modeled based on the liner type data from the 1995 EPRI Survey (EPRI, 1997).

3.4.2 Modeling Approach and Assumptions

The starting point for the landfill source-term model simulation was the time when the landfill is closed (i.e., when the unit is filled with CCW).[11] As described in detail below, the full-scale analysis modeled contaminants leaching from CCW into precipitation infiltrating the landfill, which exits the landfills as leachate. Contaminant loss in leachate was taken into account at closure by subtracting the cumulative amount of contaminant mass loss that occurred during the unit's active life from the amount of contaminant mass present at the time of landfill closure. Loss calculations in the landfill source-term model continued after closure until the contaminant was depleted from the waste mass in the landfill. This is a conservative assumption, as some metal will not leach from the waste mass.

3.4.2.1 Infiltration and Leaching

The average rate at which water percolates through a landfill over time (the long-term infiltration rate) drives the leaching process in the landfill, which results from partitioning of the constituent from the waste into the infiltrating water. The methodology, assumptions, and data

[11] The simple landfill model used in this assessment cannot model a landfill as it is being filled prior to closure. Although leaching does occur during a landfill's operating life, risks from these releases are insignificant when compared to postclosure releases, given the long time it takes metal-bearing wastes to leach and reach peak concentrations in groundwater wells surrounding the landfill. For lined units, the liner system would be functional and governing during the active period of the landfill. For the unlined case, the landfill model assumes that the cap soils are no less permeable than the ambient soils around and under the landfill. So the majority of the cases would not have greater infiltration before closure. For these reasons, EPA does not believe that the additional risks from the preclosure period justify the additional complexity, data, and effort required to model an operating landfill.

used to determine infiltration rates for each CCW liner scenario were consistent with the approach used in EPA's Industrial D guidance, as described in Section 4.3 and Appendix A of the *EPACMTP Parameter/Data Background Document* (U.S. EPA, 2003a) and Section 4.2.2 of the *Industrial Waste Evaluation Model (IWEM) Technical Background Document* (U.S. EPA, 2002b). EPA developed the IWEM model as part of a guide for managing nonhazardous industrial wastes in landfills and surface impoundments (http://www.epa.gov/industrialwaste). To help ensure that it was technically sound, the model (including the liner scenarios and algorithms used in the CCW risk assessment) was developed with a large stakeholder working group, including representatives from industry. The model was also subjected to a peer review in 1999 (64 FR 54889–54890, October 8, 1999, *Peer Reviews Associated with the Guide for Industrial Waste Management*), and the model was updated and improved in response to those comments before its final release in 2003. That update included the addition of a more robust liner leakage database to support the existing algorithms for calculating infiltration rates through composite liner systems.

No-Liner (Unlined) Scenario. For the no-liner scenario, infiltration rates were selected from a database in EPACMTP that contains 306 infiltration rates already calculated using EPA's Hydrologic Evaluation of Landfill Performance (HELP) water balance model (Schroeder, et al., 1994a, b). HELP is a product of an interagency agreement between EPA and the U.S. Army Corps of Engineers Waterways Experiment Station, and was subjected to the Agency's peer and administrative review. All of the infiltration rates were calculated based on the single typical landfill design described in **Section 3.4.1**, with the only variables that changed between HELP simulations being the meteorological data associated with 102 nationwide climate centers and the type of cover soil applied at closure. Three cover soil categories representing coarse-grained soils, medium-grained soils, and fine-grained soils were used. The selection of an infiltration rate from the database depends on the type of cover soil selected for the landfill and the assignment of the landfill to a HELP climate center. The unlined HELP-derived infiltration rates are presented in U.S. EPA (2003a) by climate center. The assignment of HELP climate centers and soil categories to each CCW site modeled is described in **Appendix C**.

Clay Liner Scenario. The clay liner scenario is very similar to the unlined scenario in that previously calculated HELP infiltration rates for a single clay-lined, clay-capped landfill design were used. The scenario was based on a typical engineered compacted clay liner that is 3 feet thick with a design hydraulic conductivity of 1×10^{-7} cm/sec. The one difference from the unlined case is that the clay liner and cover control the rate of water percolation through the landfill and thus infiltration rate does not vary with cover soil (i.e., there is one clay liner infiltration rate per climate center). The clay liner HELP-derived infiltration rates are provided in U.S. EPA (2003a).

Composite Liner Scenario. Composite liner infiltration rates were compiled from monthly average leak detection system (LDS) flow rates for industrial landfill cells reported by TetraTech (2001). The liner configurations are consistent with the composite liner design assumptions presented in **Section 3.4.1** and are the same as those assumed for defaults in EPA's Industrial D landfill guidance (U.S. EPA, 2002b). The LDS flow rates were taken from 27 municipal landfill cells and used in the IWEM model (U.S. EPA, 2002b). As shown in **Table 3-7**, these LDS flow rates included 22 operating landfill cells and 5 closed landfill cells located in eastern United States: 23 in the northeastern region, 1 in the mid-Atlantic region, and 3 in the southeastern region. Each of the landfill cells is underlain by a geomembrane/ geosynthetic clay liner which consists of a high-density polyethylene geomembrane of thickness between 1 and 1.5 mm, overlying a 6-mm composite geosynthetic clay layer consisting of two geotextile outer layers with a uniform core of bentonite clay to form a hydraulic barrier. Each liner system is underlain by an LDS.

Table 3-7. Leak Detection System Flow Rate Data Used to Develop Landfill Composite Liner Infiltration Rates

Cell ID	Status	Flow Rate (m/y)	Location
G228	Operating	2.1E-04	Mid-Atlantic
G232	Operating	4.0E-04	Northeast
G232	Closed	7.3E-05	Northeast
G233	Operating	0	Northeast
G233	Closed	0	Northeast
G234	Operating	7.3E-05	Northeast
G234	Closed	0	Northeast
G235	Operating	1.5E-04	Northeast
G235	Closed	3.7E-05	Northeast
G236	Operating	3.7E-05	Northeast
G236	Closed	0	Northeast
G237	Operating	7.3E-05	Northeast
G238	Operating	0	Northeast
G239	Operating	7.3E-05	Northeast
G240	Operating	0	Northeast
G241	Operating	0	Northeast
G242	Operating	0	Northeast
G243	Operating	0	Northeast
G244	Operating	0	Northeast
G245	Operating	0	Northeast
G246	Operating	0	Northeast
G247	Operating	0	Northeast
G248	Operating	0	Northeast
G249	Operating	7.3E-05	Northeast
G250	Operating	2.2E-04	Southeast
G251	Operating	0	Southeast
G252	Operating	0	Southeast

Source: U.S. EPA (2002a); original data from TetraTech (2001).

As described in U.S. EPA (2002b), only a subset of the TetraTech (2001) flow rates were used to develop the composite liner infiltration rates. LDS flow rates for geomembrane/ compacted clay composite-lined landfill cells were not used in the distribution because compacted clay liners (including composite geomembrane/compacted clay liners) can release water during consolidation and contribute an unknown amount of water to LDS flow, which makes it difficult to determine how much of the LDS flow is due to liner leakage versus clay consolidation. Also, LDS flow rates from three geomembrane/geosynthetic clay lined-cells were not used. For one cell, postclosure flow rates were very high, and were more than twice as high as those recorded during the cell's operating period. Data were not used for two other cells because of inconsistencies with the data for the 27 landfill cells used to develop composite liner infiltration rates (U.S. EPA, 2002b). The composite liner infiltration rates were specified as an empirically distributed input to the landfill model (see U.S. EPA, 2003a).

3.4.2.2 Source Depletion and Mass Balance

For this assessment, the landfill source-term model represented releases from landfills as a finite source where the mass of a constituent in a landfill is finite and depleted over time by leaching. The landfill source-term model was set as a pulse source, where the leachate concentration is constant over a prescribed period of time and then goes to zero when the constituent is depleted from the landfill. A pulse source is appropriate for metals and other constituents whose sorption behavior is nonlinear. Because all but one (nitrate/nitrite) of the constituents addressed in the full-scale analysis were metals, releases from landfills were modeled as pulse sources.

For a pulse source, basic mass balance considerations require leaching from the landfill to stop when all of the constituent mass has leached from the landfill. For the constant concentration pulse source condition, the pulse duration is given by

$$TSOURC = \frac{CWASTE \times DEPTH \times FRACT \times CTDENS}{CZERO \times SINFIL} \tag{3-1}$$

where

TSOURC	=	Pulse duration (yr)
CWASTE	=	Constituent concentration in the waste (mg/kg)
DEPTH	=	Depth of landfill (m)
FRACT	=	Volume fraction of the landfill occupied by the waste (unitless)
CTDENS	=	Waste density (g/cm^3)
CZERO	=	Initial waste leachate concentration (mg/L)
SINFIL	=	Annual areal infiltration rate (m/yr).

The landfill source-term model uses the above relationship to determine the leaching duration. More details regarding the waste concentration and WMU parameters in Equation 3-1 are provided below and in **Appendices A** and **B**.

3.4.3 Landfill Model Input Parameters

Input parameters required by the landfill source-term model are discussed below. Additional details on how data for these inputs were collected for the CCW risk assessment are provided in **Appendix A** for leachate and waste concentrations and **Appendix B** for landfill dimensions and characteristics.

- **Landfill Area.** The model uses landfill area to determine the area over which infiltration rate occurs and, along with landfill depth and waste concentration, to calculate the total contaminant mass in the landfill. CCW landfill area data were obtained from the EPRI comanagment survey (EPRI, 1997). The landfill was assumed to be square.

- **Landfill Depth.** Landfill depth is one of several parameters used by the landfill source-term model to calculate the contaminant mass in the landfill. For CCW landfills, average waste depth was estimated by dividing landfill capacity by landfill area. CCW landfill capacity data were taken from the EPRI comanagement survey (EPRI, 1997).

- **Depth Below Grade.** The depth of the bottom of the landfill below the surrounding ground surface is used, along with depth to groundwater, to determine the thickness of the unsaturated zone. For CCW landfills, depth below grade was determined from a national distribution based on available measurements from a number of CCW landfills (see **Appendix B**).

- **Waste Fraction.** The landfills were assumed to be CCW monofills, which corresponds to a waste fraction of 1.0.

- **Waste Density.** The average waste bulk density, as disposed, is used to convert waste volume to waste mass. The waste bulk density for all CCW waste types was assumed to be 1.19 g/cm^3 (U.S. EPA, 1998b).

- **Leachate Concentration.** The concentration of waste constituents in leachate was assumed to be constant until all of the contaminant mass initially present in the landfill has leached out, after which the leachate concentration was assumed to be zero. The constant value used for leachate concentration is from EPA's CCW Constituent Database, described in **Appendix A**.

- **Waste Concentration.** In the finite-source scenario modeled, the total waste concentration is used, along with the waste bulk density and landfill area and depth, to determine the total amount of a constituent available for leaching. Measured total CCW concentrations were paired with leachate concentrations, as described in **Appendix A** and provided in **Attachment A-2**.

- **Liner Type.** The type of liner is used to determine the infiltration/leaching scenario used to calculate leachate flux from the landfill. **Table 3-8** shows the crosswalk used to assign one of the three liner scenarios to each facility based on the liner data in the 1995 EPRI survey (EPRI, 1997). **Attachment B-2** to **Appendix B** provides these assignments, along with the original EPRI liner type, for each CCW landfill facility modeled. One uncertainty in these liner assumptions is how representative the EPRI survey data are of current conditions at coal combustion facilities.

Table 3-8. Crosswalk Between EPRI and CCW Source Model Liner Types

EPRI Liner Type	Model Liner Code	Description
Compacted ash	0	no liner
Compacted clay	1	clay

(continued)

Crosswalk Between EPRI and CCW Source Model Liner Types (continued)

EPRI Liner Type	Model Liner Code	Description
Composite clay/membrane	2	composite
Double	2	composite
Geosynthetic membrane	2	composite
None/natural soils	0	no liner

3.4.4 Model Outputs

For each year in the simulation, the landfill source-term model uses the average annual leachate concentration and infiltration rate to calculate a constituent flux through the bottom of the landfill. This time series was used as an input for the EPACMTP unsaturated zone model.

3.5 Surface Impoundment Model

Releases from surface impoundments were modeled using a surface impoundment source-term model contained in EPACMTP. An overview and statement of assumptions for the surface impoundment model are presented here, followed by a listing of inputs to the surface impoundment source-term model and a brief discussion of the output generated by the model. The primary differences between the treatment of landfills and surface impoundments are (1) the integration of the surface impoundment source term into the unsaturated flow solution, and (2) clean closure of the impoundment after the operating period is over.

3.5.1 Conceptual Model

The surface impoundment model treats a surface impoundment as a temporary WMU with a prescribed operational life. Unlike the landfill model, clean closure is assumed; that is, at the end of the unit's operational life, the model assumes that all wastes are removed and there is no further release of waste constituents to groundwater. Although this simplifying assumption limits the length of potential exposure, and is not consistent with the practice to close CCW surface impoundments with these wastes in place, the peak annual leachate concentrations on which the CCW risk results are based are not likely to be affected, because they are highest when the surface impoundment is in operation due to the higher hydraulic head in an operating impoundment, which drives leachate into the underlying soil with greater force than infiltration after the impoundment is covered and closed. This higher head results in a greater flux of contaminants to groundwater during the active life of the surface impoundment, especially in unlined units. These assumptions are discussed further in **Section 3.5.3.**

Following the unit's closure, the surface impoundment model assumes that the contaminated liquid and sediment in the surface impoundment are replaced by uncontaminated liquid and sediment with otherwise identical configurations and properties. The contaminants that have migrated to the unsaturated zone during operation continue to migrate towards the water table with the same infiltration rate as during operation. By continuing infiltration after the wastes are removed, the infiltration through the surface impoundment unit can be modeled as a single steady-state flow regime until concentrations in groundwater are no longer affected by constituents released from the surface impoundment during its operation.

The EPACMTP surface impoundment model assumes a square footprint and a constant ponding depth during the impoundment's operational life (**Figure 3-5**). For an unlined impoundment, the model assumes that while the impoundment is in operation, a consolidated layer of sediment accumulates at the bottom of the impoundment. The leakage (infiltration) rate through the unlined impoundment is a function of the ponding depth in the impoundment and the thickness and effective permeability of the consolidated sediment layer at the bottom of the impoundment. The rate of leakage is constrained to ensure that there is not a physically unrealistic high rate of leakage, which would cause groundwater mounding beneath the unit to rise above the ground surface. Underlying the assumption of a constant ponding depth, the surface impoundment source-term model assumes that wastewater in the impoundment is continually replenished while the impoundment is in operation. It also assumes, from the beginning of the unit's operation, that the sediment is always in equilibrium with the wastewater (i.e., the presence of sediment does not alter the concentration of leachate). Accordingly, the surface impoundment source-term model also assumes that the leachate concentration is constant during the impoundment operational life and equal to the concentration in the porewater in the sediments at the bottom of the impoundment.

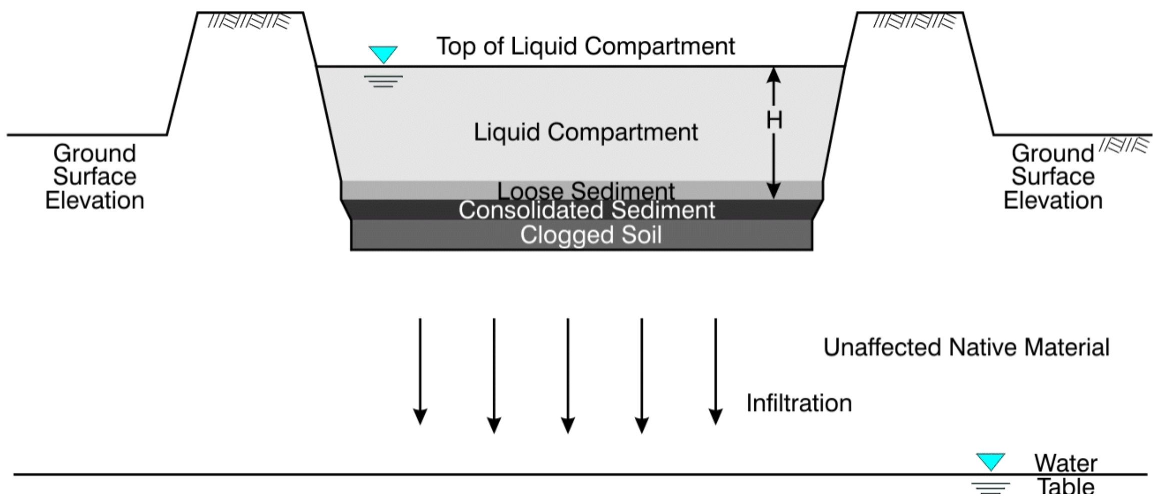

Figure 3-5. Schematic cross-section view of surface impoundment.

Three liner scenarios were modeled: a no-liner (unlined) scenario, a compacted clay liner, and a composite liner.

In the unlined scenario, wastewater is placed directly on local soils and the depth of water is constant over the entire life of the impoundment, pre- and post-closure. As described above, sediments accumulate and consolidate at the bottom of the impoundment and migrate into the underlying native soils, where they clog pore spaces and provide some barrier to flow. The surface impoundment model assumes that the thickness of the consolidated sediments is equal to one-half of the total sediment thickness, which is an input to the model. The sediment thickness was assumed to be 0.2 m for all simulations. The model also assumes that the thickness of the clogged region of native soils is always 0.5 m and has a hydraulic conductivity 10 percent of that of the native soil underlying the impoundment.

In the clay liner scenario, wastewater is placed on a compacted clay liner, which is installed on the local soils. The assumptions for an unlined impoundment also apply to the compacted clay liner scenario, except that a compacted clay liner filters out the sediments that clog the native soils in the unlined case, so the effect of clogging the native materials is not included in the calculation of the infiltration rate. The thickness of the compacted clay liner was assumed to be 3 feet and the hydraulic conductivity was assumed to be $1x10^{-7}$ cm/sec (U.S. EPA, 1988c).

In the composite liner scenario, wastewater is placed on a synthetic membrane with an underlying geosynthetic or natural compacted clay liner with a hydraulic conductivity of $1x10^{-7}$ cm/sec. The membrane liner was assumed to have a number of pinhole leaks of uniform size (6 mm^2). The distribution of leak densities (expressed as number of leaks per hectare) was compiled from 26 leak density values reported in TetraTech (2001), the best available data on liner leaks. These leak densities are based on liners installed with formal construction quality assurance programs. The 26 sites with leak density data are mostly located outside the United States: 3 in Canada, 7 in France, 14 in the United Kingdom, and 2 in unknown locations; EPA assumed that these are representative of U.S. conditions. The WMUs at these sites (8 landfills, 4 surface impoundments, and 14 of unknown type) are underlain by a layer of geomembrane with a thickness varying from 1.14 mm to 3 mm. The majority of the geomembranes (23 of 26) are made from HDPE, and the remaining 3 are made from prefabricated bituminous geomembrane or polypropylene. One of the sites has a layer of compacted clay liner beneath the geomembrane; however, for 25 of the 26 sites, material types below the geomembrane layer are not reported. The empirical distribution used in the analysis can be found in IWEM (U.S. EPA, 2002b), along with a table showing details about the 26 liners used to develop the distribution.

3.5.2 Modeling Approach and Assumptions

Figure 3-5 illustrates a compartmentalized surface impoundment with stratified sediment. Shown in the figure are the liquid compartment, the sediment compartment (with loose and consolidated sediments), and the unsaturated zone (with clogged and unaffected native materials). The model assumes that all sediment layer thicknesses remain unchanged throughout the life of the unit.

The EPACMTP surface impoundment model uses the unsaturated zone flow model to calculate the infiltration rate out of the bottom of the impoundment. This model is designed to simulate steady-state downward flow through an unsaturated (vadose) zone consisting of one or more soil layers. Steady-state means that the rate of flow does not change with time. In the case of flow out of an unlined surface impoundment, the model simulates flow through a system consisting of three layers: a consolidated sediment layer, a clogged soil layer, and a native soil layer.

The native unsaturated soil extends downward to the water table. The steady-state infiltration rate out of the surface impoundment is driven by the head gradient between the water ponded in the impoundment and the head at the water table. The pressure head at the top of the consolidated sediment layer is equal to the water depth in the impoundment plus the thickness of the unconsolidated sediment.

The *EPACMTP Technical Background Document* (U.S. EPA, 2003c) describes the algorithms used in this model to calculate the infiltration rate from surface impoundment units, and discusses in detail the maximum allowable infiltration rate based on the groundwater mounding condition. This information is summarized here.

The EPACMTP surface impoundment source-term model calculates infiltration through the accumulated sediment at the bottom of an impoundment, accounting for clogging of the native soil materials underlying the impoundment, liner conditions, and mounding due to infiltration. The modeled infiltration is governed by the depth of liquid in the impoundment and the following limiting factors:

- **Effective hydraulic conductivity and thickness of the consolidated sediment layer.** As sediment accumulates at the base of the impoundment, the weight of the liquid and upper sediments tends to compress (or consolidate) the lower sediments. The consolidation process reduces the hydraulic conductivity of the sediment layer, and the layer of consolidated sediment will act as a restricting layer for flow out of the impoundment. By contrast, the layer of loose, unconsolidated sediment that overlies the consolidated sediment layer is assumed not to restrict the flow rate out of the unit, so it is not explicitly considered in the surface impoundment flow model.

- **Effective hydraulic conductivity of the clogged native material.** As liquids infiltrate soil underlying the impoundment, suspended particulate matter accumulates in the soil pore spaces, reducing hydraulic conductivity and lowering infiltration rates.

- **Effective hydraulic conductivity and thickness of a clay liner.** When the surface impoundment is underlain by a compacted clay liner, the rate of infiltration is also determined by simulating flow through a three-layer system, substituting the characteristics of the clay liner for those of the clogged soil layer.

- **Leak rate of a composite liner.** For cases where the surface impoundment is underlain by a composite liner (a geomembrane underlain by a low permeability liner such as a compacted clay liner or a geosynthetic clay liner), the surface impoundment source-term model uses a modified equation of Bonaparte et al. (1989) to calculate the infiltration rate. The equation uses, among other inputs, the head generated by the water and unconsolidated sediments in the unit, a leak density selected from an empirical distribution derived from a TetraTech (2001) study of liner leakage, a uniform leak size of 6 mm^2, and an assumed hydraulic conductivity of 1×10^{-7} cm/sec for the 3 feet of underlying compacted clay material.

- **Limitations on maximum infiltration rate from mounding.** If the calculated infiltration rate exceeds the rate at which the saturated zone can transport the groundwater, the groundwater level will rise into the unsaturated zone. The model accounts for groundwater mounding when calculating the infiltration rate from the surface impoundment unit and, if necessary, constrains the value to ensure that the groundwater mound does not rise to the bottom of the surface impoundment unit.

3.5.3 Surface Impoundment Model Input Parameters

Input parameters required by the surface impoundment source-term model are discussed below. Additional details on how data for these inputs were collected for the CCW risk assessment are provided in **Appendix A** for waste concentrations and **Appendix B** for surface impoundment dimensions and characteristics.

- **Surface Impoundment Area.** The model uses surface impoundment area to determine the area over which infiltration occurs. CCW surface impoundment area data were obtained from the EPRI comanagement survey (EPRI, 1997). The impoundment was assumed to be square.

- **Areal Infiltration Rate.** The surface impoundment leachate infiltration rate (or flux) is computed internally by the surface impoundment source-term model, as described in **Section 3.5.2**.

- **Depth Below Grade.** The depth of the bottom of the impoundment below the surrounding ground surface is used, along with depth to groundwater, to determine the thickness of the unsaturated zone beneath the impoundment. For CCW impoundments, depth below grade was sampled from an empirical distribution based on available measurements from a number of CCW surface impoundments (see **Appendix B**).

- **Operating Depth.** The operating (or ponding) depth is the long-term average depth of wastewater and sediment in the impoundment, measured from the base of the impoundment. For CCW surface impoundments, depth was estimated by dividing impoundment capacity by impoundment area. CCW impoundment capacity data were taken from the EPRI comanagement survey (EPRI, 1997).

- **Total Thickness of Sediment.** By default, EPACMTP models unlined surface impoundments with a layer of "sludge" or sediment above the base of the unit. The sediment layer is divided into two sublayers: an upper, loose sediment sublayer and a lower, consolidated sediment sublayer. The consolidated sediment has a relatively low hydraulic conductivity and acts to impede flow. The calculated infiltration rate is inversely related to the thickness of the consolidated sediment sublayer. A thinner consolidated sediment layer will result in a higher infiltration rate and a greater rate of constituent loss from the impoundment. The surface impoundment source-term model uses the total sediment thickness as an input parameter and assumes that it consists of equal thicknesses of loose and consolidated material. Because data were not available on CCW sediment layer thicknesses, the CCW risk assessment used the Tier 1 IWEM model assumption: a total (unconsolidated plus consolidated) sediment layer thickness of 0.2 meters (U.S. EPA, 2002b). It is not known how representative this assumption is with respect to unlined CCW surface impoundments, but it is reasonable to assume that a sediment layer would accumulate and restrict flow from the bottom of a CCW impoundment.

- **Distance to the Nearest Surface Water Body.** The distance to the nearest waterbody is used to determine the location of a fully penetrating surface waterbody at which groundwater mass and water fluxes will be calculated and reported. The distance to the nearest surface waterbody is also used as a surrogate for the distance to the nearest point at which the water table elevation is kept at a fixed value. That distance is used to calculate the estimated height of groundwater mounding underneath the impoundment to ensure that excessively high infiltration rates, which may be calculated for deep, unlined impoundments, do not occur. If necessary, the model reduces the infiltration rate to ensure the predicted water table does not rise above the ground surface. For the CCW sites, distance to surface water was sampled from an empirical distribution developed from aerial photo measurements at 59 coal-fired power plants with onsite landfills or surface impoundments (**Appendix C**).

- **Leachate Concentration.** The annual average leachate concentration is modeled as a constant concentration pulse with a defined duration. For a particular model run, the leachate concentration was assumed to be constant during the operation of the unit; there is no reduction in leachate concentration until the impoundment ceases operation. Leachate concentrations for CCW impoundments were obtained by waste type from surface impoundment porewater data from EPA's CCW Constituent Database, as described in **Appendix A**.

- **Source Leaching Duration.** For surface impoundments, the addition and removal of waste during the operational life period are more or less balanced, without significant net accumulation of waste. In the finite-source implementation used for CCW surface impoundments, the duration of the leaching period is assumed to be the same as the operational life of the surface impoundment. Based on industry data (see **Appendix B**) for CCW surface impoundments, EPA used a high-end (90th percentile) fixed surface impoundment operating life of 75 years. A high-end value was appropriate because CCW surface impoundments are typically closed with waste in place, while the surface impoundment source-term model assumes clean closure (waste removed). In addition, operating life is not a particularly sensitive parameter in this analysis: the difference between the 50th percentile value (40 years) and the 90th percentile value used (75 years) is less than a factor of two.

- **Liner Type, Thickness, Hydraulic Conductivity, and Leak Density.** The type of liner is used to calculate leachate flux from the impoundment. To assign one of the three liner scenarios to each facility in the EPRI survey (EPRI, 1997), EPA used the same crosswalk as for landfills (see Table 3-7). Attachment B-2 to **Appendix B** provides these assignments, along with the original EPRI liner type, for each CCW surface impoundment modeled.

As with IWEM (U.S. EPA, 2002b), clay liners were assumed to be 3 feet thick and to have a constant hydraulic conductivity of 10^{-7} cm/s, reflecting typical design specifications for clay liners. For composite liners, infiltration was assumed to result from defects (pin holes) in the geomembrane. The pin holes were assumed to be circular and uniformly sized (6 mm^2). The leak density was defined as the average number of circular pin holes per square meter and was obtained from a study of industrial surface impoundment membrane liner leak rates by Tetra Tech (2001).

3.5.4 Surface Impoundment Model Outputs

For each year in the simulation, the surface impoundment source-term model uses the average annual leachate concentration and calculates an infiltration rate to estimate the constituent flux through the bottom of the impoundment. This time series was used as an input to the EPACMTP unsaturated zone model.

3.6 Groundwater Model

This section describes the methodology and the models that were used to predict the fate and transport of chemical constituents in soil and groundwater to determine impacts on drinking water wells and surface water that is connected to groundwater. The surface water model used to address the groundwater-to-surface water pathways is described in **Section 3.7**.

3.6.1 Conceptual Model

The groundwater pathway was modeled to determine the receptor well concentrations and contaminant flux to surface water resulting from the release of waste constituents from a WMU. The release of a constituent occurs when liquid percolating through the WMU becomes leachate as it infiltrates from the bottom of the WMU into the subsurface. For landfills, the liquid percolating through the landfill is from water in the waste and precipitation. For surface impoundments, the percolating liquid is primarily the wastewater managed in the impoundments.

Waste constituents dissolved in the leachate are transported through the unsaturated zone (the soil layer under the WMU) to the underlying saturated zone (i.e., groundwater). Once in the groundwater, contaminants are transported downgradient to a hypothetical receptor well or waterbody. For this analysis, the groundwater concentration was evaluated for two receptor locations, each at a specified distance from the downgradient edge of the WMU:

- The intake point of a hypothetical residential drinking water well (the receptor well), which was used for the residential drinking water pathway
- A nearby river, stream, or lake, which is modeled as a fully penetrating surface waterbody and was used for the fish ingestion and ecological pathways.

Figure 3-6 shows the conceptual model of the groundwater fate and transport of contaminant releases from a WMU to a downgradient receptor well.

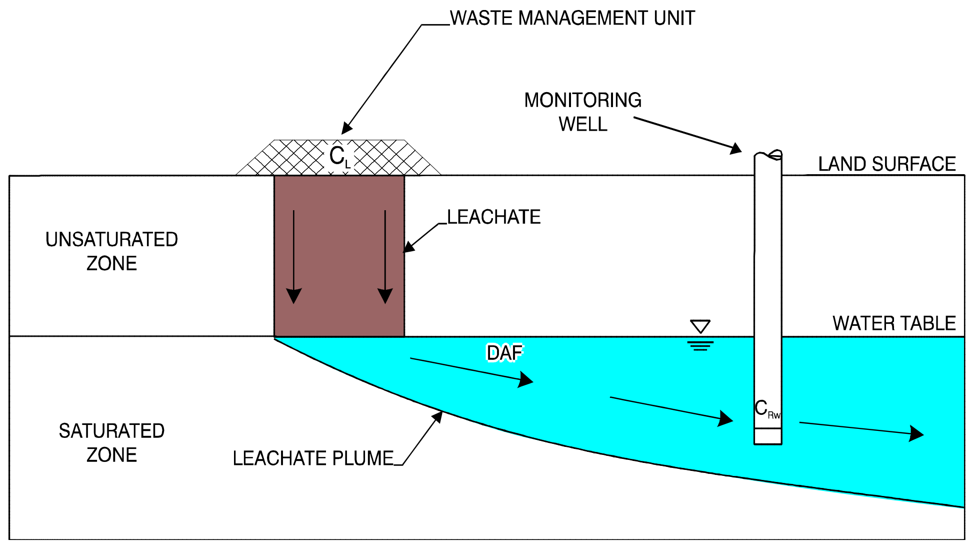

Figure 3-6. Conceptual model of the groundwater modeling scenario.

3.6.2 Modeling Approach and Assumptions

The transport of leachate from the WMU through the unsaturated and saturated zones was modeled using EPACMTP (U.S. EPA, 1996a, 1997a, 2003a,c,d). EPACMTP is a composite model consisting of two coupled modules: (1) a one-dimensional module that simulates infiltration and dissolved contaminant transport through unsaturated soils, and (2) a 3-dimensional saturated zone flow and transport module to model groundwater fate and transport. EPACMTP has been used by EPA to make regulatory decisions for wastes managed in land disposal units (including landfills and surface impoundments) for a number of solid waste and hazardous waste regulatory efforts, and as noted earlier, has undergone extensive peer review. EPACMTP simulates the concentration arriving at a specified receptor location (such as a well or stream).

The primary subsurface transport mechanisms modeled by EPACMTP are (1) downward (1-dimensional) movement along with infiltrating water flow in the unsaturated zone soils and (2) movement and dispersion along with ambient groundwater flow in the saturated zone. EPACMTP models soils and aquifer as uniform porous media and does not account for preferential pathways such as fractures and macropores or for facilitated transport, which may affect migration of strongly sorbing constituents such as metals.

In the unsaturated zone, flow is gravity driven and prevails in the downward direction. Therefore, the flow is modeled in the unsaturated zone as one-dimensional in the vertical direction. The model also assumes that transverse (sideways) dispersion (from both mechanical and molecular diffusion processes) is negligible in the unsaturated zone because the scale of lateral migration due to transverse dispersion is negligible compared with the size of the WMUs. This assumption is also environmentally protective because it allows the leading front of the contaminant plume to arrive at the water table with greater peak concentration in the case of a finite source.

In the saturated zone, the EPACMTP model assumes that movement of chemicals is driven primarily by ambient groundwater flow, which in turn is controlled by a regional hydraulic gradient and hydraulic conductivity in the aquifer formation. The model does take into account the effects of infiltration through the WMU, as well as regional recharge into the aquifer around the WMU. Infiltration through the WMU increases the groundwater flow in all directions under and near the WMU and may result in groundwater mounding. This 3-dimensional flow pattern enhances the horizontal and vertical spreading of the contaminant plume. The effect of recharge (outside the WMU) is to cause a downward (vertical) movement of the contaminant plume as it travels along groundwater flow direction. In addition to advective movement with the groundwater flow, the model simulates mixing of contaminants with groundwater due to hydrodynamic dispersion, which acts along the groundwater flow direction, as well as vertically and in the horizontal transverse direction.

To model sorption of CCW constituents in the unsaturated zone, soil-water partitioning coefficients (K_d values) for metal constituents were selected from nonlinear sorption isotherms generated from the equilibrium geochemical speciation model MINTEQA2 (U.S. EPA, 2001a). Chemicals with low K_d values will have low retardation factors, which means that they will move at nearly the same velocity as the groundwater. Chemicals with high K_d values will have high retardation factors and may move many times slower than groundwater. As described in **Appendix D**, CCW-specific partition coefficients were developed with MINTEQA2 considering CCW leachate chemistry, including the highly alkaline chemistries that are characteristic of some CCWs. Although a complete listing of all K_d values available in the MINTEQA2 isotherms used in these analyses would not be practicable, Table D-1 presents a sampling of the K_d values used.

MINTEQA2 is a product of ORD, and like EPACMTP, has a long history of peer- and SAB-review during its development, use, and continued improvement for regulatory support over the past two decades. These reviews largely focused on the use of MINTEQA2 to generate sorption isotherms for metals for EPACMTP, which is how it was used in the CCW risk assessment. Two of the more recent peer reviews include one for application within the 3MRA model (U.S. EPA, 1999d) and a review of its use and application to RCRA rulemaking and guidance support, including revisions made to the model to support IWEM and the CCW rulemaking efforts (U.S. EPA, 2003f). In the latter review, three experts found that the revisions made to the MINTEQA2 model were appropriate, but also suggested further improvements in how the model addresses environments with highly alkaline leachate (such as CCW sites). As explained in **Appendix D**, these comments were addressed in this application of MINTEQA2 to CCW waste transport by the development of sorption isotherms that are specific to geochemical conditions encountered in CCW landfills and surface impoundments.

3.6.3 Model Inputs and Receptor Locations

EPACMTP requires information about soil and aquifer properties as model inputs. For soils, EPACMTP uses soil texture to generate consistent hydrological properties for the unsaturated zone model, and soil pH and organic matter to select appropriate sorption coefficients to model contaminant sorption in the soil. As described in **Appendix C, Attachment C-2**, site-specific soil texture, pH, and organic carbon data were collected around each site from the STATSGO soils database. Similarly, the hydrogeological setting around each

WMU was used to select appropriate aquifer conditions from EPACMTP's Hydrogeologic Database (HGDB; see **Appendix C**).

Recharge is water percolating through the soil to the aquifer outside the footprint of the WMU. The recharge rate is determined by precipitation and soil texture. For the CCW landfills and surface impoundments, recharge rates were selected by soil texture and meteorological station assignment from a database of HELP model–derived recharge rates for climate stations across the country that is included in the EPACMTP input files. Further details about how these rates were determined and other options for determining recharge rates outside of the EPACMTP model can be found in the *EPACMTP Parameters/Data Background Document* (U.S. EPA, 2003a).

One of the most important inputs for EPACMTP is receptor location, which for this risk assessment includes residential drinking water wells and surface water bodies. **Figure 3-7** shows a schematic of how residential well drinking water intakes were defined in terms of their radial downgradient distance from the WMU and the angle off the contaminant plume centerline. The shaded areas in Figure 3-7 represent the horizontal extent of the contaminant plume.

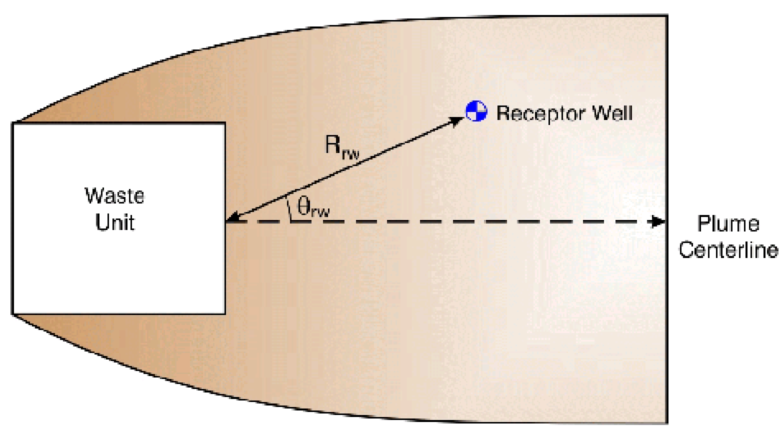

Figure 3-7. Schematic plan view showing idealized maximum lateral contaminant plume extent and receptor well location.

In this analysis, receptor wells were located randomly within the contaminant plume, as follows:

- Because residential well distance data are not available for CCW WMUs, EPA based the radial downgradient distance on a nationwide distribution of the nearest downgradient residential or municipal wells from a survey of Subtitle D municipal solid waste landfills (U.S. EPA, 1988a; see **Appendix C**). The maximum radial distance in this survey was 1 mile. EPA believes that this distribution is protective of CCW WMUs. A well distance, (R_{rw} in Figure 3-7) was randomly selected from this distribution.

- The angle off the contaminant plume centerline (θ_{rw} in Figure 3-7) was selected from a uniform distribution ranging from 0 to 90 degrees.

- The receptor well was located based on R_{rw} and θ_{rw} as shown in Figure 3-7.
- The maximum lateral extent of a groundwater plume, based on lateral dispersion, was calculated using the dimensions of the WMU sampled for that simulation, a sampled value for lateral dispersivity in the groundwater, and the downgradient distance to the receptor well.
- If the receptor well was located *inside* the idealized maximum plume extent, the shaded portion in Figure 3-7 (the distance from the well to the centerline was less than the lateral extent of the calculated in the previous step), the well location was used for that simulation. Otherwise, new values for R_{rw} and θ_{rw} were sampled and the process repeated for the same WMU. The depth of the well intake point was based on a uniform distribution with limits of 0 (i.e., well at the water table) to 10 meters (or the total saturated aquifer thickness if the aquifer is less than 10 meters thick).

The location of the surface waterbody intercepting groundwater flow was specified for each flow and transport simulation. The waterbody was constrained to lie across the contaminant plume centerline and perpendicular to the groundwater flow direction. The waterbody is assumed to fully penetrate the aquifer thickness. Downgradient distance to the surface waterbody was determined from an empirical distribution of distances measured for CCW landfills and surface impoundments (see **Appendix C**), which was randomly sampled to develop the distances used in EPACMTP to calculate groundwater concentrations at those distances in the Monte Carlo analysis.

3.6.4 Groundwater Model Outputs

The output of EPACMTP is a prediction of the contaminant concentration arriving at a downgradient groundwater receptor location (either a well or a surface water body). Because a finite-source scenario was used, the concentration is time-dependent. A maximum time-averaged concentration was calculated for each constituent across the exposure duration selected in each Monte Carlo iteration.

3.7 Surface Water Models

For the groundwater-to-surface-water pathway, chemical contaminants leach out of WMUs and into groundwater, and this contaminated groundwater then discharges into a surface waterbody through groundwater discharge. Once in the waterbody, the continued fate and transport of the contaminants is modeled with a surface water model, which uniformly mixes the contaminants in a single stream segment. Surface water flows in and out of the stream segment. Surface water flowing into the stream segment is assumed to have zero constituent concentration, and surface water flowing out has nonzero constituent concentrations due to the groundwater contamination. The primary simplifying assumptions in EPACMTP are as follows: (1) the groundwater–surface water interface is assumed to be perpendicular to the regional groundwater flow direction; (2) the interface is infinite in its lateral extent so as to intercept the entire width of the dissolved contaminant plume; and (3) the intercepting surface water body fully penetrates the saturated region of the subsurface. Therefore, all of the mass in the contaminated groundwater is available to be transferred to the surface water model. If stream flow is greater than the available groundwater flow, then all of the mass available in the groundwater is assumed to be transferred to the surface waterbody. It is important to note that while a mass transfer is assumed to take place between the two systems, mass is not actually removed from the groundwater—it is still available to be observed at a receptor well placed beyond the groundwater-surface water interface.

To ensure that an unrealistic transfer of mass from the contaminated groundwater into the surface waterbody does not occur, the available groundwater flow is compared to the stream flow. If the groundwater flow exceeds the stream flow, all of the stream flow is assumed to be from groundwater discharge and the total concentration in the stream is equal to the groundwater concentration.

The waterbody considered in the CCW risk assessment is a river, stream, or lake located downgradient of the WMU. As described in **Appendix C**, the flow characteristics and dimensions for this waterbody were determined by site-specific stream flow data, the width of the groundwater contaminant plume as it intersects the waterbody, and established relationships between flow and stream depth. The stream segment modeled in this assessment was assumed to be homogeneously mixed.

Simple equilibrium partitioning models were used to estimate contaminant concentrations in the water column, suspended and bed sediments (see **Section 3.7.1**), and aquatic organisms (see **Section 3.7.2**). Special modeling provisions for aluminum are described in **Section 3.7.3**.

3.7.1 Equilibrium Partitioning Model

The primary surface water model used to estimate groundwater impacts on waterbodies is a simple steady-state equilibrium-partitioning model adapted from models in EPA's Indirect Exposure Methodology (IEM; U.S. EPA, 1998c) and Human Health Risk Assessment Protocol (HHRAP; U.S. EPA, 1998d). This model is based on the concept that dissolved and sorbed concentrations can be related through equilibrium partitioning coefficients. This model was used for all constituents except aluminum, which was modeled based on a solubility approach (see **Section 3.7.3**). Although these models have not been specifically peer reviewed in this application, they have been subject to the Agency's peer review process as part of the development of the IEM and HHRAP.

The model partitions the total mass of chemical contaminant in the waterbody into four compartments:

- Constituents dissolved in the water column
- Constituents sorbed onto suspended solids
- Constituents sorbed onto sediment particles at the bottom of the waterbody
- Constituents dissolved in porewater in the sediment layer.

Table 3-9 provides the partitioning coefficients used by the surface water model to estimate contaminant partitioning between water and suspended solids in the water column and between sediment and porewater in the sediment layer. These distributions were derived from published empirical data as described in U.S. EPA (1999b).

Table 3-9. Sediment/Water Partition Coefficients: Empirical Distributions[a]

Chemical	Distribution Type	Minimum	Mean	Maximum	SD
Aluminum	not used				
Antimony	log normal	0.6	3.6	4.8	1.8
Arsenic	log normal	1.6	2.4	4.3	0.7
Barium	log normal	0.9	2.5	3.2	0.8
Boron	log normal	−0.5	0.8	1.4	0.5
Cadmium	log normal	0.5	3.3	7.3	1.8
Cobalt	log normal	2.2	3.9	5.3	0.8
Lead	log normal	2.0	4.6	7.0	1.9
Molybdenum	log normal	1.3	2.2	3.2	0.9
Selenium IV	log normal	1.0	3.6	4.0	1.2
Selenium VI	log normal	−1.4	0.6	3.0	1.2
Thallium	log normal	−0.5	1.3	3.5	1.1
Total Nitrate Nitrogen	constant	0	0	0	0

Source: U.S. EPA (1999b).
SD = standard deviation.
[a] All values are log values.

Following calculation of the constituent loading and loss rates, the surface water model estimates steady-state, equilibrium waterbody contaminant concentrations in each compartment using equations presented in Attachment E-1 to **Appendix E**. For evaluating risks to human health from fish consumption, the model calculates waterbody concentrations using groundwater loadings that are explicitly averaged over the exposure period for the each human receptor (i.e., adult and child fishers). These average waterbody concentrations are then used to calculate fish concentrations as described in **Section 3.7.2**. Ecological risks were based on waterbody concentrations calculated using the peak annual groundwater loading value from EPACMTP. The equilibrium–partitioning model, as implemented, is conservative because there are no loss mechanisms (e.g., burial) for any of the constituents.

3.7.2 Aquatic Food Web Model

An aquatic food web model was used to estimate the concentration of CCW constituents that accumulate in fish. This risk assessment assumed that fish are a food source for a recreational fisher. Trophic level three (TL3) and four (TL4) fish[12] were considered in this analysis because most of the fish that humans eat are T4 fish (e.g., salmon, trout, walleye, bass) and medium to large T3 fish (e.g., carp, smelt, perch, catfish, sucker, bullhead, sauger). The aquatic food web model has been peer reviewed as part of the 3MRA model development effort (see http://www.epa.gov/osw/hazard/wastetypes/wasteid/hwirwste/peer03/aquatic/aqtfoods.pdf).

12 TL3 fish are those that consume invertebrates and plankton; TL4 fish are those that consume other fish.

The aquatic food web model calculates the concentration in fish from the concentration calculated for the waterbody downgradient from the CCW disposal site. The contaminants in the water column consist of dissolved constituents and constituents sorbed to suspended solids. For all constituents, the contaminant concentrations in fish were calculated from the total waterbody concentration (i.e., dissolved plus sorbed to suspended solids) using BCFs, which are presented in **Table 3-10**. The equations used to model fish tissue concentrations are provided in Attachment E-2 to **Appendix E**.

Table 3-10. Bioconcentration Factors for Fish

CAS	Chemical	TL3 Value	TL4 Value	Units	Reference
7429-90-5	Aluminum	ND	ND	L/kg	
7440-36-0	Antimony	0	0	L/kg	Barrows et al. (1980)
22569-72-8	Arsenic (III)	4.0E+00	4.0E+00	L/kg	Barrows et al. (1980)
15584-04-0	Arsenic (V)	4.0E+00	4.0E+00	L/kg	Barrows et al. (1980)
7440-39-3	Barium	ND	ND	L/kg	
7440-42-8	Boron	ND	ND	L/kg	
7440-43-9	Cadmium	2.7E+02	2.7E+02	L/kg	Kumada et al. (1972)
7440-48-4	Cobalt	ND	ND	L/kg	
7439-92-1	Lead	4.6E+01	4.6E+01	L/kg	Stephan (1993)
7439-98-7	Molybdenum	4.0E+00	4.0E+00	L/kg	Eisler (1989)
10026-03-6	Selenium (IV)	4.9E+02	1.7E+03	L/kg	Lemly (1985)
7782-49-2	Selenium (VI)	4.9E+02	1.7E+03	L/kg	Lemly (1985)
7440-28-0	Thallium	3.4E+01	1.3E+02	L/kg	T3: Barrows et al. (1980) T4: Stephan (1993)
14797-55-8	Total Nitrate Nitrogen	ND	ND	L/kg	

ND = No Data. Fish concentrations were not calculated for constituents with no BCF data.

3.7.3 Aluminum Precipitation Model

Aluminum is generally solubility limited in natural waters; therefore, a simple precipitation model was used for aluminum in lieu of the equilibrium-partitioning model. The MINTEQA2 model was used to estimate total soluble aluminum concentrations as a function of pH for a typical surface waterbody (Stumm and Morgan, 1996; Drever, 1988). By assuming the common aluminum silicate mineral gibbsite was the equilibrium solid phase, the computed values of total dissolved aluminum were interpreted as the maximum expected for each pH. If more aluminum were added to the system, it would be expected to precipitate as the mineral gibbsite for the system to maintain equilibrium. **Table 3-11** shows the maximum dissolved aluminum concentrations as a function of waterbody pH.

The precipitation model initially calculates the aluminum concentration in the surface water column by assuming that all aluminum in the groundwater flux is dissolved. If this concentration exceeds the maximum soluble concentration based on pH, the dissolved concentration is capped and the excess aluminum is assumed to precipitate as the mineral gibbsite and settle to the benthic sediment layer. The equations used in this model are presented in **Appendix E**.

Table 3-11. Aluminum Solubility as a Function of Waterbody pH[a]

Minimum pH	Maximum pH	Solubility (mg/L)
3.5	4.5	26.2
4.5	5	1.84
5	5.5	0.196
5.5	6	0.0112
6	6.5	0.00143
6.5	7	0.000662
7	7.5	0.000915
7.5	8	0.00229
8	8.5	0.00682
8.5	9	0.0212
9	9.5	0.0666
9.5	10	0.211
10	10.5	0.668

[a] Computed using MINTEQA2

Only the water column concentration for aluminum was used in subsequent exposure and risk calculations, because there is no available ecological benchmark for aluminum in sediment. The water column concentration was used to calculate human exposure via drinking water ingestion, as well as risk to ecological receptors exposed via direct contact.

3.8 Human Exposure Assessment

The human exposure component of the full-scale analysis assessed the magnitude, frequency, duration, and route of exposure to CCW contaminants that an individual may experience. The term "exposure," as defined by the EPA exposure guidelines (U.S. EPA, 1992), as the condition that occurs when a contaminant comes into contact with the outer boundary of the body. The exposure of an individual to a contaminant completes an exposure pathway (i.e., the course a constituent takes from the WMU to an exposed individual). Once the body is exposed, the constituent can cross the outer boundary and enter the body. The amount of contaminant that crosses and is available for adsorption at internal exchange boundaries is referred to as the "dose" (U.S. EPA, 1992).

This risk assessment evaluated the risk from CCW contaminants to receptors in the vicinity of a WMU. The individuals evaluated were those residents closest to the WMU. The distances from the WMU to the residents were taken from a distribution of distances to the nearest residential drinking water well measured for municipal landfills and, for the recreational fisher, a distribution of the distance of the nearest surface water body from CCW landfills and surface impoundments (see **Appendix C**).

Section 3.8.1 presents an overview of the receptors and selected exposure pathways considered for this assessment, including a discussion of how childhood exposure was considered in the analysis. **Section 3.8.2** presents exposure factors (i.e., values needed to calculate human exposure) used in the analysis. **Section 3.8.3** describes the methods used to estimate dose, including average daily dose (ADD) and lifetime average daily dose (LADD).

3.8.1 Receptors and Exposure Pathways

Human receptors may come into contact with constituents present in environmental media through a variety of pathways. The exposure pathways considered in the full-scale analysis were ingestion of drinking water from contaminated groundwater sources and ingestion of fish from surface water contaminated by groundwater.

- **Ingestion of Drinking Water.** Groundwater from an offsite well was assumed to be used for drinking water for residents (adult and child).
- **Ingestion of Fish.** Fish are exposed to constituents via uptake of contaminants from surface water. Adult recreational fishers and their children were assumed to consume fish caught in local waterbodies contaminated by CCW constituents through the groundwater-to-surface-water pathway. EPA considers this assumption to be reasonable and protective for fishers relying on locally caught fish as a food source.

Table 3-12 lists each human receptor type considered in this analysis along with the specific exposure pathways that apply to that receptor. Both adult and child residents are exposed by drinking groundwater, and adult fishers and their children are exposed by eating fish caught in streams and lakes impacted by CCW.

Table 3-12. Receptors and Exposure Pathways

Receptor	Ingestion of Drinking Water	Ingestion of Fish
Adult resident	✓	
Child resident	✓	
Adult recreational fisher		✓
Child of recreational fisher		✓

Children are an important subpopulation to consider in a risk assessment because they may be more sensitive to exposures than adults. Compared with adults, children may eat more food and drink more fluids per unit of body weight. This higher intake-rate-to-body-weight ratio can result in a higher ADD for children than adults.

As children mature, their physical characteristics and behavior patterns change. To capture these changes in the analysis, the life of a child was considered in stages represented by the following cohorts: cohort 1 (ages 1 to 5), cohort 2 (ages 6 to 11), cohort 3 (ages 12 to 19), and cohort 4 (ages 20 to 70). Associated with each cohort are distributions of exposure parameters that reflect the physical characteristics and behavior patterns of that age range. These exposure parameters are required to calculate exposure to an individual. The distributions for the 20- to 70-year-old cohort were the same as those used for adult receptors.

To capture the higher intake-rate-to-body-weight ratio of children, a start age of 1 year was selected for the child receptors. The exposure duration distribution for cohort 1 (a 1- to 5-year-old) was used to define exposure duration for the child receptors for each of the 10,000 iterations in the probabilistic analysis. For each individual iteration, the child receptor was aged through the age cohorts as appropriate until the age corresponding to the selected exposure duration was reached (e.g., if an exposure duration of 25 years was selected for an iteration, the child was aged from 1 year to 25 years, spending 5 years in cohort 1, 6 years in cohort 2, 8 years in cohort 3, and 6 years in cohort 4, for a total of 25 years).

3.8.2 Exposure Factors

The exposure factors used in the risk assessment are listed in **Table 3-13**, along with their data sources and variable type (i.e., whether they were represented as a distribution or a fixed value in the Monte Carlo analysis). These exposure factors were used to calculate the dose of a chemical based on contact with contaminated media or food, the duration of that contact, and the body weight of the exposed individuals.

Table 3-13. Human Exposure Factor Input Parameters and Data Sources

Parameter	Variable Type	Data Source
Body weight (adult, child)	Distribution	U.S. EPA (1997c)
Ingestion rate: fish (adult, child)	Distribution	U.S. EPA (1997d)
Ingestion rate: drinking water (adult, child)	Distribution	U.S. EPA (1997c)
Exposure duration (adult, child)	Distribution	U.S. EPA (1997e)
Exposure frequency (adult, child)	Fixed (constant)	U.S. EPA policy
Fraction contaminated: drinking water	Fixed (constant)	U.S. EPA policy
Fraction contaminated: fish	Fixed (constant)	U.S. EPA policy
Fraction of TL3 fish consumed	Fixed (constant)	U.S. EPA (1997d)
Fraction of TL4 fish consumed	Fixed (constant)	U.S. EPA (1997d)
Human lifetime (used in carcinogenic risk calculation)	Fixed (constant)	U.S. EPA policy

The primary data source of human exposure model inputs used in this risk assessment was EPA's *Exposure Factors Handbook* (EFH; U.S. EPA, 1997c-e). The EFH summarizes data on human behaviors and characteristics related to human exposure from relevant key studies and provides recommendations and associated confidence estimates on the values of exposure factors. These data were carefully reviewed and evaluated for quality before being included in the EFH. EPA's evaluation criteria included peer review, reproducibility, pertinence to the United States, currency, adequacy of the data collection period, validity of the approach, representativeness of the population, characterization of variability, lack of bias in study design, and measurement error (U.S. EPA, 1997c-e). For exposure factors that were varied in the Monte Carlo analysis, probability distribution functions were developed from the values in the EFH.

The data sources and assumptions for intake and other human exposure factors used in this analysis are described below. **Appendix F** presents the exposure factors used and describes the rationale and data used to select the form of the distributions (e.g., normal, lognormal, gamma, Weibull) for those exposure factors that were varied in the probabilistic analysis. Data for three child cohorts (ages 1–5, 6–11, and 12–19 years) and adults were used. However, as most infants are breastfed and therefore are not exposed to fish or water, they were excluded from the risk assessment (i.e., modeling start age for a child is 1 year).

- **Body Weight.** Distributions of body weight were developed for adult and child receptors based on data from the EFH.

- **Fish Ingestion Rate.** Fish ingestion rates were based on a recreational angler who catches and eats some fish from a waterbody impacted by contaminants released from CCW WMUs. Distributions of fish intake rates were developed for adult fishers based on data from the 1997 EFH. At the time the risk assessment was conducted (May-June 2003), separate fish ingestion rates for children of recreational anglers were not available.

- **Drinking Water Ingestion Rate.** Distributions of drinking water intake rates were developed for the adult and child resident based on data from the EFH.

- **Exposure Duration.** Exposure duration refers to the amount of time that a receptor is exposed to a contaminant source. Exposure duration was assumed to correspond with the receptor's residence time in the same house. Exposure durations were determined using data on residential occupancy from the EFH. The data used to develop parameter information for resident receptors were age-specific. Thus, separate exposure duration distributions were developed for adult and child residents. For children, the modeling start age is 1 year, and exposure duration was used to determine the amount of time spent in each cohort (e.g., if exposure duration was 2 years, consumption rates and body weights were based only on cohort 1 data; however, if exposure duration was 21 years, the child spends 5 years in cohort 1, 6 years in cohort 2, 8 years in cohort 3, and 2 years in cohort 4/adult). Infants between birth and 1 year are not modeled because they are assumed to either breastfeed or consume commercial formula.

- **Exposure Frequency.** Exposure frequency is the frequency with which the receptor is exposed to the contaminated source during the exposure duration. Exposure frequency is not expected to vary much, so distributions were not developed for exposure frequency. All receptors were assumed to be exposed to the contaminant source 350 days/year. This value was based on the assumption that individuals are away from their homes (e.g., on vacation) approximately 2 weeks out of the year, but are otherwise exposed daily.

- **Lifetime and Averaging Time.** Averaging time is the period of time over which a receptor's dose is averaged. To evaluate carcinogens, total dose was averaged over the lifetime of the individual, assumed to be 70 years. To evaluate noncarcinogens, dose was averaged over the last year of exposure because noncancer effects may become evident during less-than-lifetime exposure durations if toxic thresholds are exceeded. Essentially, this amounts to setting exposure duration and averaging time equal so that they cancel each other out in the equation for ADD. Thus, neither exposure duration nor averaging time is included in the ADD equation.

3.8.3 Dose Estimates

An exposure assessment estimates the dose to each receptor from the contaminant concentration in the exposure medium (e.g., drinking water, fish) and the intake rate for that medium (e.g., ingestion rate of drinking water, ingestion rate of fish). For this assessment, exposure estimates were based on the *potential* dose (e.g., the dose ingested) rather than the *applied* dose (e.g., the dose delivered to the gastrointestinal tract) or the *internal* dose (e.g., the dose delivered to the target organ). Doses from groundwater or fish ingestion were calculated by multiplying the contaminant concentration in groundwater or fish by the respective intake rate on a per kilogram body weight basis. Doses were then summed over the exposure duration, resulting in an ADD received from ingestion exposure. The ADD was used to assess noncancer risk from ingestion exposures and is defined as

$$ADD = C \times IR \tag{3-2}$$

where

C = average concentration (mass/volume or mass/mass)
IR = intake rate (mass/body weight mass/time, or volume/body weight mass/time).

Contaminant concentration represents the concentration of a chemical in a medium that contacts the body. The ADD was calculated from concentrations averaged over the exposure duration for each receptor.

For cancer effects, where the biological response is described in terms of lifetime probabilities even though exposure may not occur over the entire lifetime, dose is presented as a LADD. The LADD was used to assess cancer risks from each exposure route (i.e., ingestion) and is defined as

$$LADD = \frac{C \times IR \times ED \times EF}{AT \times 365} \tag{3-3}$$

where

C = average concentration (mass/mass or mass/volume)
IR = intake rate (mass/body weight mass/time, or volume/body weight mass/time)
ED = exposure duration (yr)
EF = exposure frequency (d/yr)
AT = averaging time (yr)
365 = units conversion factor (d/yr).

As with the ADD, contaminant concentration represents the concentration of a chemical in a medium that contacts the body. Intake rate depends on the route of exposure; for example, it might be an inhalation rate or an ingestion rate. Exposure frequency is the number of days per year the receptor is exposed to the contaminated source during the exposure duration.

For cancer effects, biological responses are described in terms of lifetime probabilities, even though exposure may not be lifelong; consequently, the exposure duration (the length of time of contact with a contaminant) was used to average the ADD over a lifetime (70 years). The media concentrations used were averaged over the duration of exposure.

3.9 Risk Estimation

The final step of the risk assessment process is to estimate the risk posed to human and ecological receptors (e.g., residents, fishers; aquatic organisms). In this step, estimates of toxicity (the human health and ecological benchmarks) and exposure doses or exposure concentrations are integrated into quantitative expressions of risk. For the CCW constituents modeled in the full-scale assessment, the CCW human risk assessment used estimates of dose and toxicity to calculate individual excess lifetime carcinogenic risk estimates and noncancer HQs (**Section 3.9.1**). The risk calculations for ecological receptors differ from those for humans because the ecological benchmarks are developed as media concentrations (i.e., they are calculated considering ecological exposure). Thus the CCW risk assessment used estimates of exposure (media) concentrations and toxicity (media-specific concentration limits) to calculate an ecological HQ (**Section 3.9.2**).

3.9.1 Human Health Risk Estimation

The full-scale analysis focused on two human health exposure pathways: groundwater-to-drinking-water and groundwater-to-surface-water via fish consumption by recreational fishers. The cancer and noncancer health impacts of ingesting groundwater and fish contaminated by CCW leachate were estimated using the risk endpoints shown in **Table 3-14**. These endpoints were generated for each iteration of the Monte Carlo analysis. Only the cancer endpoint was used for arsenic, because it is the more sensitive endpoint compared to noncancer effects. For the other 11 constituents, only noncancer HQs were calculated, using the appropriate noncancer endpoint.

Table 3-14. Risk Endpoints Used for Human Health

Risk Category	Risk Endpoints	Definition
Cancer Effects (arsenic only)	Lifetime excess cancer risk by pathway and chemical	Lifetime excess cancer risk resulting from single pathway exposure
Noncancer Effects	Ingestion HQ by pathway and chemical	Ingestion HQ resulting from single pathway exposure
	Ingestion HQ based on drinking water action level for lead and copper	Lead and copper ingestion HQ resulting from drinking water pathway
	Average daily dose for fish consumption for lead	Lead exposure resulting from fish ingestion pathway

Cancer risks for arsenic were characterized using lifetime excess cancer risk estimates, which represent the excess probability of developing cancer over a lifetime as a result of exposure to the chemical of interest. Lifetime excess cancer risk estimates use the LADD (see **Section 3.8.3**) as the exposure metric. Lifetime excess cancer risk estimates are the product of the LADD for a specific receptor and the corresponding cancer slope factor, as shown in Equation 3-4.

$$Lifetime\ excess\ cancer\ risk_i = LADD_i \times CSF \quad (3\text{-}4)$$

where

LADD = lifetime average daily dose for ingestion pathway i (mg/kg BW/d)
i = pathway index
CSF = cancer slope factor $(mg/kg\ BW/d)^{-1}$.

Noncancer risk was characterized through the use of HQs, which are generated by dividing an ADD (see **Section 3.8.3**) for ingestion pathways by the corresponding RfD.[13] An HQ establishes whether a particular individual has experienced exposure above a threshold for a specific health effect. Therefore, unlike cancer risk estimates, HQs are not probability statements. Rather, the RfD represents an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It can be derived from a no observed adverse exposure level (NOAEL), lowest observed adverse exposure level (LOAEL), or benchmark dose, with uncertainty factors generally applied to reflect limitations of the data used. Equation 3-5 shows the calculation for the ingestion HQ. This calculation was completed for each pathway considered (i.e., drinking water ingestion and fish consumption).

$$HQ_i = \frac{ADD_i}{RfD} \tag{3-5}$$

where

ADD_i = average daily dose for ingestion pathway i (mg/kg-d)
i = pathway index
RfD = reference dose (mg/kg-d).

The risk results address risk from exposure via the groundwater-to-drinking-water and groundwater-to-surface-water pathway separately. This is appropriate because the resident consuming contaminated groundwater may not be the recreational fisher who is consuming contaminated fish. Also, the arrival time of the contaminant plume to the stream and the human receptor may not be the same for a particular iteration.[14] However, a resident may consume fish caught from a nearby stream or lake and contaminated drinking water if the travel times are similar, so that possibility should be considered as an uncertainty in this analysis (see **Section 4.4.1**).

For each receptor type, lifetime excess cancer risk estimates for arsenic were calculated separately for the drinking water and fish consumption pathways.

3.9.2 Ecological Risk Estimation

The full-scale analysis addressed two routes of exposure for ecological receptors: direct contact with contaminated media and ingestion of contaminated food items. HQs were calculated using chemical-specific media concentrations assumed to be protective of ecological receptors of concern through either exposure route (CSCLs). As described in **Section 3.1.2**, these ecological benchmarks were developed for representative organisms and communities in each environmental medium of concern.

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[13] HQs calculated for lead in drinking water were based on the drinking water action level (0.015 mg/L); lead exposures from fish ingestion are reported as an ADD.
[14] Stream distance and well distance were sampled independently in the Monte Carlo analysis.

For a particular Monte Carlo iteration, HQs were calculated for sediment and surface water as the ratio between the media concentration and the ecological benchmark. Because the CSCLs were derived for an HQ of 1 (for relevant ecological endpoints), the ratio of a constituent concentration in a media to the media-specific CSCL represents the HQ for that constituent and pathway. For surface water, the HQ was calculated as follows:

$$HQ_{surface\ water} = C_{sw} / CSCL_{sw} \tag{3-6}$$

where

C_{sw} = total concentration in surface water column (mg/L)
$CSCL_{sw}$ = ecological benchmark for surface water (mg/L).

Similarly, for sediment, the HQ was calculated as

$$HQ_{sediment} = C_{sediment} / CSCL_{sediment} \tag{3-7}$$

where

$C_{sediment}$ = total concentration in sediment (mg/kg)
$CSCL_{sediment}$ = ecological benchmark for sediment (mg/kg).

Because the sediment and surface water benchmarks were based on separate receptor communities, it is not appropriate to add HQs across pathways.

4.0 Risk Characterization

This section summarizes the results of the full-scale Monte Carlo analysis and characterizes those results in terms of significant uncertainties and the scenarios and factors that influence risks to human health and the environment. Results are presented at a high-end (90th percentile) and typical (50th percentile) exposure for both pathways under each combination of WMU type, ash type, and liner type.

An overview of the assessment on which these results were based (e.g., waste management scenarios, analysis framework) is provided in **Section 2**. **Section 3** provides more details on analysis methodologies, parameter values, and assumptions. In this section, **Section 4.1** presents results from the human health risk assessment and includes an analysis of how liner conditions influence results. **Section 4.2** presents the results from the ecological risk assessment. Tables summarizing the human and ecological results are presented in each section. **Section 4.3** describes the sensitivity analysis conducted for the CCW risk assessment, and **Section 4.4** discusses how variability and uncertainty have been addressed, including a semi-quantitative review of the potential impact of some of the more significant uncertainties on results.

The probabilistic results were based on a Monte Carlo simulation in which many model input parameter values were varied over 10,000 iterations of the model per waste management scenario to yield a statistical distribution of exposures and risks. Per the Guidance for Risk Characterization developed by the EPA Science Policy Council in 1995 (http://www.epa.gov/OSA/spc/pdfs/rcguide.pdf), EPA defined the high end of the risk distribution at the 90th percentile risk or hazard estimate generated during the Monte Carlo simulation. Thus, the 90th percentile risk results are shown in this section as the high-end estimate of the risk distribution generated during the Monte Carlo simulation of constituent release, fate and transport, and exposure associated with CCW disposal in landfills and surface impoundments. In addition, the 50th percentile results are presented as the central tendency estimate of that risk distribution.

For exposure scenarios describing the waste management unit type (e.g., lined landfill; unlined surface impoundment), waste type (e.g., conventional CCW, ash mixed with coal refuse), receptor (i.e., child, adult, ecological), and health endpoint (i.e., cancer, noncancer, ecological), the 90th percentile risk represents the high-end estimate of cancer or noncancer risk that was used to help determine whether CCW disposal practices are protective of public health. To evaluate the significance of the estimated cancer risks or noncancer hazards that are attributable to CCW disposal for the exposure pathways assessed in this assessment, EPA compared the risk estimates to a risk range (for carcinogens) or to a specific risk criterion (for noncarcinogens) that are protective of human health and the environment:

- An estimate of the excess lifetime cancer risk for individuals exposed to carcinogenic (cancer-causing) contaminants ranging from 1 chance in 1,000,000 (10^{-6} excess cancer risk) to 1 chance in 10,000 (10^{-4} excess cancer risk). For decisions made to screen out certain constituents from further consideration, a 1 in 100,000 (10^{-5}) excess lifetime cancer risk) was used.[1]

- For constituents that cause adverse, noncancer health effects (noncarcinogens), the criterion is an HQ of greater than 1, with the HQ being the ratio of the average daily exposure level to a protective exposure level corresponding to the maximum level at which no appreciable effects are likely to occur.

- An HQ greater than 1 for was used to identify constituents with adverse effects to ecological receptors.

In general, the full-scale analysis showed lower risks than the screening analysis, but still showed risks within or above the cancer risk range or above an HQ of 1 for certain CCW constituents, WMU types, pathways, and receptors at the 90th percentile. At the 50th percentile, risks are still above these levels for both WMU types, but for fewer constituents and pathways. The results presented herein are subject to further interpretation, as EPA queries the CCW risk inputs and outputs to investigate how the results may be affected by (1) waste types and environmental and waste management conditions, (2) assumptions made about these conditions in designing the probabilistic analysis, and (3) the availability of newer facility data.

4.1 Human Health Risks

This section presents the 90th and 50th percentile risk results for the two human exposure pathways evaluated in the full-scale analysis: (1) groundwater-to-drinking-water and (2) groundwater-to-surface-water (fish consumption). Results are presented for the two WMU types addressed in the analysis: landfills and surface impoundments, and show the distribution of risks across all waste types by liner type from the EPRI survey data (see **Section 4.1.3** for further discussion of liners).

4.1.1 Groundwater-to-Drinking-Water Results by Waste Type/WMU Scenario

As described in **Section 3.3**, the CCW risk assessment was organized by waste type so that different waste chemistries could be accounted for in the fate and transport modeling. The results discussed so far in this report address conventional CCW (fly ash, bottom ash, boiler slag, FGD sludge) and conventional CCW codisposed with coal refuse.[2] **Section 4.1.1.1** presents these results by waste type. FBC wastes were also modeled in this assessment. However, there was a very small number of FBC waste disposal sites (seven) in the EPRI/EPA database. For this reason, the FBC results are treated separately in **Section 4.1.1.2**. Groundwater results are reported for a resident's child because these consistently led to higher HQs, with the exception of arsenic cancer values, which were consistently higher in adults. Thus, the cancer risks reported are for adults.

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1 The typical cancer risk range used by the Office of Solid Waste and Emergency Response is 10^{-4} to 10^{-6}.

2 Coal refuse is the waste coal produced from coal handling, crushing, and sizing operations, and tends to have a high sulfur content and low pH. In the CCW constituent database, codisposed coal refuse includes "combined ash and coal gob," "combined ash and coal refuse," and "combined bottom ash and pyrites."

Note that only the chemicals for which constituent data were adequate to model and assess risks were modeled in the full-scale assessment, and only those modeled chemical/pathway/WMU scenarios are shown in the tables and figures. For example, antimony and thallium risks are not presented for surface impoundments and mercury is not shown for either landfills or surface impoundments because more than 90% of the measurements were nondetects. For further discussion of how nondetects were treated, see **Section 4.4.3.1**. Although screening-level human health risks for aluminum and barium were below the screening criteria, they were modeled in the risk assessment due to their potential to cause ecological harm. Additionally, there were nine constituents that failed the screen but were not modeled. Instead, these constituents were dealt with using risk attenuation factors, as described in **Section 4.1.4**. The screening analysis results in **Section 3.2.4** and **Table 3-6** show which CCW constituents were modeled.

Results for two constituents (arsenic and selenium) also varied based on chemical speciation. An earlier draft of this document showed results assuming 100% trivalent arsenic (arsenic III) and 100% hexavalent selenium (selenium VI) because these forms are more mobile in soil and groundwater, and thus would show higher estimated risks than either arsenic V or selenium IV. This revised draft also presents results for arsenic V and selenium IV. The results for the two species of arsenic and selenium bound the range of possible risks for these two constituents. For further discussion of speciation, see **Section 4.4.2**.

4.1.1.1 Conventional CCW and CCW Codisposed with Coal Refuse

Tables 4-1 and **4-2** show 90th and 50th percentile risk results, respectively, by waste type and liner type for CCW landfills for the drinking water pathway. Although some risks were higher for conventional CCW and others for codisposed CCW, there was generally little difference in results between waste types for landfills. Although risks are greater for unlined landfills than for clay-lined landfills, those with composite liners show zero, or near-zero, risks for all constituents modeled in this assessment (see **Section 4.1.3** for a further discussion of risks by liner type).

Tables 4-3 and **4-4** show the 90th and 50th percentile risk results, respectively, by waste type and liner type for CCW surface impoundments for the drinking water pathway. The difference in risks between waste types is greater for surface impoundments than for landfills. For surface impoundments, some constituents present higher risks from CCW managed alone (boron, molybdenum, nitrate, and selenium). However, others presented higher risks when CCW is comanaged with coal refuse (arsenic, cadmium, cobalt, and lead). This result is likely due to the higher metal concentrations and the acidity of coal refuse leachate[3] for surface impoundments in the CCW database, which in turn result from the association of these elements (and acidity) with the sulfide minerals[4] that are concentrated in coal refuse (Finkelman, 1995). As with landfills, clay-lined units show lower risks than unlined units, and composite liners show zero, or near-zero, risks for either waste type.

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3 Many metals tend to be more soluble and mobile in acidic leachate.
4 Arsenic: pyrite, cadmium: sphalerite, lead: galena, cobalt: pyrite.

When viewing the results in Tables 4-1 through 4-4, readers should note that these risks assume that the contaminated groundwater plume will intercept a receptor well. Because approximately two-thirds of the model runs showed surface water bodies intersecting the groundwater plume, there could be a significant number of instances where a well is either not contaminated or is less contaminated than the results below would indicate. This uncertainty is discussed further in **Section 4.4.3.3**.

Table 4-1. 90th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Drinking-Water Pathway

Chemical	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 79 landfills			
Cancer			
Arsenic III	4E-04	2E-04	0
Arsenic V	2E-04	3E-05	0
Noncancer			
Aluminum	2E-03	1E-04	0
Antimony	2	0.8	0
Barium	3E-03	7E-04	0
Boron	0.7	0.4	0
Cadmium	0.7	0.4	0
Cobalt	1	0.4	0
Lead (MCL)[b]	1	0.3	0
Molybdenum	2	0.8	0
Nitrate/nitrite (MCL)[b]	0.1	0.06	2E-06
Selenium IV	0.01	3E-3	0
Selenium VI	0.2	0.1	0
Thallium	3	2	0
Codisposed CCW and Coal Refuse – 41 landfills			
Cancer			
Arsenic III	5E-04	2E-04	0
Arsenic V	4E-04	6E-05	0
Noncancer			
Aluminum	0.02	4E-04	0
Antimony	0.8	0.3	0
Barium	0.04	4E-03	0
Boron	0.3	0.1	0
Cadmium	0.2	0.07	0
Cobalt	0.8	0.09	0
Lead (MCL)[b]	0.7	0.09	0
Molybdenum	2	0.6	0

(continued)

90th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Drinking-Water Pathway (continued)

Chemical	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Nitrate/nitrite (MCL)[b]	0.2	0.1	3E-06
Selenium IV	0.1	0.04	0
Selenium VI	0.7	0.3	0
Thallium	2	1	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Values are ratios of exposure concentration to MCL.

Table 4-2. 50th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Drinking-Water Pathway

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 79 landfills			
Cancer			
Arsenic III	6E-06	4E-06	0
Arsenic V	6E-10	3E-14	0
Noncancer			
Aluminum	5E-07	3E-07	0
Antimony	0.04	0.02	0
Barium	0	0	0
Boron	0.01	0.01	0
Cadmium	0.01	8E-03	0
Cobalt	3E-03	8E-06	0
Lead (MCL)[b]	4E-04	2E-08	0
Molybdenum	0.1	0.04	0
Nitrate/nitrite (MCL)[b]	0.004	0.003	0
Selenium IV	0	0	0
Selenium VI	9E-03	6E-03	0
Thallium	0.2	0.1	0
Codisposed CCW and Coal Refuse – 41 landfills			
Cancer			
Arsenic III	2E-05	6E-06	0
Arsenic V	6E-06	7E-10	0

(continued)

50th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Drinking-Water Pathway (continued)

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Noncancer			
Aluminum	4E-06	2E-09	0
Antimony	0.05	0.02	0
Barium	5E-05	7E-07	0
Boron	8E-03	3E-03	0
Cadmium	0.02	4E-03	0
Cobalt	2E-05	0	0
Lead (MCL)[b]	0.01	2E-07	0
Molybdenum	0.02	6E-03	0
Nitrate/nitrite (MCL)[b]	0.04	0.009	0
Selenium IV	2E-09	2E-15	0
Selenium VI	0.03	0.01	0
Thallium	0.2	0.07	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.
[b] Values are ratios of exposure concentration to MCL.

Table 4-3. 90th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Drinking-Water Pathway

Chemical	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 44 surface impoundments			
Cancer			
Arsenic III	2E-03	9E-04	2E-07
Arsenic V	7E-04	2E-04	0
Noncancer			
Aluminum	2E-03	1E-03	2E-07
Barium	5E-03	3E-03	2E-11
Boron	7	4	5E-03
Cadmium	0.5	0.3	4E-11
Cobalt	0.9	0.4	0
Lead (MCL)[b]	3	0.7	1E-21
Molybdenum	8	5	7E-03
Nitrate/nitrite (MCL)[b]	20	10	9E-04
Selenium IV	0.4	0.1	1E-04

(continued)

90th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Drinking-Water Pathway (continued)

Chemical	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Selenium VI	2	1	1E-03
Codisposed CCW and Coal Refuse – 72 surface impoundments			
Cancer			
Arsenic III	2E-02	7E-03	4E-06
Arsenic V	2E-02	2E-03	3E-09
Noncancer			
Aluminum	0.3	0.07	6E-07
Barium	7E-03	3E-03	9E-07
Boron	1	0.5	2E-03
Cadmium	9	3	5E-05
Cobalt	500	200	3E-06
Lead (MCL)[b]	9	1	1E-19
Molybdenum	3	2	4E-03
Nitrate/nitrite (MCL)[b]	0.4	0.2	1E-04
Selenium IV	0.3	0.1	3E-10
Selenium VI	0.8	0.4	1E-03

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Values are ratios of exposure concentration to MCL.

Table 4-4. 50th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Drinking-Water Pathway

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite–Lined Units
Conventional CCW – 44 surface impoundments			
Cancer			
Arsenic III	1E-04	6E-05	0
Arsenic V	2E-05	4E-06	0
Noncancer			
Aluminum	2E-05	1E-05	8E-20
Barium	1E-04	1E-04	0
Boron	0.4	0.2	3E-11
Cadmium	0.05	0.02	0
Cobalt	0.2	0.05	0

(continued)

50th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Drinking-Water Pathway (continued)

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite–Lined Units
Lead (MCL)[b]	0.05	0.007	0
Molybdenum	1	0.5	2E-11
Nitrate/nitrite (MCL)[b]	0.1	0.05	7E-08
Selenium IV	8E-04	4E-10	0
Selenium VI	0.1	0.07	2E-11
Codisposed CCW and Coal Refuse – 72 surface impoundments			
Cancer			
Arsenic III	6E-04	2E-04	0
Arsenic V	3E-04	4E-05	0
Noncancer			
Aluminum	5E-04	4E-05	0
Barium	4E-04	2E-04	0
Boron	0.1	0.06	5E-15
Cadmium	0.1	0.05	0
Cobalt	20	6	0
Lead (MCL)[b]	0.1	0.01	0
Molybdenum	0.8	0.3	3E-18
Nitrate/nitrite (MCL)[b]	0.03	0.01	4E-08
Selenium IV	3E-03	9E-05	0
Selenium VI	0.1	0.03	5E-15

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.
[b] Values are ratios of exposure concentration to MCL.

4.1.1.2 FBC Wastes

Tables 4-5 and **4-6** show the 90th and 50th percentile risk results for FBC landfills by liner type. These results suggest lower risks than for conventional CCW and CCW codisposed with coal refuse. The difference may be attributed to lower FBC leachate concentrations and the alkaline nature of FBC waste. Note that clay-lined FBC landfills show higher risks than unlined facilities, which is counterintuitive considering how clay-lined and unlined units are designed and operated. This result reflects the characteristics of the limited number and locations of FBC landfills.[5] When the risk results of an exposure pathway are viewed at a resolution finer than the analysis design, a small sample size, along with the interactions of liner type with other site-

[5] FBC WMU data were available for only seven landfills (3 unlined, 3 clay-lined, and 1 composite-lined), and it is not known how representative these data are with respect to WMU characteristics and locations throughout the United States.

based inputs, can produce unexpected results. In the case of FBC wastes, the characteristics of the three unlined landfills (primarily infiltration rate and areas) were such that their risks were lower than the three clay-lined FBC landfills.

Table 4-5. 90th Percentile Risk Results for FBC Wastes: Landfills, Groundwater-to-Drinking-Water Pathway

Chemical	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
FBC Waste – 7 landfills			
Cancer			
Arsenic III	3E-05	6E-05	0
Arsenic V	2E-05	2E-05	0
Noncancer			
Aluminum	4E-06	2E-05	0
Antimony	0.8	3	0
Barium	4E-04	2E-03	0
Boron	0.02	0.07	0
Cadmium	0.1	0.3	0
Cobalt	0.4	0.8	0
Lead (MCL)[b]	0.4	0.6	0
Molybdenum	0.2	0.5	0
Nitrate/nitrite (MCL)[b]	0.03	0.07	5E-08
Selenium IV	3E-14	0.05	0
Selenium VI	0.08	0.1	0
Thallium	1	4	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000-year period of the analysis.

[b] Values are ratios of exposure concentration to MCL.

Table 4-6. 50th Percentile Risk Results for FBC Wastes: Landfills, Groundwater-to-Drinking-Water Pathway

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
FBC Waste – 7 landfills			
Cancer			
Arsenic III	0	4E-07	0
Arsenic V	0	5E-10	0
Noncancer			
Aluminum	0	0	0
Antimony	0	0.09	0

(continued)

50th Percentile Risk Results for FBC Wastes: Landfills, Groundwater-to-Drinking-Water Pathway (continued)

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Barium	0	0	0
Boron	0	0.003	0
Cadmium	0	0.01	0
Cobalt	0	3E-03	0
Lead (MCL)[b]	0	2E-04	0
Molybdenum	0	0.04	0
Nitrate/nitrite (MCL)[b]	3E-08	0.004	0
Selenium IV	0	5E-15	0
Selenium VI	0	0.01	0
Thallium	0	0.2	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000-year period of the analysis.
[b] Values are ratios of exposure concentration to MCL.

4.1.1.3 Comparing Landfills and Surface Impoundments

The full-scale analysis produced lower risks for landfills than for surface impoundments. The higher risks for surface impoundments as compared to landfills reflect higher constituent concentrations in the surface impoundment wastes and a higher hydraulic head in an impoundment that drives leachate into the underlying soil with greater force than infiltration in landfills. This higher head results in a greater flux of contaminants to groundwater during the active life of the surface impoundment, especially in unlined units. In combination with the higher CCW constituent concentrations in surface impoundment porewater and a greater proportion of unlined units, these factors lead to more and higher risk exceedances for surface impoundments than for landfills.

4.1.1.4 The Effect of Liners

The analysis demonstrates that the presence of liners, especially composite liners, reduce leaching and risks from CCW landfills and surface impoundments. Note that 90th percentile risks from composite liners are zero for most constituents for landfills, which means that in 90 percent of the cases, the contaminant did not reach the receptor well in the 10,000 year limit for this analysis. Composite liners also reduced risks for surface impoundments for several constituents at the 90th percentile by 4 to 10 orders of magnitude and generated risk results well below the cancer risk range or noncancer risk criterion used for this analysis. Infiltration rates for composite-lined surface impoundments are largely controlled by leak density (see **Section 3.5**), which is an empirical distribution from the same source as the landfill infiltration rates (U.S. EPA, 2002b), and are subject to similar uncertainties.

Zero values reflect the liner leakage rates in the empirical data set used to develop composite landfill liner infiltration rates used in this risk assessment (from U.S. EPA, 2002b; see **Section 3.4.2**), which are mostly zero values or very low in terms of infiltration rate. Although these infiltration rates are based on the best data available to EPA, these data are not specific to CCW facilities. This represents an uncertainty in the analysis (see **Sections 3.4.2** and **4.4.3.2**).

4.1.1.5 Modeled Peak Concentration Arrival Times

Arrival times for the peak well concentrations used to calculate groundwater to drinking water risks for selected CCW constituents (arsenic, boron, cobalt, selenium, and thallium) are plotted as cumulative distributions for surface impoundments and landfills in the figures in **Appendix L.** These constituents were selected to represent the chemicals with the highest risks and to span the range of mobility in the subsurface. **Table 4-7** summarizes these time of travel results by showing selected percentiles from these distributions for each WMU/liner combination modeled in the risk assessment.

As can be seen in Table 4-7, the peak arrival times for most constituents in unlined surface impoundment is less than 100 years (i.e., peak concentration occurs before or shortly after surface impoundment closure). The 10th percentile ranges from 70 years (for arsenic III, boron, and selenium VI) to 76 years (for selenium IV). The 50th percentile arrival times remain under 100 years for most constituents, with only the less mobile forms of arsenic and selenium having 50th percentile arrival times later than 100 years.

Arrival times for unlined landfills are much longer, ranging up to thousands of years. For boron and selenium IV, the 50th percentiles are 2,000 and 10,000 years respectively. However, even at the 10th percentile, arrival times ranged from 300 years (for boron) to 4,600 years (for selenium IV).

At the higher percentiles, arrival times shown as greater than 10,000 years indicate that the contaminant plume did not reach the well before the simulation ended. Although the plume might eventually reach the well in these cases, EPA does not believe that extending the simulation beyond 10,000 years would have captured any significant risk beyond what was captured by the selection of the 90th percentile values, which reflect cases where the plume did reach the well. In other words, the 90th percentile values would not be influenced by whether lower percentile concentrations were zero or the concentration at a peak beyond 10,000 years.

Table 4-7. Time to Peak Well Concentration by WMU and Liner Type as Modeled

Liner	Time to Peak (years)[a,b]							
	Percentile	Arsenic III	Arsenic IV	Boron	Cobalt	Selenium IV	Selenium VI	Thallium[c]
Landfills (all waste types)								
Unlined	10	400	2,000	300	1,200	4,600	400	580
	30	1,100	7,100	880	4,100	9,400	1,000	1,100
	50	2,800	9,700	2,000	7,800	10,000	2,600	2,300
	70	6,400	10,000	4,300	10,000	>10,000	5,500	4,400
	90	>10,000	>10,000	9,400	>10,000	>10,000	10,000	9,700

(continued)

Time to Peak Well Concentration by WMU and Liner Type as Modeled (continued)

Liner	Time to Peak (years)[a,b]							
	Percentile	Arsenic III	Arsenic IV	Boron	Cobalt	Selenium IV	Selenium VI	Thallium[c]
Compacted clay	10	400	1,900	550	1,400	8,100	400	570
	30	1,400	8,200	1,400	5,900	>10,000	1,300	1,200
	50	4,000	10,000	5,600	10,000	>10,000	5,100	4,300
	70	>10,000	>10,000	10,000	>10,000	>10,000	10,000	10,000
	90	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
Synthetic or composite (clay and synthetic)	10	10,000	>10,000	9,600	>10,000	10,000	9,000	>10,000
	30	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
	50	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
	70	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
	90	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
Surface Impoundments (all waste types)								
Unlined	10	70	73	70	71	76	70	N/A
	30	73	97	72	78	610	72	N/A
	50	78	220	74	97	4,400	74	N/A
	70	91	890	80	190	10,000	80	N/A
	90	170	6,500	110	970	>10,000	110	N/A
Compacted clay	10	75	95	75	86	81	75	N/A
	30	86	350	80	140	3,000	80	N/A
	50	110	1,300	90	270	7,900	90	N/A
	70	150	5,000	110	690	10,000	110	N/A
	90	340	10,000	150	3,100	>10,000	150	N/A
Synthetic or composite (clay and synthetic)	10	1,300	10,000	960	9,500	1,900	990	N/A
	30	3,900	>10,000	2,800	>10,000	6,900	2,800	N/A
	50	8,600	>10,000	4,400	>10,000	>10,000	4,600	N/A
	70	>10,000	>10,000	7,000	>10,000	>10,000	7,300	N/A
	90	>10,000	>10,000	10,000	>10,000	>10,000	10,000	N/A

[a] Arrival times have been rounded to two significant digits.
[b] >10,000 indicates that the contaminant plume did not reach the receptor well during the modeled period.
[c] N/A = Not Applicable. Thallium was not modeled for surface impoundments (see **Section 4.1.1** above).

As with the higher constituent concentrations that are characteristic of surface impoundments, the shorter arrival times for surface impoundments are primarily due to the hydraulic head of the waste liquids in the unit; by contrast, landfill leaching is driven solely by infiltration of precipitation through the cap and liner of the unit and the peak concentration takes much longer to reach the well.

The arrival times presented in Table 4-7 correspond to the arrival of the maximum estimated risks for each model run. However, for model runs where the risk range or HQ criterion was exceeded, the first exceedence would sometimes occur earlier than the maximum risk arrivals reported in Table 4-7. This is consistent with the appearance of damage cases described in U.S. EPA (2007), which were sometimes observed sooner than the time-to-peak estimates in Table 4-7.

4.1.2 Groundwater-to-Surface-Water (Fish Consumption) Pathway

Like the drinking water results above, the fish consumption results are organized by waste type so that different waste chemistries could be accounted for. **Section 4.1.2.1** presents the results for conventional CCW and codisposed CCW by WMU and liner type. FBC wastes were also modeled for the surface water pathway, and these results are treated separately in **Section 4.1.2.2**. Note that only the four constituents that failed the surface water screen were probabilistically modeled for this scenario. Of those, thallium risks are not presented for surface impoundments because of a high proportion (>90%) of nondetects in the surface impoundment data (see **Section 4.4.3.1** for further discussion). The screening analysis results in **Section 3.2.4** and **Table 3-6** show which CCW constituents exceeded the surface water screening criteria.

4.1.2.1 Conventional CCW and CCW Codisposed with Coal Refuse

Tables 4-8 and **4-9** present the 90th and 50th percentile risk results, respectively, by waste type and liner type for CCW landfills for the fish consumption pathway. The results presented are for a fisher's child because those risks were consistently higher than the risks for the adult fisher. As seen in these tables, the results for landfills that codispose of CCW are not drastically different from those that handle only conventional CCW. At the 90th percentile, only unlined landfills that comanage CCW present risks at an HQ of 1 (for selenium). The remainder of the modeled constituents had risks below an excess cancer risk of 1 in 100,000 or an HQ of 1 at the 90th percentile. 50th percentile results were all well below these levels for both cancer and noncancer risks.

Tables 4-10 and **4-11** present the 90th and 50th percentile risk results, respectively, by waste type and liner for CCW surface impoundments for the fish consumption pathway. Again, risks are higher for surface impoundments than for landfills because of the higher waste concentrations and the higher hydraulic head in these units, as discussed previously for the drinking water pathway. Results at that 90th percentile exceeded an HQ of 1 for selenium in unlined (HQ of 3) and clay-lined (HQ of 2) impoundments managing conventional CCW, and also exhibited excess cancer risks just above 1 in 100,000 for arsenic in unlined (3 in 100,000) and clay-lined (2 in 100,000) impoundments comanaging CCW. Fish consumption pathway 50th percentile results are well below an excess cancer risk of 1 in 1,000,000 and an HQ of 1 for all constituents, waste management scenarios, and liner types.

Table 4-8. 90th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Surface-Water Pathway

Chemical[b]	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 79 landfills			
Cancer			
Arsenic III	1E-06	1E-07	0
Arsenic V	4E-07	3E-09	0

(continued)

90th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Surface-Water Pathway (continued)

Chemical[b]	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Noncancer			
Cadmium	0.09	6E-03	0
Selenium IV	6E-05	1E-04	0
Selenium VI	0.3	0.04	0
Thallium	0.4	0.04	0
Codisposed CCW and Coal Refuse – 41 landfills			
Cancer			
Arsenic III	2E-06	8E-07	0
Arsenic V	2E-06	2E-07	0
Noncancer			
Cadmium	0.05	0.01	0
Selenium IV	0.03	9E-03	0
Selenium VI	1	0.4	0
Thallium	0.4	0.2	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Note that only the chemicals with adequate data that were identified in the screening analysis as needing further assessment (see **Section 3.2.4**) were modeled.

Table 4-9. 50th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Surface-Water Pathway

Chemical[b]	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 79 landfills			
Cancer			
Arsenic III	3E-10	7E-11	0
Arsenic V	4E-14	1E-18	0
Noncancer			
Cadmium	2E-05	3E-06	0
Selenium IV	0	0	0
Selenium VI	2E-04	4E-05	0
Thallium	1E-04	5E-05	0

(continued)

50th Percentile Risk Results by CCW Type: Landfills, Groundwater-to-Surface-Water Pathway (continued)

Chemical[b]	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Codisposed CCW and Coal Refuse – 41 landfills			
Cancer			
Arsenic III	4E-09	3E-09	0
Arsenic V	2E-10	8E-14	0
Noncancer			
Cadmium	1E-04	6E-05	0
Selenium IV	6E-10	1E-15	0
Selenium VI	3E-03	3E-03	0
Thallium	1E-03	1E-03	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Note that only the chemicals with adequate data that were identified in the screening analysis as needing further assessment (see **Section 3.2.4**) were modeled.

Table 4-10. 90th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Surface-Water Pathway

Chemical[b]	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Conventional CCW – 44 surface impoundments			
Cancer			
Arsenic III	8E-06	4E-06	1E-12
Arsenic V	2E-06	4E-07	0
Noncancer			
Cadmium	0.09	0.04	2E-15
Selenium IV	0.6	0.04	1E-07
Selenium VI	3	2	2E-06
Codisposed CCW and Coal Refuse – 72 surface impoundments			
Cancer			
Arsenic III	3E-05	2E-05	1E-14
Arsenic V	2E-05	8E-06	6E-19
Noncancer			
Cadmium	0.5	0.3	8E-13
Selenium IV	0.2	0.05	0

(continued)

90th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Surface-Water Pathway (continued)

Chemical[b]	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Selenium VI	1	0.8	7E-10

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Note that only the chemicals with adequate data that were identified in the screening analysis as needing further assessment (see **Section 3.2.4**) were modeled.

Table 4-11. 50th Percentile Risk Results by CCW Type: Surface Impoundments, Groundwater-to-Surface-Water Pathway

Chemical[b]	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite–Lined Units
Conventional CCW – 44 surface impoundments			
Cancer			
Arsenic III	4E-08	6E-10	0
Arsenic V	7E-09	2E-11	0
Noncancer			
Cadmium	6E-04	6E-06	0
Selenium IV	5E-05	1E-11	0
Selenium VI	0.02	3E-04	0
Codisposed CCW and Coal Refuse – 72 surface impoundments			
Cancer			
Arsenic III	6E-08	1E-08	0
Arsenic V	3E-08	2E-09	0
Noncancer			
Cadmium	1E-03	2E-04	0
Selenium IV	8E-05	4E-07	0
Selenium VI	3E-03	8E-04	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Note that only the chemicals with adequate data that were identified in the screening analysis as needing further assessment (see **Section 3.2.4**) were modeled.

As with the groundwater-to-drinking-water pathway analysis, the absence of risk from composite-lined units indicates that the liners modeled in this analysis are effective at preventing contaminants from reaching the surface waterbodies of interest. One should keep in mind that all surface water results are calculated assuming that constituents are being added to the waterbodies only via groundwater. However, for surface impoundment operation, effluent is constantly being discharged directly into that same waterbody. These discharges are regulated under the Clean Water Act, and although they pose an uncertainty in the analysis, they are outside the scope of the risk assessment (see **Section 4.4.1** for further discussion).

4.1.2.2 FBC Wastes

Tables 4-12 and **4-13** show the 90th and 50th percentile risk results for FBC landfills by liner type. These results are much lower than those for conventional CCW and comanaged CCW landfills seen above, and suggest that releases from FBC landfills do not present a hazard to surface waters. This difference may be attributed to lower FBC leachate concentrations and the alkaline nature of FBC wastes. However, as with the FBC results reported for drinking water, the results here are strongly influenced by the small sample size of site data available. Thus, the limitation of only having seven sites may present an uncertainty in the analysis.

Table 4-12. 90th Percentile Risk Results for FBC Wastes: Landfills, Groundwater-to-Surface-Water Pathway

Chemical	90th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
FBC Waste – 7 landfills			
Cancer			
Arsenic III	4E-12	7E-08	0
Arsenic V	3E-12	3E-08	0
Noncancer			
Cadmium	7E-07	0.02	0
Selenium IV	3E-17	8E-03	0
Selenium VI	5E-06	0.1	0
Thallium	5E-06	0.2	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Note that only the chemicals with adequate data that were identified in the screening analysis as needing further assessment (see Section 3.2.4) were modeled.

Table 4-13. 50th Percentile Risk Results for FBC Wastes: Landfills, Groundwater-to-Surface-Water Pathway

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
FBC Waste – 7 landfills			
Cancer			
Arsenic III	0	3E-13	0
Arsenic V	0	6E-14	0

(continued)

50th Percentile Risk Results for FBC Wastes: Landfills, Groundwater-to-Surface-Water Pathway (continued)

Chemical	50th Percentile HQ or Cancer Risk Value[a]		
	Unlined Units	Clay-Lined Units	Composite-Lined Units
Noncancer			
Cadmium	0	2E-05	0
Selenium IV	0	8E-16	0
Selenium VI	0	1E-03	0
Thallium	0	1E-03	0

[a] Values are HQs for all chemicals except arsenic; arsenic values are cancer risk. Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

[b] Note that only the chemicals with adequate data that were identified in the screening analysis as needing further assessment (see Section 3.2.4) were modeled.

4.1.3 Results by Liner Type

The effect of liner type on human health risk for the groundwater-to-drinking-water pathways can be seen in Tables 4-1 through 4-6 and for the groundwater-to-surface water pathway in Tables 4-8 through 4-13, which present risks for WMUs that are unlined, clay lined, and lined with composite liners from the 1995 EPRI survey data (EPRI, 1997). At the 90th percentile, lined units produced lower risk estimates than unlined units for all constituents modeled. Composite liners produced very low to zero risk estimates as compared to clay liners for all constituents modeled for both landfills and surface impoundments. For surface impoundments, clay liners produced higher risk estimates for all constituents as compared to clay liners in landfills. Similar trends are evident at the 50th percentile, where composite liners produced risk estimates of zero or near zero for all constituents for surface impoundments.

Table 4-14 shows how frequent each of the liner types is in the 1995 EPRI survey data modeled in this analysis, and it compares these data with the liner type frequency in the more recent DOE/EPA study (U.S. DOE, 2006). The 56 WMUs surveyed in the U.S. DOE 2006 study were commissioned between 1994 and 2004. Although the actual number of WMUs that were established in that timeframe cannot be verified, based on proxy data (i.e., CCW available for disposal in those states with identified, new WMUs and coal-fired power plant generating capacity), the sample coverage is estimated to be at least 61–63 percent of the total population of the newly commissioned WMUs.[6] With the exception of one landfill, the newly constructed facilities are all lined, with either clay, synthetic, or composite liners. The single unlined landfill identified in the recent DOE report receives bottom ash, which is characterized as an inert waste by the state, and therefore, a liner is not required.

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[6] For additional details as to how these estimates were derived, the reader is referred to the DOE study, pages S-2 – S-3 of the Summary Section and Section 3.1.2..

Table 4-14. Liner Types in EPRI Survey

Liner Type	Landfills	Surface Impoundments
1995 EPRI Survey[a] – 181 facilities		
Unlined	40%	68%
Compacted clay	45%	27%
Synthetic or composite (clay and synthetic)	16%	5%
Total	100%	100%
2004 DOE Survey[b] – 56 Facilities		
Unlined	3%	0%
Compacted clay	29%	17%
Synthetic or composite (clay and synthetic)	68%	83%
Total	100%	100%

[a] EPRI (1997)
[b] U.S.DOE (2006)

As Table 4-14 shows, there is a marked trend away from unlined WMUs in favor of lined units, with a distinct preference for synthetic or composite liners. Comparison of the 26 coal combustion plants in both the EPRI survey and the DOE/EPA survey (U.S. DOE, 2006) shows that although most of those facilities (17 of 26) were using unlined WMUs in 1995, all 26 are now placing wastes in new or expanded landfills or surface impoundments that are lined with clay, synthetic, or composite liners. However, it is likely that the older unlined units were closed with wastes in place, and that these wastes could therefore still pose a threat through groundwater pathways. Also, the number of unlined unit that continue to operate in the United States cannot be determined from the available data.

As described in **Sections 3.4.1** and **3.5.1**, the characteristics of the liners used in the CCW risk were taken from the IWEM model as representative of the general performance of each liner type. For landfills, an engineered compacted clay liner (3 feet thick, with a hydraulic conductivity of 1×10^{-7} cm/s) reduced the 90th percentile risk by a factor of about 2 to 4 compared to no liner, but did not change the constituents at or above an excess cancer risk of 1 in 100,000 (arsenic, excess cancer risk of 1 in 5,000) or an HQ of 1 (thallium, HQ of 2). For surface impoundments, clay liners did reduce the risk to just below an HQ of 1 for cobalt, lead, and selenium.

Composite (clay and synthetic) liners, as modeled in this risk assessment (see **Sections 3.4** and **3.5**), were much more effective at reducing risk for all constituents; 90th (and 50th) percentile risks with composite liners for landfills were zero[7] for arsenic and metals and very low or zero for reactive nitrogen compounds (nitrate and nitrite), and were well below an excess cancer risk of 1 in 100,000 or an HQ of 1 for all constituents for surface impoundments. The analysis used data collected for composite liner performance at industrial waste management

[7] The absence of risk indicates that contaminant infiltration rates were too small for the contaminant plume to reach the receptor well during the 10,000 year period of the analysis. See Section 3.2.2 for a discussion of the empirical liner infiltration data used in this analysis.

facilities, including liner leakage rate for landfills and the number of liner perforations for surface impoundments (TetraTech, 2001). Because data on CCW liner leakage rates were not available, there is some uncertainty in applying these Industrial D Guidance liner performance data to CCW disposal units. Still, these rates do reflect actual performance data from liners under real WMUs. They demonstrate that composite liners can be effective in reducing leaching from CCW WMUs and suggest that there will be a decrease in risk from CCW disposal if more facilities line their WMUs with composite or clay liners. Information from the more recent DOE/EPA study (U.S. DOE, 2006) indicates that composite liners are becoming more prevalent in newly constructed facilities, so the risks from CCW disposal should be lower for newer CCW landfills and surface impoundments.

4.1.4 Constituents Not Modeled in the Full-Scale Assessment

As described in **Section 3.2.4**, full-scale modeling was not conducted for all 21 constituents that were above the screening criteria in the initial screening analysis; only constituents that were judged likely to have generally higher risks to human health and ecological health were modeled in the full-scale risk assessment.[8] Five chemicals (chromium, fluoride, manganese, vanadium, and nickel) had drinking water pathway HQs in the screening analysis ranging from 1 to less than 6 for surface impoundments, and three (chromium, fluoride, and vanadium) had screening HQs of 2 for landfills.

To address these unmodeled constituents, EPA developed surrogate risk attenuation factors by dividing the screening risk results by the full-scale risk results, across all unit (liner) types combined, for the constituents modeled in the full-scale assessment. This comparison was done only for the drinking water exposure pathway, the only human health exposure pathway for which the risks for these constituents were above the screening criteria. **Table 4-15** shows the risk attenuation factor statistics for the modeled constituents, and **Table 4-16** shows the results of applying the median and 10th percentile attenuation factors to the screening risk results for the marginal constituents. Differences in attenuation among the modeled constituents reflect differences in contaminant sorption and mobility. To be conservative, the 10th percentile attenuation factor was selected as a high-end value representing the more mobile constituents, such as arsenic, selenium, and molybdenum. The 50th percentile (or median) risk represents a central tendency value.

Table 4-15. Risk Attenuation Factor[a] Statistics for Modeled Constituents— Groundwater to Drinking Water Pathway

Statistic	Landfill	Surface Impoundment
10th percentile	7	1.6
50th percentile	12	2.6
Average	16	3.3
Maximum	40	9.3

(continued)

[8] These constituents of concern had human health HQs greater than 6 or both ecological HQs greater than 100 at the 90th percentile.

Risk Attenuation Factor[a] Statistics for Modeled Constituents— Groundwater to Drinking Water Pathway (continued)

Statistic	Landfill	Surface Impoundment
Number of data points	9	8

[a] The risk attenuation factor is the ratio of the full-scale analysis risk and screening analysis risk for a constituent modeled in the full-scale analysis.

Table 4-16. Summary of Risk Screening Values for Unmodeled Constituents Using Risk Attenuation Factors—Groundwater-to-Drinking-Water Pathway

WMU/Pathway	Landfill			Surface Impoundment		
	Screening HQ	HQ with Median Attenuation	HQ with 10th Percentile Attenuation	Screening HQ	HQ with Median Attenuation	HQ with 10th Percentile Attenuation
Chromium VI	2.3	0.2	0.3	4.2	1.6	2.6
Fluoride	1.8	0.2	0.3	5.2	2.0	3.3
Manganese	1	0.1	0.1	5.6	2.2	3.5
Vanadium	2.2	0.2	0.3	2.3	0.9	1.4
Nickel	-	-	-	1.3	0.5	0.8

For landfills, the risk attenuation factors ranged from 6 to 40, with the lower attenuation factors mainly representing the more mobile constituents (i.e., those with lower soil sorption potential). Both the median and 10th percentile risk attenuation factors were adequate to reduce risks for all nine constituents below an HQ of 1.

For surface impoundments, risk attenuation factors were considerably lower, ranging from 1 to 9, reflecting higher contaminant mobility due to the higher hydraulic head in surface impoundments (as compared to landfills) and a lower proportion of liners. For the same reason, the screening HQs for surface impoundments were higher than the landfill HQs. As a result of this combination of higher HQs and lower risk attenuation factors, only the HQ for nickel was reduced to below 1 by applying the attenuation factors. The other constituents (chromium, fluoride, manganese, and vanadium) still show risks slightly above an HQ of 1, with HQs ranging from 1.4 to 3.5 at 10th percentile attenuation. This is consistent with the general trend in this analysis of surface impoundments showing higher risks than CCW landfills.

4.1.5 Human Health (Groundwater and Fish Consumption) Damage Case Review

Table 4-17 summarizes the proven damage cases from U.S. EPA (2007) that showed an impact on groundwater, usually through an exceedence of an MCL or state groundwater standard for one or more metals. As detailed in U.S. EPA (2007), these facilities represent worst-case disposal conditions: all are unlined, several represent fills in old quarries, and many have wastes disposed of below the water table. Groundwater standard exceedences are usually onsite or closely offsite. As one can see in the table, the same metals showing risk exceedences for unlined facilities (arsenic, boron, cadmium, lead, molybdenum, and selenium) in this analysis were reported as exceedences in the groundwater damage cases. Other incidents of groundwater contamination supporting the conclusions of this risk assessment can be found in the published literature in references such as Lang and Schlictmann (2004) and Zilmer and Fauble (2004).

Table 4-18 summarizes the five proven damage cases from U.S. EPA (2007) that showed a fish consumption advisory for selenium. Although these were all cases where CCW surface impoundments directly discharged to a lake, and hence larger fluxes of surface impoundment waters into the waterbody of interest than through the groundwater-to-surface-water pathway, they do support the finding of this risk assessment that the fish consumption pathway is of potential concern for selenium in CCW.

Table 4-17. Summary of Proven Damage Cases with Groundwater Impacts (U.S. EPA, 2007)

Proven NODA Damage Case[a]	Reported Groundwater Impacts
1. Salem Acres Site, MA (lagoons and fly ash pile)	Minor – As, Cr, Pb
2. City of Beverly/ Vitale Brothers Fly Ash Pit, MA (quarry fill)	Al, As, Fe, Mn, Se over MCLs
3. Don Frame Trucking, Inc. Fly Ash Landfill, NY	Pb, Mn over MCLs
4. Virginia Electric Power Co. (VEPCO) Possum Point, VA (ash ponds)	Cd, Ni over MCLs
5. PEPCO Morgantown Generating Station Faulkner Off-site Disposal Facility, MD (landfills and settling ponds)	Low pH, iron staining
6. Virginia Power Yorktown Power Station Chisman Creek Disposal Site, VA (quarry fill)	Se, sulfate over MCL; green staining; As, Be, Cr, Cu, Mo, Ni, V over background
9. DOE Oak Ridge Y-12 Plant Chestnut Ridge Operable Unit 2, TN (ash pond)	Al, As, Fe, Pb, Mn over MCL
10. South Carolina Electric & Gas Canadys Plant, SC (ash ponds)	As above MCL outside compliance boundary; NI above state standard
13. Dairyland Power Cooperative E.J. Stoneman Generating Station Ash Disposal Pond, WI	Cd, Cr, sulfate, Mn, Fe, and Zn over MCLs onsite; B over background offsite
14. WEPCO Highway 59 Landfill, WI	As, Se, sulfate, B, Mn, Cl-, Fe over state standards
15. Alliant Nelson Dewey Ash Disposal Facility, WI	As, Se, sulfate, B, F- over state standards
16. WEPCO Cedar-Sauk Landfill, WI	Se, sulfate over MCLs; B over state standard
17. WEPCO Port Washington Facility, WI (quarry fill)	B over state standard; elevated Se
18. Lansing Board of Water & Light North Lansing Landfill, MI (quarry fill)	Li, Mn, Se above state standards
19. Northern Indiana Public Service Corp. Yard 520 Landfill Site, IN	As, B, Mn,, Mo, Pb contaminated residential wells
23. Basin Electric Power Cooperative W.J. Neal Station Surface Impoundment, ND	Al, As, Cd, Cr, Zn above MCL
24. Cooperative Power Association/United Power Coal Creek Station Surface Impoundments, ND	As, Se, sulfate, Cl above MCL; elevated B

[a] Numbers represent original case numbers in U.S. EPA (2007)

Table 4-18. Summary of Proven Damage Cases with Fish Consumption Advisories (U.S. EPA, 2007)

Proven NODA Damage Case	Reported Fish Consumption Advisory
7. Hyco Lake, Roxboro, North Carolina (surface impoundment discharge)	Selenium fish consumption advisory
11. Belews Lake, NC (surface impoundment discharge)	Selenium fish consumption advisory
20. Brandy Branch Reservoir, Texas (ash pond discharge)	Selenium fish consumption advisory
21. Southwestern Electric Power Company Welsh Reservoir, TX (ash pond discharge)	Selenium fish consumption advisory
22. Texas Utilities Electric Martin Lake Reservoir, TX (ash pond discharge)	Selenium fish consumption advisory; elevated selenium in birds

EPA has also found that CCW contaminants of concern in the damage cases agree with those exceeding a 1 in 100,000 excess cancer risk or an HQ of 1 in this analysis, building confidence that the risk assessment captures national conditions. **Table 4-19** compares the results from the 2007 draft risk assessment with the damage cases reported in the *Coal Combustion Waste Damage Case Assessments* (U.S. EPA, 2007) for the groundwater pathway.

Table 4-19. Modeled 90th and 50th Percentile Risk Results vs. Reported Groundwater Exceedences

Constituent	2007 Risk Assessment[a]		Damage Cases[b]			Consistent Results as of 2007[f]
	90th %ile	50th %ile	Human Health Effects[c]	Cosmetic/ Aesthetic Effects[d]	State Standard[e]	
Aluminum	–	–	–	✓	–	Yes
Antimony	✓	–	–	–	–	No
Arsenic	✓	T	✓	–	✓	Yes
Barium	–	–	–	–	–	Yes
Beryllium	Screened		–	–	–	Yes
Boron	✓	–	✓	–	✓	Yes
Cadmium	✓	–	✓	–	–	Yes
Chloride	Not Screened		–	✓	✓	N/A
Chromium	RAF		✓	–	–	Uncertain
Cobalt	✓	T	–	–	–	No
Copper	Screened		–	–	–	Yes
Fluoride	RAF		–	–	✓	Uncertain
Iron	Not Screened		–	✓	✓	N/A
Lead	✓	–	✓	–	–	Yes
Lithium	Not Screened		–	–	✓	N/A
Manganese	RAF		✓	✓	✓	Uncertain
Molybdenum	✓	–	✓	–	–	Yes
Nickel	RAF		✓	–	✓	Uncertain
Nitrate/Nitrite	✓	–	–	–	–	No
Selenium	✓	–	✓	–	✓	Yes
Silver	Screened		–	–	–	Yes
Sulfate	Not Screened		–	✓	✓	N/A
Thallium	✓	–	–	–	–	No
Vanadium	RAF		–	–	–	Uncertain

(continued)

Modeled 90th and 50th Percentile Risk Results vs. Reported Groundwater Exceedences (continued)

Constituent	2007 Risk Assessment[a]		Damage Cases[b]			Consistent Results as of 2007[f]
	90th %ile	50th %ile	Human Health Effects[c]	Cosmetic/ Aesthetic Effects[d]	State Standard[e]	
Zinc	Screened		–	✓	–	Yes

[a] Not Screened = Constituent was not considered due to lack of health-based benchmarks.
Screened = Constituent showed no risk potential in the screening assessment.
RAF = Constituent showed risk potential in the screening assessment, and was analyzed with risk attenuation factors.
✓ = Constituent underwent full probabilistic modeling and was shown to pose a risk to human health in the landfill scenario, the surface impoundment scenario, or both.
– = Constituent underwent full probabilistic modeling and was not shown to pose a risk to human health

[b] ✓ = At least one proven damage case showed an exceedence of this constituent.
– = No proven damage cases have yet shown an exceedence of this constituent.

c ✓ = Exceedences of primary maximum contaminant levels (MCLs) or other health-based numbers published by EPA.

[d] ✓ = Exceedences of secondary MCLs, which would not result in harm to human health.

e ✓ = Exceedences of a relevant state standard.

f Yes = Results of risk assessment and damage cases either both indicated a risk to human health or both indicated no risk to human health.
No = The risk assessment indicated risks where none have yet been found in a proven damage case.
Uncertain = It is possible that the results were consistent, but due to lack of probabilistic modeling, no definitive conclusion can be made.
N/A = Constituent was not examined at any stage in the 2007 risk assessment, so it was not possible to draw any conclusions as to consistency.

The first category of constituents is those for which the risk assessment and the damage cases agree, either because both the risk assessment results and the damage cases indicated risks, or because both the risk assessment results and damage cases did not indicate risks. The former group had model results exceeding the cancer risk range or an HQ of 1, and also appeared in the damage cases with exceedances of maximum contaminant levels (MCLs), state groundwater standards, or other health-based numbers (arsenic, boron, cadmium, lead, molybdenum, and selenium). The latter group did not show the potential for risks above an HQ of 1 from the risk assessment and did not appear in the damage case literature (aluminum, barium, beryllium, copper, silver, and zinc).

The second category of constituents is those for which the risk assessment and the damage cases did not agree. Four modeled constituents (antimony, cobalt, thallium, and nitrate/nitrite) showed risk at the 90th percentile but no damage cases had been proven as of 2007. This could indicate that (1) the risk assessment was conservative for these constituents, (2) not enough time has passed to see the remaining constituents appear in damage cases, (3) corrective action was taken when the first constituent(s) was observed, so further constituents that would have appeared at the same site were never seen, or (4) these constituents are not tested for as frequently as the constituents found in the proven damage cases.

The third category of constituents is those that were not screened out, and were analyzed using risk attenuation factors (chromium, fluoride, manganese, nickel, and vanadium). Because all that is known is that these constituents have the potential to pose a risk to human health, they cannot currently be compared to the damage case results.

The final category of constituents is those that were not evaluated at either the screening or modeling stages because no health-based values were available for comparison. These four constituents (chlorine, iron, lithium, and sulfate) appeared in damage cases because of exceedences of aesthetic or state levels, not because of a known risk to human health.

Table 4-20 compares the results from the 2007 draft risk assessment with the damage cases reported in U.S. EPA (2007) for the fish consumption pathway. The only fish consumption advisories documented in CCW damage cases are for selenium. This is consistent with the risk assessment for selenium. The two constituents that do not pose a risk in the risk assessment (cadmium and thallium) were also not part of any fish consumption advisories in the damage cases. The one inconsistency is arsenic, for which the risk assessment shows a cancer risk of 1 in 50,000, slightly exceeding an excess cancer risk of 1 in 100,000. However, no arsenic fish consumption advisories exist at proven damage case sites. This inconsistency could indicate that (1) the risk assessment was conservative with respect to arsenic, (2) not enough time has passed to see arsenic appear in fish advisories at these sites, or (3) the arsenic exceedences have not been detected in random fish tissue samples thus far.

Table 4-20. Modeled 90th and 50th Percentile Risk Results vs. Reported Fish Consumption Exceedences

Constituent	2007 Risk Assessment[a]		Damage Cases[b]	Consistent Results as of 2007[c]
	90th %ile	50th %ile		
Arsenic	✓	–	–	No
Cadmium	–	–	–	Yes
Selenium	✓	–	✓	Yes
Thallium	–	–	–	Yes

[a] ✓ = Constituent underwent full probabilistic modeling and was shown to pose a risk to human health in the landfill scenario, the surface impoundment scenario, or both.
– = Constituent underwent full probabilistic modeling and was not shown to pose a risk to human health
[b] ✓ = At least one proven damage case showed a fish consumption advisory for this constituent.
– = No proven damage cases have yet shown a fish consumption advisory for this constituent.
[c] Yes = Results of risk assessment and damage cases either both indicated a risk to human health or both indicated no risk to human health.
No = The risk assessment indicated risks where none have yet been found in a proven damage case.

4.2 Ecological Risks

EPA defines ecological risk characterization in terms of (1) the risk estimation, which integrates the exposure and stressor-response profile to estimate the likelihood of adverse ecological effects and (2) the risk description, which synthesizes the overall conclusion of the assessment and addresses assumptions, uncertainty, and limitations.

For assessments that are based on a HQ approach, as this one was, the comparison of modeled exposure concentrations to CSCLs to estimate risk has a binary outcome: either the constituent concentration is above the concentration corresponding to an HQ of 1 or the concentration is less than or equal to the concentration corresponding to an HQ of 1. For the full-scale analysis, an ecological HQ greater than 1 was selected by EPA as a criterion for decision making. Because the CSCLs were based on *de minimis* ecological effects, it is generally presumed that an HQ at or below 1 indicates a low potential for adverse ecological effects for those receptors included in the analysis for which data are available. However, it is important to recognize that although this method provides important insight into the potential for adverse ecological effects, the results are relevant only to those receptors that were included in the assessment and for which data were available. The results have limited utility in interpreting the ecological significance of predicted effects, and caution should be exercised in extrapolating to ecosystems (e.g., wetlands) and receptors (e.g., threatened and endangered species) not explicitly modeled.

This section presents risk results for direct surface impoundment exposure (as evaluated in the 1998 CCW risk assessment, U.S. EPA, 1998a,b), screening results for boron that indicate risks to plants from aboveground exposure, and the two groundwater-to-surface-water ecological exposure pathways investigated in the full-scale analysis: (1) receptors exposed to CCW constituents in the water column (surface water receptors) and (2) receptors exposed to CCW constituents in bed sediment (sediment receptors). Results are presented for the two WMU types addressed in the analysis: landfills and surface impoundments, and are broken out separately for the different unit (liner) types. Finally, ecological damage case reports from U.S. EPA (2007) and from the published literature are summarized as field evidence supporting the conclusions of this risk assessment.

The ecological risk results and damage cases suggest the potential for adverse ecological effects to plants, terrestrial organisms, and aquatic systems from CCW releases into the subsurface and subsequent connection with surface waters, particularly for CCW managed in unlined surface impoundments. As with human health risks, the higher prevalence of liners in newer facilities should result in lower risks in current and future CCW disposal facilities than those presented in this risk assessment.

4.2.1 Direct Surface Impoundment Exposure

The current risk assessment addresses exposure to receptors in offsite surface waterbodies impacted by groundwater, where both the aquatic communities and upper trophic level terrestrial receptors would need to be protected.[7] The 2003 CCW constituent database used

[7] The 2002 CCW constituent database does not include impoundment water samples, and the direct exposure pathway was not addressed.

in this analysis does not include impoundment water samples, and the direct exposure pathway could not be addressed for ecological risk. However, the CCW risk assessment conducted in 1998 (U.S. EPA, 1998a,b) did consider direct exposure of ecological receptors to surface impoundment waters. The approach in the 1998 study restricted the analysis to terrestrial receptors that obtain food and prey from the surface impoundments and excluded aquatic receptors living in the water column because surface impoundments are not intended to be a habitat for aquatic species. For the terrestrial and aquatic receptors considered, the 1998 analysis used the same CSCLs and a similar methodology to that used in the CCW screening analysis (e.g., comparison of 90th percentile waste concentrations with CSCLs).

The 1998 direct exposure results are provided in **Figure 4-1** and show HQs greater than 100 for boron, selenium, lead, barium, and cadmium. This, along with the damage case results presented in **Section 4.2.4**, show a clear likelihood of risks to terrestrial organisms that obtain food and prey from CCW surface impoundments. It is probable that ecological receptors eat and drink from CCW surface impoundments in some settings. In addition, ecological receptors, particularly amphibians who may lay their eggs in surface impoundments, are probably exposed through chronic contact with wastewater. Because amphibians are prey to a large variety of animals (e.g., raptors; wading birds; mammalian omnivores, such as foxes, raccoons, and weasels), this exposure is transferred up the food chain. Aquatic plants, although not often a focus of this ecological risk assessment, are directly exposed in surface impoundments. Plants, in turn, may be ingested by vertebrates and invertebrates at higher trophic levels.

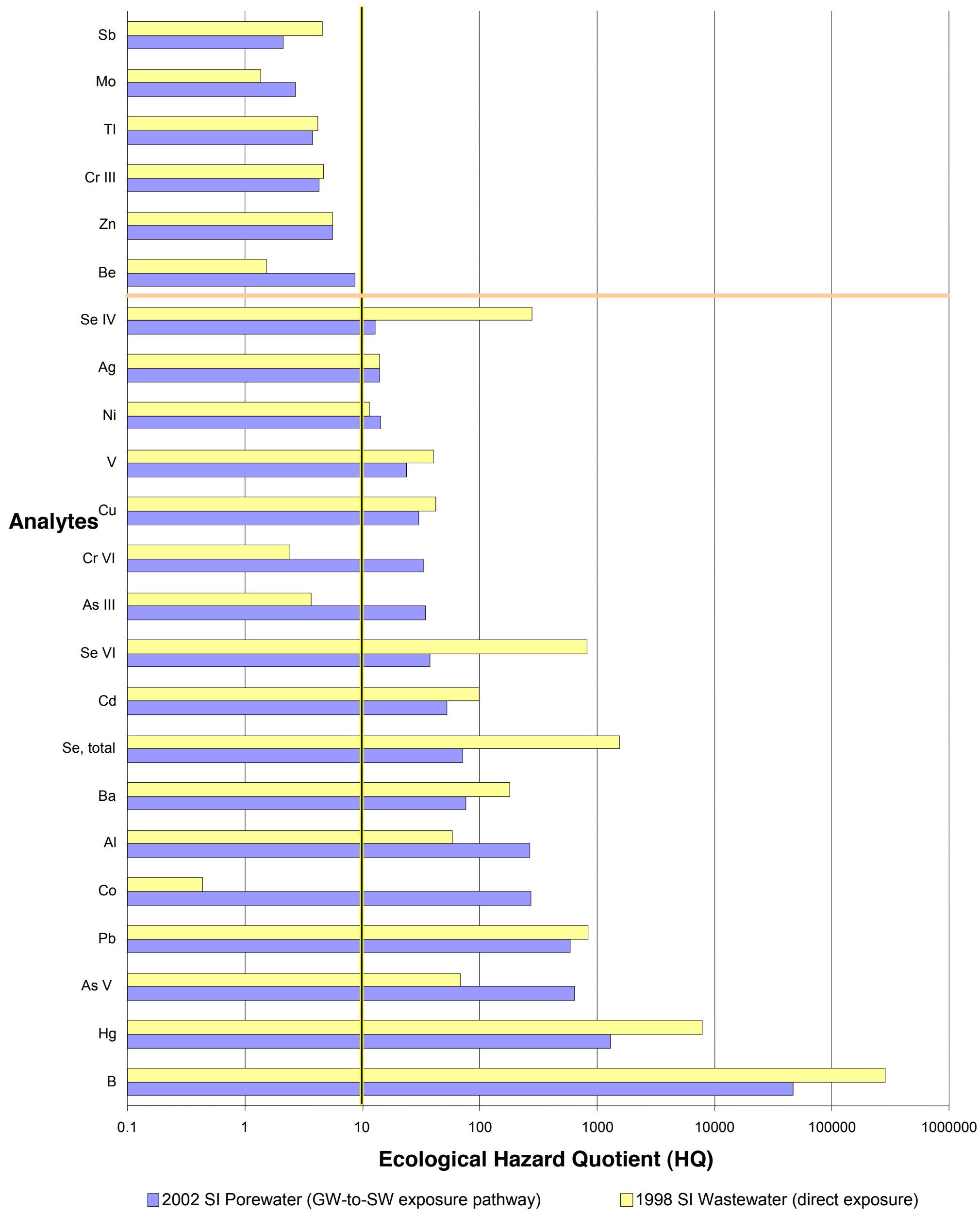


Figure 4-1. CCW surface impoundment ecological screening risks: Direct exposure to surface impoundment wastewater.

4.2.2 Surface Water Receptors (Full-Scale Analysis)

Tables 4-21 and **4-22** present the 90th and 50th percentile results from the full-scale ecological risk assessment of the groundwater-to-surface-water pathway for surface water receptors for CCW landfills and surface impoundments. For landfills, boron (HQ of 281) , lead (HQ of 8), selenium (HQ of 2), arsenic (HQ of 2), and barium (HQ of 2) show risks above an HQ of 1 at the 90th percentile for the unlined units. Clay liners reduce the risks below an HQ of 1 for all constituents except for boron, which still has a very high HQ (78 for the clay liner versus 281 for unlined). For surface impoundments, all modeled constituents except cadmium and aluminum showed 90th percentile risks above the ecological risk criterion, with boron showing an HQ over 2,000 for the unlined units, and other HQs ranging from 3 to 22 for unlined units. The 50th percentile results are all well below an HQ of 1 for landfills and only exceed an HQ of 1 for boron in unlined surface impoundments (HQ = 7).

As with other pathways and receptors, the difference in the number and magnitude of ecological HQs that exceed the risk criterion between landfills and surface impoundments is likely the result of (1) higher CCW constituent concentrations in surface impoundment porewater and (2) the greater flux of contaminants to groundwater predicted during the active life of the surface impoundment. As discussed in **Section 4.1**, the higher infiltration rates for surface impoundments result from a higher hydraulic head in the impoundment and a higher proportion of unlined surface impoundments than landfills in the 1995 EPRI survey data used for this risk assessment.

Table 4-21. Summary of 90th Percentile Full-Scale CCW Ecological Risk Results: Groundwater-to-Surface-Water Pathway, Aquatic Receptors[a]

Chemical	90th Percentile Ecological HQ			Exposure Pathway	Receptor
	Unlined Units	Clay-Lined Units	Composite-Lined Units		
Landfills					
Boron	281	78	0.07	direct contact	aquatic biota
Lead	8	0.4	2E-06	ingestion	river otter
Selenium (VI)	2	0.7	3E-04	direct contact	aquatic biota
Arsenic (V)	2	0.1	4E-08	direct contact	aquatic biota
Barium	2	0.2	0	direct contact	aquatic biota
Cadmium	0.5	0.1	3E-05	direct contact	aquatic biota
Aluminum	0.01	0.003	1E-07	direct contact	aquatic biota
Surface Impoundments					
Boron	2,375	854	257	direct contact	aquatic biota
Lead	22	7	2	ingestion	river otter
Arsenic (V)	13	4	5	direct contact	aquatic biota
Selenium (VI)	12	4	1	direct contact	aquatic biota
Cobalt	6	3	5	direct contact	aquatic biota
Barium	3	1	0.8	direct contact	aquatic biota
Cadmium	1	0.7	0.4	direct contact	aquatic biota
Aluminum	0.03	0.01	0.008	direct contact	aquatic biota

[a] Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

Table 4-22. Summary of 50th Percentile Full-Scale CCW Ecological Risk Results: Groundwater-to-Surface-Water Pathway, Aquatic Receptors[a]

Chemical	50th Percentile Ecological HQ			Exposure Pathway	Receptor
	Unlined Units	Clay-Lined Units	Composite-Lined Units		
Landfills					
Boron	0.2	0.1	0	direct contact	aquatic biota
Lead	7E-05	4E-08	0	ingestion	river otter
Selenium (VI)	0.002	0.001	0	direct contact	aquatic biota
Arsenic (V)	4E-06	5E-09	0	direct contact	aquatic biota
Barium	1E-10	4E-12	0	direct contact	aquatic biota
Cadmium	2E-04	9E-05	0	direct contact	aquatic biota
Aluminum	3E-07	8E-09	0	direct contact	aquatic biota
Surface Impoundments					
Boron	7	0.4	5E-05	direct contact	aquatic biota
Lead	0.05	0.0008	0	ingestion	river otter
Arsenic (V)	0.03	0.0007	0	direct contact	aquatic biota
Selenium (VI)	0.03	0.002	4E-07	direct contact	aquatic biota
Cobalt	0.01	0.001	0	direct contact	aquatic biota
Barium	0.006	0.0004	0	direct contact	aquatic biota
Cadmium	0.008	0.0003	0	direct contact	aquatic biota
Aluminum	0.0007	4E-05	4E-11	direct contact	aquatic biota

[a] Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

4.2.3 Sediment Receptors (Full-Scale Analysis)

Tables 4-23 and 4-24 present the 90th and 50th percentile results of the ground-water-to-surface-water pathway for sediment receptors for landfills and surface impoundments. For unlined landfills, lead (HQ of 58), arsenic (HQ of 11), cadmium (HQ of 5), and antimony (HQ of 2) show 90th percentile risks above the ecological risk criterion. For clay lined landfills, only arsenic (HQ of 3) has an ecological HQ greater than 1. For surface impoundments, lead, arsenic, and cadmium showed 90th percentile HQs above 1 for unlined, clay-lined, and composite-lined units (with HQs ranging from 2 to 311). Although cadmium was not above the risk criterion in surface water, it did have an HQ of 30 in sediments at the 90th percentile for unlined surface impoundments and HQs of 9 and 2 for clay- and composite-lined impoundments respectively. None of the constituents modeled showed sediment risks at or above an HQ of 1 at the 50th percentile.

Table 4-23. Summary of 90th Percentile Full-Scale CCW Ecological Risk Results: Groundwater-to-Surface-Water Pathway, Sediment Receptors[a]

Chemical	90th Percentile Ecological HQ			Exposure Pathway	Receptor
	Unlined Units	Clay-Lined Units	Composite-Lined Units		
Landfills					
Lead	58	1	1E-06	direct contact	aquatic biota
Arsenic (III)	11	3	5E-04	ingestion	river otter
Cadmium	5	1	6E-05	direct contact	aquatic biota
Antimony	2	0.5	7E-05	direct contact	aquatic biota
Molybdenum	0.1	0.03	2E-05	direct contact	aquatic biota
Barium	0.006	6e-04	0	direct contact	aquatic biota
Surface Impoundments					
Lead	311	58	4	direct contact	aquatic biota
Arsenic (III)	127	55	31	ingestion	river otter
Cadmium	30	9	2	direct contact	aquatic biota
Molybdenum	0.9	0.3	0.1	direct contact	aquatic biota
Barium	0.008	0.004	0.002	direct contact	aquatic biota

[a] Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

Table 4-24. Summary of 50th Percentile Full-Scale CCW Ecological Risk Results: Groundwater-to-Surface-Water Pathway, Sediment Receptors[a]

Chemical	50th Percentile Ecological HQ			Exposure Pathway	Receptor
	Unlined Units	Clay-Lined Units	Composite-Lined Units		
Landfills					
Lead	6E-05	9E-08	0	ingestion	spotted sandpiper
Arsenic (III)	4E-03	0.002	0	ingestion	spotted sandpiper
Cadmium	5E-04	2E-04	0	direct contact	sediment biota
Antimony	3E-04	1E-04	0	direct contact	sediment biota
Molybdenum	5E-05	3E-05	0	ingestion	spotted sandpiper
Barium	3E-13	8E-15	0	ingestion	spotted sandpiper
Surface Impoundments					
Lead	0.1	0.001	0	ingestion	spotted sandpiper
Arsenic (III)	0.4	0.02	4E-09	ingestion	spotted sandpiper
Cadmium	0.02	0.0007	0	direct contact	sediment biota
Molybdenum	0.004	0.0002	2E-08	ingestion	spotted sandpiper
Barium	1E-05	1E-06	0	ingestion	spotted sandpiper

[a] Zero results indicate that contaminant infiltration rates were too small for the contaminant plume to reach the receptor during the 10,000 year period of the analysis.

4.2.4 Constituents Not Modeled in the Full-Scale Assessment

As described in **Section 3.2.4**, full-scale modeling was not conducted for 6 constituents with generally lower risks to ecological receptors.[9] These chemicals (chromium, vanadium, beryllium, copper, silver, and zinc), had surface water pathway HQs in the screening analysis ranging from 16 to 110 for landfills, and four (chromium, vanadium, copper, and silver) had screening HQs ranging from 14 to 33 for surface impoundments.

These constituents were addressed using risk attenuation factors developed by dividing the screening risk results by the full-scale risk results for the constituents that were modeled in the full-scale assessment. **Tables 4-25** and **4-26** show the results of this comparison for the surface water ecological risk exposure pathway. Table 4-23 shows the risk attenuation factors for the modeled constituents, and Table 4-24 shows the results of applying the median (central tendency) and 10th percentile (conservative) attenuation factors to the screening risk results for constituents that were not modeled.

For landfills, the risk attenuation factors ranged from 50 to 2,000. Both the median and 10th percentile risk attenuation factors were adequate to reduce risks to an HQ below 1 for all constituents except for silver. Although silver shows an HQ of 1.5 using the 10th percentile attenuation factor, silver's low mobility would probably result in a higher attenuation factor (i.e., at the median or greater).

For surface impoundments, risk attenuation factors ranged from 7.1 to 64, reflecting higher contaminant mobility from the higher hydraulic head in the surface impoundments and a lower prevalence of liners (compared to landfills) in the 1995 EPRI data. HQs were reduced below 1 for all four unmodeled constituents with the median attenuation factor (38), and the HQ for silver was reduced to 0.8 by applying the 10th percentile attenuation factor (17). The other three constituents (chromium, vanadium, and copper) show HQs slightly above 1 with the10th percentile attenuation (HQs ranging from 1.4 to 1.9). Note that the risks for chromium are based on the protective assumption of 100 percent hexavalent chromium in CCW.

Table 4-25. Risk Attenuation Factor[a] Statistics for Modeled Constituents— Ecological Risk, Surface Water Pathway (all unit types combined)

Statistic	Landfill	Surface Impoundment
10th percentile	75	17
50th percentile	178	38
Average	483	38
Maximum	2,000	64
Number of data points	6	7

[a] The risk attenuation factor is the ratio of the full-scale analysis risk and screening analysis risk for a constituent modeled in the full-scale analysis.

[9] These constituents had only one or no ecological HQs greater than 100.

Table 4-26. Summary of Risk Screening Values for Unmodeled Constituents Using Risk Attenuation Factors—Ecological Risk, Surface Water Pathway

WMU/Pathway	Landfill			Surface Impoundment		
	Screening HQ	HQ with Median Attenuation	HQ with 10th Percentile Attenuation	Screening HQ	HQ with Median Attenuation	HQ with 10th Percentile Attenuation
Chromium VI	18	0.1	0.2	33	0.9	1.9
Vanadium	23	0.1	0.3	24	0.6	1.4
Beryllium	24	0.1	0.3	-	-	-
Copper	16	0.09	0.2	31	0.8	1.8
Silver	110	0.6	1.5	14	0.4	0.8
Zinc	16	0.09	0.2	-	-	-

4.2.5 Ecological Damage Cases

Cases of damages to terrestrial and aquatic organisms from improperly managed CCW are common in the literature. For example, Carlson and Adriano (1993) summarize such damage incidents, including those resulting from alkaline CCW effluent discharge to surface waterbodies and boron toxicity to plants. Rowe et al. (2002) provide a more comprehensive review, assessment, and meta-analysis of the ecotoxicity of CCW, focusing on aquatic disposal (i.e., CCW surface impoundments) and tabulating damages from over 20 years of field and laboratory studies in the published literature. Selenium and arsenic are most commonly associated with CCW damages to terrestrial and aquatic organisms. Cadmium, boron, chromium, and lead are also associated with CCW ecological risk. Hopkins et al. (2006) show deformities and reproductive effects in amphibians living on or near CCW disposal sites in Georgia, which are mainly attributed to selenium exposure.

Table 4-27 summarizes the proven CCW ecological damage cases from U.S. EPA (2007). Most of these cases are from surface impoundments and direct discharge into lakes and other water bodies. Along with the published results discussed in **Section 4.1.5**, these cases clearly support selenium and arsenic in coal ash as risks to aquatic ecosystems, as well as the adverse impacts of coal ash on terrestrial vegetation.

Table 4-27. Summary of Proven Damage Cases with Ecological Impacts (U.S. EPA, 2007)

Proven NODA Damage Case	Reported Ecological Impacts
2. City of Beverly/ Vitale Brothers Fly Ash Pit, MA (quarry fill)	Contamination of wetlands and surface waters
5. PEPCO Morgantown Generating Station Faulkner Off-site Disposal Facility, MD (landfills and settling ponds)	Vegetative damages, contamination of stream and wetland by GW
6. Virginia Power Yorktown Power Station Chisman Creek Disposal Site, VA (quarry fill)	As, Be, Cr, Cu, Mo, Ni, Se, V contamination of onsite ponds and offsite creek
7. Hyco Lake, Roxboro, North Carolina (surface impoundment discharge)	Se fish advisory; fish reproduction and population effects
8. Georgia Power Company, Plant Bowen, Cartersville, GA (ash pond over sinkhole)	Ash slurry release damaged creek
9. DOE Oak Ridge Y-12 Plant Chestnut Ridge Operable Unit 2, TN (ash pond)	Se, As, Tl elevated in bass; As over screening criteria; deformed fish; stress on aquatic ecosystem; Se plant and mammal uptake
11. Belews Lake, NC (surface impoundment discharge)	Fish advisory for Se; 16 of 20 fish species eliminated from lake
12. U.S. Department of Energy Savannah River Project, SC (landfill)	Impacts on amphibians (deformities) and snake (metabolic effects)
16. WEPCO Cedar-Sauk Landfill, WI	Wetland vegetative damage from B in groundwater
20. Brandy Branch Reservoir, Texas (ash pond discharge)	Se fish consumption advisory
21. Southwestern Electric Power Company Welsh Reservoir, TX (ash pond discharge)	Se fish consumption advisory
22. Texas Utilities Electric Martin Lake Reservoir, TX (ash pond discharge)	Se fish consumption advisory; elevated Se in birds

4.3 Sensitivity Analysis

EPA conducted a sensitivity analysis (U.S. EPA, 2009b) on the probabilistic risk assessment to determine which model inputs were most important to risk, which in turn helped focus additional analyses and data collection efforts on the most important drivers of risk, and helped identify the important factors to consider when evaluating regulatory and management options for CCW. The sensitivity analysis also helped identify parameters that are both sensitive and highly uncertain, which affects the confidence in the results.

The CCW sensitivity analysis used a response-surface regression method that derives a statistical model for risk (as the dependent variable) based on the input parameters from the probabilistic analysis (as independent variables). Environmental concentration (rather than risk) was chosen as the dependent variable for the sensitivity analysis because (1) there is a direct, linear relationship between environmental concentrations and risks and (2) the additional inputs used to calculate risk from environmental concentration (i.e., exposure factors, such as body weight, ingestion rates) are lifestyle variables that are not amenable to regulation to reduce or manage risk. Furthermore, these variables have well-established, peer-reviewed, national distributions, which are regularly used in the probabilistic national risk analyses conducted by EPA. Therefore, the contribution of the exposure factors to the variability in risk was not particularly useful for the primary purposes of the sensitivity analysis, to better understand sources of uncertainty in the CCW risk results and to help focus regulatory development on sensitive variables that can be addressed through the RCRA regulatory process.

The outputs from the sensitivity analysis were goodness-of-fit values for the regression models and the relative importance of each input parameter in determining environmental concentrations across different WMU, waste type, and constituent scenarios. The goodness-of-fit values of the regression models were moderate to very good for the drinking water pathway (R^2=0.53–0.90) and good to very good for fish consumption (R^2=0.76–0.90). In general, the drinking water pathway had more input parameters that were significant (seven) than the fish consumption pathway (three). The most sensitive parameters for most (over 70 percent) of the drinking water scenarios[10] evaluated were parameters impacting groundwater flow:

- Infiltration rate within the WMU footprint
- Leachate concentration from the WMU
- Aquifer hydraulic conductivity and groundwater gradient (i.e., groundwater velocity).

For many (over 30 percent) of the scenarios, including those corresponding to strongly sorbing contaminants (i.e., metals with high soil/water partition coefficients), sorption and travel time parameters are also important, including

- Adsorption isotherm coefficient
- Depth to groundwater
- Receptor well distance.

For the fish consumption pathway, only three variables were consistently significant across scenarios:

- Infiltration rate within the WMU footprint
- Leachate concentration from the WMU
- Waterbody flow rate.

Additional detail on how the CCW sensitivity analysis was conducted can be found in U.S. EPA (2009b). In terms of the model inputs, the sensitivity analysis found that the most consistent drivers of the risk results were constituent concentration in waste leachate (i.e., the source term for the risk assessment and infiltration rate through the WMU), which is largely controlled by the liner conditions and, to a lesser extent, soil type and (for landfills only) precipitation. These variables and their uncertainties are discussed in the following section.

[10] Scenarios represent unique combinations of WMU, waste type, chemical, exposure pathway, and receptor.

4.4 Variability and Uncertainty

Variability and uncertainty are different conceptually in their relevance to a probabilistic risk assessment. Variability represents true heterogeneity in characteristics, such as body weight differences within a population or differences in pollutant levels in the environment. It accounts for the distribution of risk within the exposed population. Although variability may be known with great certainty (e.g., age distribution of a population may be known and represented by the mean age and its standard deviation), it cannot be eliminated and needs to be treated explicitly in the assessment. Uncertainty is a description of the imperfection in knowledge of the true value of a particular parameter. In contrast to variability, uncertainty can be reduced through additional information-gathering or analysis (i.e., better data, better models). EPA typically classifies the major areas of uncertainty in risk assessments as scenario uncertainty, model uncertainty, and parameter uncertainty. Scenario uncertainty refers to missing or incomplete information needed to fully define exposure and dose. Model uncertainty is a measure of how well the model simulates reality. Parameter uncertainty is the lack of knowledge regarding the true value of a parameter used in the assessment.

> **Variability** arises from true heterogeneity in characteristics, such as body weight differences within a population or differences in contaminant levels in the environment.
>
> **Uncertainty** represents a lack of knowledge about factors such as the nature of adverse effects from exposure to constituents, which may be reduced with additional research to improve data or models.

Uncertainty and variability can be addressed two ways:

- By varying parameter values in a probabilistic assessment such as a Monte Carlo analysis
- By comparing the data or results to other data or other studies such as damage cases or alternative results based on different assumptions.

In planning this assessment, EPA addressed as much of the variability as possible, either directly in the Monte Carlo analysis or through aggregation of the data into discrete elements of the analysis. For example, spatial variability in soil, aquifer, and climate data was accounted for by using distributions for soil and aquifer properties around the facility when the actual environmental characteristics around a WMU are uncertain. Conversely, variability in waste leachate concentrations was represented by a national database of CCW constituent concentrations from disposal sites around the country. These data were aggregated by waste and WMU types that were defined by statistically significant differences in concentration. Variability in human exposure factors (e.g., body weight, ingestion rates) was accounted for using national distributions that represent the range of possible values.

Because CCW is generated nationwide, its disposal may occur anywhere in the United States. Thus, this assessment characterized environmental conditions that influence the fate and transport of constituents in the environment using site-specific data collected around coal-fired power plants with onsite CCW disposal facilities. Spatial variability in environmental setting was accounted for by the site-to-site variables for the 181 CCW disposal sites modeled in the analysis using 41 different climate regions and 9 different hydrologic regions throughout the contiguous 48 states.

In summary, a distribution of exposures was developed that included specific consideration of the variability in the following sensitive model parameters

- WMU characteristics, in particular liner type (which strongly influences infiltration rate)
- CCW constituent concentrations in waste leachate
- Distance to nearest well
- Site-specific environmental conditions (especially groundwater flow conditions)
- Human exposure factors.

Uncertainty was also considered in the analysis by using reasonable ranges and distributions when variables were not known exactly. For example, when a soil texture or groundwater flow conditions could not be precisely assigned at a site, multiple soil types or hydrogeologic environments were sampled based on the soil and aquifer types that were likely to be present at the site.

The treatment of variability and uncertainty in model parameters using a Monte Carlo simulation formed the basis for the national exposure distributions used in this analysis to estimate risk. Previous sections of this document describe how EPA generated distributions and estimated input parameter values and then used these values in models to estimate risk. The discussion in this section focuses on how this treatment of variability and uncertainty affects the analysis results and on various comparisons we performed on the results or critical input data to evaluate uncertainty. **Table 4-28** lists the more important uncertainties described in this section, along with whether the uncertainty is likely to underestimate or overestimate risk, or if its effect on the risk results is uncertain.

Table 4-28. Summary of CCW Uncertainties and Their Effect on Risk Estimates

Uncertainty	Likely Effect on Risk		
	Overestimates	Uncertain	Underestimates
Scenario Uncertainties			
CCW Management Unit Data (1995 EPRI Survey)		✓	
Liner type (as built, 1995; liners more prevalent today)	✓		
Direct discharge from CCW impoundments (not addressed in CCW risk assessment; covered by NPDES)			✓
Effect of the 10,000-year timeframe for groundwater (complete leaching, long timeframe)	✓		
Receptor populations evaluated (high-end receptor and child living near CCW WMU)	✓		
Additive risks across pathways (not considered)			✓
Co-occurrence of ecological receptors and constituents	✓		
Ecosystems and receptors at risk		✓	

(continued)

Summary of CCW Uncertainties and Their Effect on Risk Estimates (continued)

Uncertainty	Likely Effect on Risk		
	Overestimates	**Uncertain**	**Underestimates**
Model Uncertainties			
Clean closure of surface impoundments			✓
Arsenic and selenium speciation	✓		
100% bioavailability of constituents to ecological receptors	✓		
Compaction of landfilled waste	✓		
Landfills above water table			✓
Indirect ecological effects (not considered)			✓
Full mixing effects on aquifer pH (full mixing assumed; effect depends on constituent)	✓	✓	✓
Goethite versus hydrous ferric oxide sorbent	✓		
Multiple constituent exposures (not considered)			✓
Parameter Uncertainties			
Waste concentrations (2002 CCW constituent database)		✓	
Appropriateness of leachate data (TCLP results)		✓ (noncancer)	✓ (cancer)
Constituents with many nondetect analyses (e.g., mercury)		✓	
Treatment of nondetect analyses at half detection limit		✓	
WMU locations (1995 EPRI survey data)		✓	
WMU characteristics (1995 EPRI survey liner types, unit sizes)	✓		
Well location (MSW landfill survey data)		✓	
Well location (well always within plume)	✓		
Location and characteristics of waterbodies		✓	
Soil and aquifer characteristics		✓	
Waterbodies intercepting the groundwater plume	✓		
Human exposure factors		✓	
All drinking water from CCW-contaminated well)	✓		
Human health benchmarks	✓ (cancer)	✓ (noncancer)	
Ecological benchmarks		✓	

4.4.1 Scenario Uncertainty

Sources of scenario uncertainty include the assumptions and modeling decisions that are made to represent an exposure scenario. Because this risk assessment attempted to characterize current conditions by estimating risks from actual CCW disposal sites across the country, it was subject to less scenario uncertainty than risk assessments that rely on hypothetical conceptual models. However, certain aspects of the scenario are uncertain.

CCW Management Unit Data. The landfills and surface impoundments modeled in this risk assessment were placed, sized, and lined according to data from the 1995 EPRI survey (EPRI, 1997). New data collected by EPA and DOE since this risk assessment was conducted (U.S. DOE, 2006) indicate that liners are much more prevalent in WMUs constructed or expanded from 1994 through 2004 than in units in place before that. This suggests that the risks may be lower for future CCW disposal facilities (although most of the unlined WMUs have been closed with wastes remaining in the units).

Liner-related questions are especially important because liner configurations greatly influence infiltration rates, one of the most sensitive parameters in the risk assessment. In terms of risks through groundwater pathways, this risk assessment has shown that liners, in particular composite (combined clay and synthetic) liners, can limit risks through subsurface exposure pathway, and the DOE/EPA survey shows that liners are more prevalent in newly constructed WMUs and WMU expansions. Although the DOE/EPA survey does not shed light on how many unlined facilities are still operating today, it does indicate that more units are lined today than were in the 1995 EPRI survey data set on which this risk assessment was based.

Although it would have been possible to address this uncertainty by evaluating different hypothetical liner scenarios for each facility, such an approach was outside the original scope of this risk assessment, which was to evaluate current CCW management activities, not hypothetical management scenarios. Furthermore, this approach likely would not have changed the general conclusion of the risk assessment that composite lined landfills pose less risk than clay lined landfills and that unlined landfills pose the greatest risk.

Direct Discharge of CCW Impoundments into Surface Water. Because this risk assessment addressed CCW disposal under RCRA, it did not include risks from the direct discharge of wastes into waterbodies, which are regulated under the Clean Water Act. Although not relevant for the management of RCRA waste disposal, EPA recognizes that CCW surface impoundment effluent may pose additional risks.

Effect of the 10,000-Year Timeframe for Groundwater. The risk assessment assumed that contaminant concentrations in the leachate remain constant throughout the 10,000-year modeling timeframe, although leaching may or may not persist for 10,000 years, depending on model inputs. The waste concentration model input was assumed to be a portion of the total waste concentration available to be leached, and it was assumed that 100% of the constituent in the waste could leach from the landfill. The nonlinear fate and transport solution used for metallic constituents in the unsaturated zone module of EPACMTP is based on the assumption that the leachate concentration released from the waste management unit is constant over time (see Section 3.3.5.3 of U.S. EPA, 2003b). Although a leaching profile that changes over time might be more realistic, the simplified leaching profile used by the model does not lead to a poorer estimate of risk associated with groundwater exposures. The adoption of a simplified leaching profile to support a non-linear sorption approach in the unsaturated zone offered a greater benefit and defensibility to the overall approach than assuming linear partitioning and a depleting leachate profile would have.

Receptor Populations Evaluated. The human receptors evaluated for the CCW risk analysis were a family with children residing near the CCW disposal facility, drinking from a private well screened in a surficial aquifer or eating fish caught from a nearby stream or lake impacted by CCW leachate. Additionally, except for a 15-day vacation, it was assumed that adults and children were exposed daily and that the private well was the only source of drinking water. Although it is possible for other types of individuals to be exposed, the use of the resident adult and child as protective of other receptors and pathways is a high-end, simplifying assumption of the analysis. The lack of information to define and model actual exposure conditions also introduces uncertainty into this assessment, but EPA believes that the national distribution of exposure factors used is appropriate for a national assessment.

In addition, not all possible exposure pathways were evaluated. For example, the risk assessment did not consider potential indirect exposure to humans through game species that may have been exposed to surface impoundment waste (e.g., deer drinking surface impoundment water). This represents a potential uncertainty in the analysis.

Additive Risks Across Pathways. The human receptors evaluated in the CCW risk assessment were assumed not to consume both contaminated fish and drinking water from the same waterbody because untreated surface water is not considered potable water (municipal water treatment facilities were assumed to reduce contaminant levels prior to consumption). EPA also did not consider the potential cumulative exposure from contaminated fish and groundwater in the CCW risk assessment, because the exposures are likely to occur over different timeframes (because of differences in transit time of the contaminant plume to wells versus surface waterbodies) and may involve different receptors (because a resident near a CCW surface impoundment or landfill and exposed via groundwater may not be a recreational fisher). Although this could potentially miss some higher exposures for a maximally exposed individual, analysis of the individual pathway results does not indicate that adding such risks would change the conclusions of this risk assessment in terms of the constituents exceeding the risk criteria. Also, risks were high enough for single chemicals for human exposure pathways (notably arsenic) that this would not change the basic conclusion of the risk assessment that there are potentially significant risks to human health from CCW disposal in landfills and surface impoundments.

Co-Occurrence of Ecological Receptors and Constituents. As a simplification for national-scale analyses in the absence of site-based data, co-occurrence of the ecological receptors and the constituents of concern is typically assumed. However, the prior probability that a receptor will be found in waterbodies affected by constituent releases from CCW WMUs is not known, nor is it known whether a receptor will forage for food in contaminated areas or if those areas do, in fact, support the type of habitat needed by the receptor. Although the assumption of co-occurrence was necessary for this analysis, relatively few field studies are available to demonstrate the relationship between adverse ecological effects and constituent releases from CCW as it is currently managed.

Ecosystems and Receptors at Risk. One challenge in conducting a predictive ecological risk assessment intended to reflect risks at a national scale is representing *all* of the receptors and ecosystems at risk. In *Wastes from the Combustion of Coal by Electric Utility Power Plants - Report to Congress* (U.S. EPA, 1988b), the authors pointed out that plants or animals of concern were located within a 5-km radius of the CCW WMUs at 12 to 32 percent of the sites. Although these figures are of limited spatial resolution, they suggest the possibility that threatened and endangered species or critical habitats may be at risk from CCW constituents. Examples of other critical assessment endpoints not evaluated in this analysis include the following:

- **Managed Lands:** Because protected lands play a critical role in preserving plant and animal species, managed areas in the United States represent well-recognized ecological values. Managed lands refer to a variety of lands designated by the federal government as worthy of protection, including National Wildlife Refuges, National Forests, Wilderness areas, and National Recreation areas.

- **Critical Habitats:** Although critical habitats may be defined in a number of ways (e.g., presence of threatened species, decreasing habitat area), wetlands are widely recognized as serving critical ecological functions (e.g., maintenance of water quality). The U.S. Fish and Wildlife Service estimates that approximately 45 percent of the Nation's threatened and endangered species directly depend on aquatic and wetland habitats. Consequently, impacts of chemical stressors on wetland habitats may have high ecological (and societal) significance. The presence of critical habitats such as wetlands is also used to inform the selection of ecological receptors (e.g., amphibians, waterfowl) and the construction of appropriate food webs.

- **Threatened and Endangered Species:** For most ecological risk assessments of chemical stressors, available data on toxicity and biological uptake are sufficient to support the evaluation of effects on representative species populations or generalized communities (e.g., the aquatic community). However, despite their obvious value, threatened and endangered species are frequently excluded from the analytical framework for national rulemakings. The assessment of threatened and endangered species requires a site-specific approach in which locations, habitats, and species of concern are identified and characterized with respect to the spatial scale of constituent releases.

Although these classes of receptors and potential ecological hazards are not explicitly considered in the analysis, conditions represented by simulations in the upper end of the risk distribution (higher risk scenarios) should reasonably characterize many situations with such sensitive species or habitats.

Impact on Groundwater as a Resource. The risk assessment did not explicitly consider potential impacts on the availability of groundwater in the future (e.g., contaminated groundwater becoming unsuitable for consumption), but the results do clearly indicate that there can be a reduction in resource availability if CCW is improperly disposed. However, the scope of the risk assessment was to evaluate human health and ecological effects associated with current waste disposal practices and conditions, and a quantitative evaluation of potential future reductions in groundwater availability as a consequence of CCW disposal practices was not conducted as part of this analysis.

4.4.2 Model Uncertainty

Model uncertainty is associated with all models used in a risk assessment because models and their mathematical expressions are simplifications of reality that are used to approximate real-world conditions and processes and their relationships. Computer models are simplifications of reality, requiring exclusion of some variables that influence predictions but that cannot be included in models either because of their complexity or because data are lacking on a particular parameter. Models do not include all parameters or equations necessary to express reality because of the inherent complexity of the natural environment and the lack of sufficient data to describe the natural environment. Because this was a probabilistic assessment that predicted what may occur with the management of CCW under actual scenarios, it is possible to compare the results of these models to specific situations.

The risk assessor needs to consider the importance of excluded variables on a case-by-case basis, because a given variable may be important in some instances and not important in others. A similar problem can occur when a model that is applicable under one set of conditions is used for a different set of conditions. In addition, in some instances, choosing the correct model form is difficult when conflicting theories seem to explain a phenomenon equally well. In other instances, EPA does not have established model forms from which to choose to address certain phenomena, such as facilitated groundwater transport.

The models used in this analysis were selected based on science, policy, and professional judgment. These models were selected because they provide the information needed for this assessment and because they are generally considered to reflect the state of the science. Even though the models used in this analysis are used widely and have been accepted for numerous applications, they each retain significant sources of uncertainty. These limitations are well documented in the model development references cited in **Section 3**.

Although the sources of model uncertainty in this assessment could result in either an overestimation or an underestimation of risk, the models used in this assessment have been developed over many years to support regulatory applications. As a result, they have been designed to be protective of the impacted populations that they represent. In other words, where simplifying assumptions are necessary, the assumptions are made in a way that will not underestimate risk.

Assumption of Clean Closure of Surface Impoundments. As described in **Section 3.5.1**, the surface impoundment model treats a surface impoundment as a temporary waste management unit with a set operational life. At the end of this life, clean closure is assumed; all wastes are removed and there is no further release of waste constituents to groundwater. Although this simplifying assumption is not consistent with the practice to close CCW surface impoundments with wastes in place, and it limits the length of potential exposure, the peak annual leachate concentrations on which the CCW risk results were based are not likely to be affected. Releases to groundwater are much higher during surface impoundment operation because the higher hydraulic head in an operating impoundment drives wastewater into the underlying soil with greater force than infiltration through the impoundment cover after the impoundment is closed. This higher head results in a greater flux of contaminants to groundwater during the active life of the surface impoundment, especially in unlined units. Thus, even if the post-closure period were modeled, the corresponding results would not be as high as the peak annual leachate concentrations used in the analysis.

Arsenic and Selenium Speciation. Because the models used in this assessment do not speciate metals during soil or groundwater transport, arsenic and selenium speciation in the subsurface is a significant groundwater modeling uncertainty in this analysis. Arsenic can occur in either a +3 (arsenic III) or +5 (arsenic V) oxidation state in groundwater, with arsenic III being the more mobile form. Selenium can occur in either a +4 (selenium IV) or +6 (selenium VI) oxidation state in groundwater, with selenium VI being the more mobile form. Because the soil and groundwater models assume one form for each model run, the risk results presented for arsenic and selenium were originally based on 100% arsenic III and selenium VI, which is a high-end assumption (i.e., arsenic III has higher risks than arsenic V and selenium VI has higher risks than selenium IV). Although arsenic is generally thought to occur in the +3 form in leachate, there is evidence from damage cases at CCW disposal sites that suggests that arsenic III is converted to arsenic V during subsurface transport at some sites (see, for example, U.S. EPA, 2000, 2003e; Lang and Schlictmann, 2004; Zillmer and Fauble, 2004). To address the uncertainty of running the model with 100% arsenic III and selenium VI, the models were also run assuming 100% arsenic V and selenium IV. The results from the two species should bracket the results expected given some mixing of oxidation states.

Bioavailability of Constituents to Ecological Receptors. For the purposes of this analysis, the model assumed that all forms of a constituent were equally bioavailable to ecological receptors, and therefore, the actual exposures that may occur in the field tend to be overestimated, thus making this a high-end assumption. Both the chemical form and the environmental conditions influence bioavailability and ultimately the expression of adverse effects. For example, as discussed above, the form of arsenic has been shown to profoundly influence mobility and toxicity.

Compaction of Landfilled Waste. The source model did not consider potential compaction of CCW waste over time. Such compaction could decrease the hydraulic conductivity and the associated water infiltration. However, no readily available data were identified to support an analysis of the influence of CCW compaction on infiltration rates. The current approach would tend to overestimate infiltration rates compared to a model that would adjust the hydraulic conductivity over time due to compaction. EPA believes this is an appropriately conservative assumption given the lack of the information needed to accurately model the effects of waste compaction.

Landfills Assumed to be Above Water Table. The landfill source model and EPACMTP assume that the source is above the water table. However, some actual CCW disposal units do extend below the water table. Because waste intersecting the saturated zone may increase groundwater concentrations, the approach may underestimate risk in some cases. However, including this effect would strengthen a general conclusion of the analysis that potentially unacceptable risks exist in some cases with unlined and clay lined CCW landfills.

Indirect Ecological Effects. Indirect ecological effects (e.g., depletion of food resources) were not considered in the analysis. For any given facility, the spatial scale of potential contamination would affect a very small proportion of the home range for typical species; determining impacts on food supply and habitat quality with regard to the landscape and overall health of the animals is not currently possible in a national-level assessment (and difficult to understand or estimate in the majority of site-specific assessments). In addition, many species are opportunistic feeders and will seek other areas if food sources decline, regardless of the source of the stress to the food supply. For these reasons, EPA does not believe that it is possible to consider indirect ecological effects in a national risk assessment like CCW.

Aquifer pH. As explained in **Section 3.4**, aquifer pH was used to select the metal sorption coefficients that were in turn used to calculate retardation coefficients for groundwater transport of the CCW constituents. To estimate pH in an aquifer impacted by CCW leachate, the

CCW risk analysis assumed that, after entering the aquifer, the leachate plume thoroughly mixes with the ambient, uncontaminated groundwater. However, because this mixing zone is largely at the periphery of the groundwater plume, thorough mixing may or may not occur at actual sites. The full mixing assumption results in higher receptor point concentrations for most metals, because metal sorption and precipitation tend to increase (i.e., Kd goes up) with higher pH and full mixing tends to reduce the pH of CCW leachate, which is normally alkaline (i.e., assuming full mixing results in a lower groundwater pH and lower sorption).

To assess the effect of this simplifying assumption on the risk results, we compared two landfill Monte Carlo simulations for coal ash waste containing As(III) and coal ash waste containing As(V): (1) the fully mixed aquifer assumption and (2) an assumption that no mixing occurs in the aquifer and the leachate pH is the governing pH for Kd selection. These two metal species were selected because their sorption isotherm behavior with pH change differs; Kds derived from As(III) isotherms tend to decrease as pH increases (which is typical of most metal species examined in the risk assessment), while Kds derived from As(V) isotherms tend to increase with increasing pH.

Percentiles of peak receptor well concentration from the As (III) and As (V) simulations were selected and compared by calculating the percent change with mixing assumption as follows:

$$\%\,Change = \frac{C_{\text{No Mix}} - C_{\text{Full Mix}}}{C_{\text{Full Mix}}} \times 100$$

where

$C_{\text{No Mix}}$ = Simulated peak receptor well concentration for a select percentile based on a no mixing assumption (mg/L)

$C_{\text{Full Mix}}$ = Simulated peak receptor well concentration for a select percentile based on a fully mixed assumption (mg/L)

Table 4-29 compares the percent change in peak receptor well As (III) and As (V) concentrations between the well mixed and no mixing scenarios over a range of peak well percentiles. The results indicate that As(V) has a sensitivity to pH that leads to increased receptor well concentrations under the no mixing assumption (i.e., when the leachate pH is used to determine Kd in the saturated zone) relative to the well-mixed assumption used in the risk assessment. These results suggest that a change in the complete leachate mixing assumption could raise the receptor well concentrations (and therefore risks) for metal constituents whose Kd values decrease with increasing pH.

Table 4-29. Change in Peak Receptor Well Concentrations for Ash Disposed in Landfills Assuming Leachate Does Not Mix in Aquifer

Percentile of Peak Concentration	Percent Change in Peak Concentration	
	As(III)	As(V)
10	0.00%	0.00%
20	0.00%	0.00%
30	0.91%	0.00%
40	0.25%	0.00%
50	0.31%	2.28%
60	0.00%	15.57%
70	0.23%	57.97%
80	0.00%	18.31%
90	0.00%	11.75%

Goethite Versus Hydrous Ferric Oxide Sorbent. The choice of iron sorbent is important because goethite is a much poorer adsorbent than hydrous ferric oxide and will result in larger leachate contaminant concentration. With respect to the use of goethite versus the use of hydrous ferric oxide, EPA had discussions with Dr. David Dzombak and Dr. Samir Mathur (developer of the goethite database). In these discussions, the group discussed the sorbent question extensively, and EPA chose to use goethite rather than hydrous ferric oxide as a best estimate that would not underestimate risk. However, because actual CCW disposal sites could have hydrous ferric oxide present in their soils, the risks for arsenic could be overestimated.

Multiple Constituent Exposures. The individual human risk from each CCW constituent was considered separately in this analysis. However, the CCW waste constituent database and recent field studies such as U.S. EPA (2006c) and U.S. EPA (2008c) suggest that exposure to multiple constituents is highly likely. Because multiple constituent exposure may be synergistic depending on the constituents, certain constituent combinations may cause adverse health impacts that a single-constituent approach may underestimate. However, the quantitative human health benchmarks used by EPA are based on the toxicity of individual chemicals. With only one carcinogen present in CCW (arsenic), it was not necessary to add carcinogenic risks. Noncarcinogenic risks can be added only for chemicals with toxic effects on the same target organs, and this could have been done for fish and drinking water ingestion risks by accounting for transit time and adding HQs for contaminants with noncancer effects on the same target organs that arrive at the same time to the receptor point.

However additivity across chemicals was not considered in this risk assessment; neither was synergism or antagonism. Noncancer hazard may, therefore, be under- or overestimated. Nevertheless, risks were high enough from human exposure to single chemicals (notably arsenic, the single carcinogen) that this would not have changed the basic conclusion of the risk assessment: that there are potentially significant risks to human health from CCW disposal in landfills and surface impoundments.

4.4.3 Parameter Uncertainty and Variability

Parameter uncertainty occurs when (1) there is a lack of data about the values used in the equations, (2) the data that are available are not representative of the particular instance being modeled, or (3) parameter values have not been measured precisely or accurately because of limitations in measurement technology. Random, or sample, errors are a common source of parameter uncertainty that is especially critical for small sample sizes, as illustrated by the FBC waste results discussed in **Section 4.1.3.2**. More difficult to recognize and address are nonrandom or systematic errors that can bias the analyses from sampling errors, faulty experimental designs, or bad assumptions.

Spatial and temporal variability in parameters used to model exposure account for the distribution in the exposed population. For example, the rainfall or precipitation rates used to calculate infiltration and recharge to groundwater are measured daily by the National Weather Service at many locations throughout the United States, and statistics about these parameters are well documented. Although the distributions of these parameters may be well known, their actual values vary spatially and temporally and cannot be predicted exactly. Thus, the annual average infiltration rates used in the source model for a particular climate station provide information on average conditions appropriate for this analysis. Additionally, using data from multiple climate stations located throughout the United States can account for some, but not all, spatial variability.

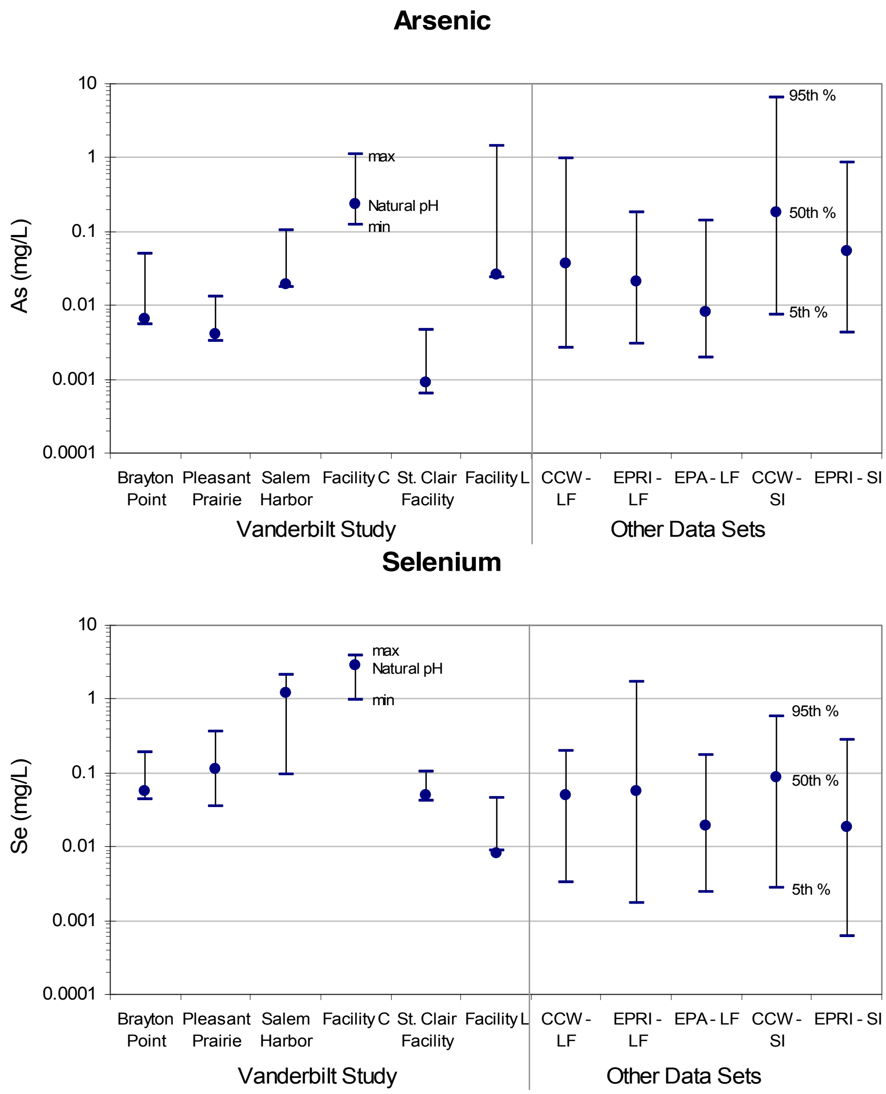
4.4.3.1 Waste Concentrations

The CCW constituent database used to represent CCW total waste and waste leachate concentrations is arguably the most important data set in terms of driving the risk assessment results. The constituent data are subject to two primary uncertainties beyond the normal sampling and analysis uncertainty associated with environmental measurements: (1) the appropriateness of the landfill leachate data used in the analysis and (2) high percentages of nondetect analyses for some CCW constituents.

Appropriateness of Leachate Data. The CCW leachate data were collected from a varying number of sites using a variety of methods. The available landfill data were largely derived from the TCLP, a laboratory test designed to estimate leachate concentrations in municipal solid waste (MSW) landfills. The TCLP has been shown to both over- and underpredict leachate concentrations for other waste disposal scenarios, so the use of the TCLP data to represent CCW leachate is another source of uncertainty. However, as noted below, the TCLP data do appear to encompass the range of variability in CCW leachate concentrations that have been measured in more recent studies.

Surface impoundment leachate is represented by porewater measurements taken beneath actual impoundments, which should more closely represent the leachate seeping from the bottom of the impoundment than would bulk surface impoundment waste concentrations. The porewater is in direct contact with the waste, so these concentrations should typically be at least as great as concentrations in the bulk surface impoundment. However, although these porewater data arguably should better represent leachate concentrations, they are fewer in number than the landfill data and therefore subject to uncertainty as to how representative they are of all CCW wastes. Results for surface impoundments for antimony, mercury, and thallium are not presented due to the paucity of leachate data (1 or 2 sites, and 11 or fewer values).

Since the CCW risk assessment was conducted in 2003, EPA-sponsored research conducted by Vanderbilt University has improved the scientific understanding of the generation of leachate from CCW, in particular for mercury, arsenic, and selenium (U.S. EPA, 2006c; U.S. EPA, 2008c). **Figure 4-2** plots the results from U.S. EPA (2006c) for arsenic and selenium, along with data from EPA's Leach2000 database and EPRI (as provided in U.S. EPA, 2006c) against the data used for landfills and surface impoundments used in the CCW analysis.



Key to data sets:

Vanderbilt	=	U.S. EPA (2006c)
CCW	=	CCW Constituent Database (this analysis)
EPRI	=	EPRI Leachate data (from U.S. EPA, 2006c)
EPA	=	Leach 2000 data (from U.S. EPA, 2000)
LF	=	landfills
SI	=	surface impoundments

Figure 4-2. Comparison of CCW leachate data with other leachate data in U.S. EPA (2006c).

For the 2006 Vanderbilt leaching study report, data are provided for each ash tested, with the minimum, maximum, and value at natural pH plotted on the chart. Percentile values (95th, 50th, 5th) are plotted for the compiled data sets (EPA, EPRI, and CCW), and mercury was not modeled for landfills because of a high number of nondetects.

For arsenic, the CCW values bracket the range found in the other studies. Selenium values also agree fairly well for CCW landfill data, although the CCW landfill values appear to be lower than some of the values from the other studies, suggesting that selenium risks may have been somewhat underestimated for landfills in this analysis. This is significant even though selenium risks from landfills were not above an HQ of 1 in this analysis, because selenium is often reported as a constituent of concern (along with arsenic and boron) in CCW damage cases (U.S. EPA, 2000, 2003e; Lang and Schlictmann, 2004; Zillmer and Fauble, 2004).

U.S. EPA (2008c) extends the work in U.S. EPA (2006c) to include laboratory leaching studies of 23 CCWs sampled from 8 coal combustion power plants. Wastes tested included fly ash, scrubber sludges, and gypsum. All of the metals addressed in this risk assessment were measured in the laboratory leaching tests.

Similar to Figure 4-2 above, Figures 46–59 on pages 77–86 in U.S. EPA (2008c) compare constituent concentration ranges in their laboratory CCW extracts to ranges reported by other CCW leachate data compilations, including the constituent data from this risk assessment. These graphs are not repeated here, but the conclusions are similar to the U.S. EPA (2006c) comparisons, in that the ranges of metals concentrations generally plot within the range reported for the laboratory tests, especially with fly ash and flue gas desulfurization sludges. For ash codisposed with coal refuse metal, concentrations tend to be an order of magnitude or more greater than the wastes studied in U.S. EPA (2008c), which did not include such codisposed wastes. Only two CCW metals plot largely outside the range for fly ash. Barium fly ash concentrations from the CCW risk assessment are an order of magnitude or more lower than those reported by U.S. EPA (2008c), and lead concentrations in the fly ash and FGD wastes modeled in this risk assessment are one to two orders of magnitude above those plotted in U.S. EPA (2008c). The latter may be an artifact of the predominance of TCLP measurements in the CCW constituent database, because the acetate buffer in the TCLP can be especially effective in complexing lead compounds into the extract solution. Finally, a few of the Vanderbilt measurements for molybdenum and selenium are above the range modeled in the CCW risk assessment.

The fact that the 2006 and 2008 Vanderbilt results are in general agreement with the CCW arsenic and selenium levels does help allay concerns that the TCLP CCW leachate values used in the analysis markedly overestimate or underestimate the concentrations actual CCW leachate.

Mercury and Nondetect Analyses. For certain of the CCW constituents addressed in this analysis, the CCW leachate database contains a large number of nondetect measurements (concentrations below an analytical instrument's ability to measure). **Table 4-30** illustrates this point by showing, by WMU type and chemical, the overall percent of nondetect values for each chemical and the percent of site-averaged values[11] that are composed entirely of nondetect measurements. Although some constituents have a large number of nondetect values, many of those could still be modeled (substituting half the detection limit for nondetect values). Where there are detections for a chemical, the specific substitute value used for nondetect values does not affect the upper percentile risks, because the upper percentile risks are associated with the higher, detectable source concentrations in the distribution rather than the lower source concentrations associated with nondetect values. Values for nondetects will be in the lower percentiles whether they are half the detection limit or some other value.

Table 4-30. Proportion of Nondetect Analyses for Modeled CCW Constituents

Chemical[a]	Measurements		Sites	
	Number	% nondetects	Number	% with all nondetects
Landfills				
Aluminum	397	18%	61	5%
Antimony	496	50%	66	41%
Arsenic	1,182	49%	128	20%
Barium	1,225	11%	126	5%
Boron	930	8%	83	2%
Cadmium	1,237	50%	124	31%
Cobalt	559	56%	52	19%
Lead	1,109	60%	125	30%
Mercury	***974***	***91%***	***101***	***58%***
Molybdenum	373	24%	58	10%
Nitrate/Nitrite	141	48%	20	15%
Selenium	1,227	49%	131	17%
Thallium	402	60%	40	45%
Surface Impoundments				
Aluminum	158	10%	16	6%
Antimony	***11***	***100%***	***2***	***100%***
Arsenic	155	16%	16	6%
Barium	161	14%	16	13%
Boron	164	7%	171	6%
Cadmium	164	68%	16	50%
Cobalt	49	59%	4	50%
Lead	138	78%	14	36%
Mercury	***1***	***100%***	***1***	***100%***
Molybdenum	161	37%	17	24%
Nitrate/Nitrite	267	59%	14	7%
Selenium	140	33%	15	20%

(continued)

[11] As explained in **Appendix A**, the CCW risk assessment used site-averaged constituent concentrations. That is, an average value was used when there were multiple measurements for a chemical at a particular site.

Proportion of Nondetect Analyses for Modeled CCW Constituents (continued)

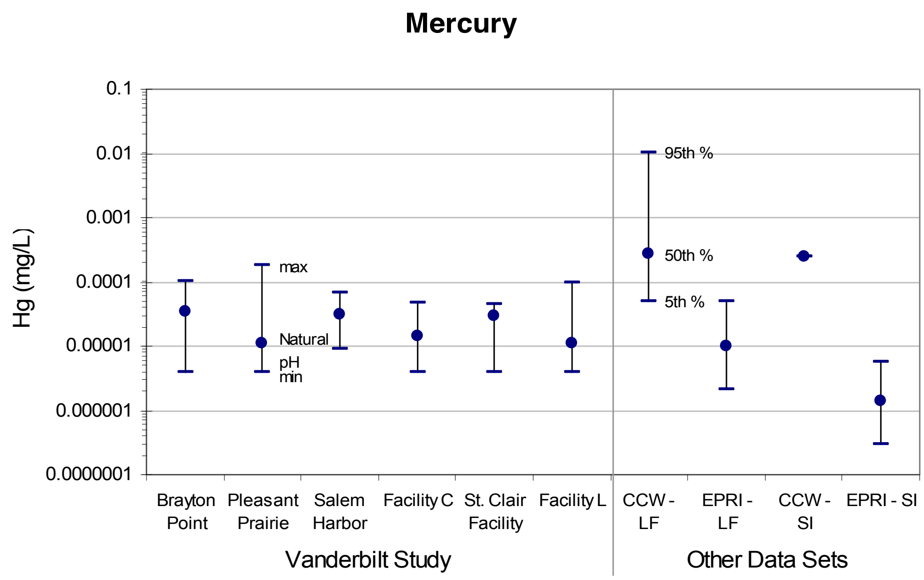
Chemical[a]	Measurements		Sites	
	Number	% nondetects	Number	% with all nondetects
Thallium	*11*	*100%*	*2*	*100%*

[a] Results for constituents shown in ***bold italics*** were not presented in this report because of high detection limits or limited data.

Constituents that could not be addressed in this analysis because of a very high number of nondetects (i.e., more than 90 percent of measurements) included mercury (for landfills and surface impoundments) and thallium and antimony (for surface impoundments only). Mercury is of particular interest because it is the only constituent with significant concern through the fish consumption pathway, and because there is the potential for mercury concentrations in CCW to increase as flue gas mercury controls are installed on coal-fired power plants in response to the Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR). However, analysis of the effect of mercury emission controls was outside the scope of the risk assessment, which was to evaluate current waste disposal conditions, not potential future changes due to emission controls.

Recent work by Vanderbilt University (U.S. EPA, 2006c, 2008c) sheds some light on mercury concentrations in leachate from some CCWs. **Figure 4-3** plots the CCW distribution of mercury concentrations (assuming half the detection limit for mercury values below detection) against results from the Vanderbilt work and recent data collected by EPRI (from U.S. EPA, 2006c; results are similar in U.S. EPA, 2008c). Assuming half the detection limit, the CCW mercury leachate values are about an order of magnitude or more higher than the Vanderbilt or EPRI data. With a single CCW leachate analysis available for surface impoundments, it is difficult to draw firm conclusions, but the concentration value is above the maximum value shown in the other studies. In short, the mercury levels in the CCW database are not useful because of high detection limits. In addition, the Vanderbilt study found that older mercury analyses, such as the ones in the CCW database, could be biased high because of cross-contamination issues.

Finally, U.S. EPA (2006c) and preliminary results of ongoing EPA studies (e.g., U.S. EPA, 2008c) suggest that both mercury levels and mercury leachability in CCW can vary depending on the flue gas mercury controls used at a power plant.



Key to data sets:

Vanderbilt	=	U.S. EPA (2006c)
CCW	=	CC Constituent Database (this analysis)
EPRI	=	EPRI Leachate data (from U.S. EPA, 2006c)
EPA	=	Leach 2000 data (from U.S. EPA, 2000, as cited in U.S. EPA, 2006c)
LF	=	landfills
SI	=	surface impoundments

Figure 4-3. CCW mercury concentrations compared with other leachate data.

4.4.3.2 WMU Locations and Characteristics

The locations of the specific sites in the United States where CCW is disposed are known, and EPA used the soil and climatic characteristics of these sites in the Monte Carlo analysis. Because most locations were facility front gates or centroids, the exact location of the CCW landfill or surface impoundment was not known. To account for this uncertainty, soil data were collected for an area around the plant and soil type distributions were sampled in the Monte Carlo analysis. Climate center assignments were combined with the soil texture distributions to select infiltration and recharge rates to use in the analysis.

WMU area, depth, volume, and liner type were not varied in the Monte Carlo analysis because values for these variables were known from the EPRI survey data. More uncertain parameters, such as depth below grade, were varied within reasonable ranges. These data were used in the source model calculations to generate the distribution of environmental releases used by the fate and transport modeling.

Three standard WMU liner scenarios (clay, composite, and unlined) were assigned to each facility based on best matches to data in the EPRI survey on liner type. Infiltration through these liners was then modeled using assumptions, models, and data developed in support of EPA's Industrial Subtitle D guidance. How well these assumptions and models represent the performance of CCW WMU landfills and surface impoundments is an uncertainty in this analysis.

With respect to the clay liners, the 2009 risk assessment used the assumption that compact clay liners were designed to have a hydraulic conductivity of 1×10^{-7} cm/sec. This is consistent with EPA's Industrial D Guidance, which states that "clay liners should be at least 2 feet thick and have a maximum hydraulic conductivity of 1×10^{-7} cm/sec" (U.S. EPA, 2006d). However, clay liners designed to meet a 1×10^{-7} cm/sec hydraulic conductivity could perform differently in practice. In one liner study (Moo-Young et al., 2004), a small set of clay-lined landfills were found to have field hydraulic conductivities ranging from 2×10^{-9} to 4.4×10^{-8} cm/sec and a small set of surface impoundments were found to have field hydraulic conductivities ranging from 3×10^{-6} to 3.2×10^{-5} cm/sec. Thus, the assumption of clay liners performing at 1×10^{-7} cm/sec could lead to an under- or over-estimate of actual risks.

Composite liners would also not be expected to perform consistently over 10,000 years as was assumed in the model. Instead, the liner would eventually perform at the level of the clay layer once the synthetic layer had deteriorated. This simplification is likely to lead to an underestimate of composite liner risks.

4.4.3.3 Fate and Transport Model Variables

The parameter values required to model contaminant fate and transport in groundwater were obtained from site-specific, regional, and national databases. Hydrogeologic environment was assigned to each site, based on geologic maps and soil conditions; where assignments were uncertain, two or three settings might be used in the Monte Carlo analysis. Because aquifer properties are highly variable and uncertain, reasonable sets of aquifer properties were selected, based on hydrogeologic environment, from a hydrogeologic database.

Receptor Location (Drinking Water Wells). The sensitivity analysis (**Section 4.3**) showed that distance of a receptor from the contaminant source is an important influence on media concentration, especially for contaminants that strongly sorb to soil and aquifer materials. For the groundwater-to-drinking-water pathway, receptor location was represented as the distance and position, relative to a contaminant plume, of residential drinking water wells from the WMU. Because no data were readily available on the distance of CCW disposal sites from residential wells, EPA used data from a survey of well distances from MSW landfills. Whether or not this is an accurate representation of well distance for CCW landfills and surface impoundment is an uncertainty in this analysis. EPA believes that the MSW well distance distribution used is protective for CCW landfills and surface impoundments. See **Appendix C**, **Section C.2**, for more details.

Location and Characteristics of Waterbodies. One aspect of the site configuration of particular relevance to the aquatic food chain modeling is the locations and characteristics of the waterbodies. The size of the waterbodies (and the distance from the WMU) affects constituent concentrations and loadings predicted for that waterbody. The distance from the WMU to the waterbody was based on an empirical distribution of measurements, taken from actual CCW sites, of the distance from the edge of the WMU to the nearest stream or lake. The uncertainty posed in this analysis is the sampling of this distribution as compared to a more certain measurement of the actual distance at each CCW site. Surface water variables, including flow and water quality parameters, were collected for the stream reach being modeled, or for a larger hydrologic region where data were not available for a particular reach.

Waterbodies Intercepting the Groundwater Plume. As discussed in **Section 3.7**, mass is not actually removed from the groundwater when the plume is intercepted by a surface waterbody. Therefore, in cases where wells are located beyond an intersecting surface water body, the draft risk assessment may not account for interactions between surface water and groundwater. Examining the input database, EPA notes that approximately two-thirds (69%) of the Monte Carlo runs contained such an intersecting surface waterbody. Thus, the 50th percentile results may overestimate groundwater risks to these receptors. However, because the WMUs with closer receptor wells exhibited higher risks on average, the 90th percentile results are not likely to be significantly affected.

Environmental Parameters. Uncertainties related to environmental parameters (soil, aquifer, surface water, climate data) have already been mentioned. The parameters with the largest impact on results are aquifer hydraulic conductivity and gradient, which were selected from a national database of aquifer properties.

Fish Bioconcentration and Bioaccumulation Factors. For fish consumption, exposure dose was calculated using BCFs to estimate the transfer of pollutants from environmental media into fish. Uncertainty is associated with models used to estimate BCFs for aquatic biota. Aquatic BCFs are developed by dividing measured concentrations in aquatic biota by total surface water concentrations. **Appendix J** lists the bioconcentration and bioaccumulation parameters used in the risk assessment, along with their sources.

4.4.3.4 Exposure and Risk Modeling Variables

Exposure parameters and benchmarks for human and ecological risk also contribute to parameter variability and uncertainty.

Human Exposure Factors. Individual physical characteristics, activities, and behavior are quite different, and thus the exposure factors that influence the exposure of an individual, including ingestion rate, body weight, and exposure duration, are quite variable. Exposure modeling relies heavily on default assumptions concerning population activity patterns, mobility, dietary habits, body weights, and other factors. The probabilistic assessment for the adult and child exposure scenario addressed the possible variability in the exposure modeling by using statistical distributions for these variables for each receptor in the assessment: adult and child resident and adult and child recreational fisher. Data on fish consumption rates were not available for children of recreational anglers; thus the adult recreational angler data were used for children in this analysis, which could overestimate risk from this pathway for children. For all exposure factors varied, a single exposure factor distribution was used for adults for both males and females. For child exposures, one age (age 1) was used to represent the age at the start of exposure, because this age group was considered to be most sensitive for most health effects.

The *Exposure Factors Handbook* (U.S. EPA, 1997c,d,e) provides the current state of the science concerning exposure assumptions and represents EPA's current guidance on exposure data, and it was used throughout this assessment to establish statistical distributions of values for each exposure parameter for each receptor. The *Exposure Factors Handbook* has been carefully reviewed and evaluated for quality. EPA's evaluation criteria included peer review, reproducibility, pertinence to the United States, currency, adequacy of the data collection period, validity of the approach, representativeness of the population, characterization of the variability, lack of bias in study design, and measurement error. There are some uncertainties, however, in the data that were used.

Site-specific fish consumption rate data were not available, but the Maine study data, where anglers fished from streams, rivers, and ponds, were consistent with the modeling scenarios used in this risk analysis and provided the detailed percentile data required for a probabilistic analysis. However, applying Maine angler consumption rates to other parts of the country may under- or overestimate exposures.

EPA's child-specific exposure guidance has been recently finalized (U.S. EPA, 2008b) but was not used in the risk assessment because the water consumption rates and body weights provided in the *Child-Specific Exposure Factors Handbook* (U.S. EPA, 2008b) do not differ significantly from those found in the 1997 *Exposure Factors Handbook* and would not have changed the results, but the use of the 1997 values may contribute some parameter uncertainty. One exception is the distribution of child fish consumption rates used. Here, U.S. EPA (2008b) consumption rates are higher than the 1997 rates used in the analysis. This introduces uncertainty into the analysis, and likely underestimates risks in the fish consumption pathway.

As is customary for EPA's RCRA risk assessments, human exposure factor data were not correlated (i.e., for each modeling run, each exposure factor was selected from its distribution independently), introducing some uncertainty because it is possible to select, for example, a high drinking water rate with a small body weight. However, although a specific modeling run may have had an unrealistic combination of exposure factors, the large number of Monte Carlo iterations performed (10,000) ensures that this is unlikely to significantly affect the risk assessment results.

Diet Assumptions for Ecological Receptors. National-scale assessments often assume maximum intake of contaminated prey in the diets of primary and secondary consumers (i.e., 100 percent of the diet originates from the contaminated area). Under field conditions, many receptors are opportunistic feeders with substantial variability in both the type of food items consumed and the geospatial patterns of feeding and foraging. The actual proportion of wildlife receptors' diets that would be contaminated depends on a number of factors such as the species' foraging range, quality of food source, season, intra- and interspecies competition. Consequently, the exclusive diet of contaminated food items tends to provide a very high-end estimate of potential risks.

Human Health Benchmarks. The uncertainties generally associated with human health benchmarks are discussed in detail in EPA's *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005), and IRIS (U.S. EPA, 2009a). EPA defines the RfD as "an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime" (U.S. EPA, 1994, 2009a). RfDs are based on an assumption of lifetime exposure and may not be appropriate when applied to less-than-lifetime exposure situations (U.S. EPA, 2009a). The CSF is an upper-bound estimate of the human cancer risk per mg of chemical per kg body weight per day. Because exposures were often less than lifetime, some uncertainty was introduced in the noncancer hazard and cancer risk estimates.

EPA routinely accounts for uncertainty in their development of RfDs and other human health benchmarks. Uncertainty and variability in the toxicological and epidemiological data from which RfDs were derived are accounted for by applying uncertainty factors. Some of these uncertainties include those associated with extrapolation from animals to humans, from LOAELs to NOAELs, and from subchronic to chronic data, and to account for sensitive subpopulations. If certain toxicological data are missing from the overall toxicological database (e.g., reproductive data), EPA accounts for this by applying an uncertainty factor.

Table 4-31 presents IRIS uncertainty factors for the RfDs for the CCW constituents that showed HQs greater than 1 in the risk assessment, along with the highest HQ observed and the disposal scenario for which this HQ was observed. IRIS defines uncertainty factors as follows:

> "Uncertainty factors (UFs) are one of several, generally 10-fold, default factors used in operationally deriving the RfD from experimental data. The factors are intended to account for (1) variation in susceptibility among the members of the human population (i.e., inter-individual or intraspecies variability); (2) uncertainty in extrapolating animal data to humans (i.e., interspecies uncertainty); (3) uncertainty in extrapolating from data obtained in a study with less-than-lifetime exposure (i.e., extrapolating from subchronic to chronic exposure); (4) uncertainty in extrapolating from a LOAEL rather than from a NOAEL; and (5) uncertainty associated with extrapolation when the database is incomplete."[12]

The constituent-specific uncertainty factors for the CCW constituents in Table 4-31 are discussed further in the source documents (e.g., IRIS) for the individual human health benchmarks used in the analysis, which are referenced in **Appendix G**. In general, EPA human health benchmarks are derived using a health-protective approach. These uncertainty factors can be considered when evaluating the constituent-specific risks presented in this document, but only in the context of the above definitions and the information presented in IRIS for each chemical.

The hierarchy of data sources that was implemented for this analysis was based largely on the rigor of review that a benchmark has received. Methodologies evolve over time, with improvements in existing methods and the development of new health benchmark practices (e.g., benchmark dose methodology). As a result, the magnitude of a given benchmark can either increase or decrease, or a given benchmark can appear or disappear in a toxicity benchmark database. An example of the latter situation, disappearance of a toxicity benchmark, occurred during the development of this report. The human health benchmark for thallium was withdrawn from IRIS in late September 2009. The modeling results, including the noncancer human health effects estimates, were retained in this document to reflect the potential for thallium releases from CCW WMUs. EPA has decided to retain these estimates, in light of the National Academy of Sciences' (NAS's) 2008 report entitled *Science and Decisions: Advancing Risk Assessment* (NAS, 2008). In that report's recommendations, the authors noted that absence of certain information from a risk characterization can result in the missing information being overlooked during the decision making process. Evidence that relatively small quantities of thallium can be

[12] http://www.epa.gov/ncea/iris/help_gloss.htm#u

fatal to humans[13] leads EPA to conclude that omitting the thallium results from this report might cause thallium's existence in coal combustion residues to be overlooked during the risk management decision making, and thus EPA has chosen to retain those modeling results in this report.

Table 4-31. RfD Uncertainty Factors for and Benchmark Confidence for CCW Constituents with HQs Over 1

Constituent	RfD (mg/kg-day)	Source	Uncertainty Factor	Benchmark Confidence	Highest CCW HQ	CCW Scenario for Highest HQ
Antimony	4.0E-04	IRIS	1,000	low	3	GW-DW, FBC wastes, clay-lined landfills
Boron	2.0E-01	IRIS	66	high	7	GW-DW, Conventional CCW, unlined SIs
Cadmium	5.0E-04	IRIS	10	high	9	GW-DW, Codisposed CCW, unlined SIs
Cobalt	3.0E-04	PPRTV	1,000	low	500	GW-DW, Codisposed CCW, unlined SIs
Molybdenum	5.0E-03	IRIS	30	medium	8	GW-DW, Conventional CCW, unlined SIs
Selenium	5.0E-03	IRIS	3	high	3	GW-SW, Conventional CCW, unlined SIs
Thallium	8.0E-05	IRIS	3,000	low	4	GW-DW, FBC wastes, clay-lined landfills

Most health benchmarks used in this analysis were from IRIS. Human health benchmarks in IRIS have been subjected to rigorous internal and external reviews and represent Agency-wide consensus human health risk information. However, some benchmarks in IRIS are quite dated. Provisional human health benchmarks derived by the Superfund Technical Support Center have been peer reviewed and are used where there is no IRIS value.

Chemical-specific health benchmarks were used for all constituents assessed in the analyses. However, the RfD for fluoride was based on fluorine; the RfDs for mercuric chloride and methyl mercury were used as surrogates for elemental mercury from food, soil, and water ingestion, and fish ingestion, respectively; and the RfD for thallium was based on thallium chloride. The use of these surrogate data is not thought to have introduced any significant uncertainty. Human health benchmarks are not age-specific, and therefore, were applied to both child and adult receptors, thereby introducing some uncertainty.

EPA used the drinking water MCL for lead to estimate risks from drinking water exposure. The IEUBK model may better quantify risk for a young child exposed to lead; therefore, use of the MCL may introduce some uncertainty. However, risks from lead exposure were relatively low, well below the risk criterion for landfills and at or slightly above the risk criterion for surface impoundments, and did not drive the risk assessment conclusions.

[13] "Temporary hair loss, vomiting, and diarrhea can also occur and death may result after exposure to large amounts of thallium for short periods. Thallium can be fatal from a dose as low as 1 gram." (ATSDR, 1992)

Ecological Criteria. CSCLs were developed for constituents when sufficient data were available. In many cases, sufficient data were unavailable for a receptor/constituent combination, and therefore, the potential risk to a receptor could not be assessed. In particular, insufficient data were available to derive chronic effects CSCLs for amphibians. Because the risk results can only be interpreted within the context of available data, the absence of data cannot be construed to mean that adverse ecological effects will not occur.

In addition to the effects of data gaps on ecological benchmarks, the ecological criteria tend to be fairly conservative because the overall approach is based on "no effects" or "lowest effects" study data. In site-specific assessments, a *de minimis* effects approach is often replaced with an effects level similar to natural population variability (e.g., sometimes as high as a 20 percent effects level). As a result, the CSCLs used in this analysis are likely to overestimate risks for representative species and communities assumed to live in surface waters impacted by CCW WMUs. Because the difference between a LOAEL and a NOAEL is often about a factor of 10, an HQ exceedance of roughly 10 may not be ecologically significant. In contrast, CSCLs based on no effects data that are developed for the protection of threatened and endangered species are presumed to be protective.

4.5 Summary and Conclusions

CCW risk assessment results at the 90th percentile suggest that the management of CCW in unlined or clay-lined WMUs result in risks greater than 1 in 100,000 for excess cancer risk to humans or an HQ greater than 1 for noncancer effects to both human and ecological receptors. Key risk findings include the following:

- For humans exposed via the groundwater-to-drinking-water pathway, risks from clay-lined units that dispose CCW or CCW comanaged with coal refuse are lower than those for unlined units. However, the 90th percentile risks for clay-lined units are still well within or above the range of concern (10^{-6} to 10^{-4}) for cancer risk and above an HQ of 1 for noncarcinogens. For example, arsenic III cancer risks in clay-lined units range from 1 in 5,000 for landfills to 9 in 10,000 in surface impoundments. The thallium HQ was as high as 2 for clay-lined landfills, and the clay-lined surface impoundment HQ was as high as 200 for cobalt and 4 for boron.

- Arsenic was the constituent with the highest risk for landfills. Clay-lined landfills presented 90th percentile risks above an excess cancer risk of 1 in 100,000 for arsenic (risks as high as 1 in 5,000) and an HQ of 1 for thallium (HQ of 2). When landfills are unlined, they also present risk above an HQ of 1 for antimony and molybdenum, each with an HQ of 2. Here, arsenic cancer risks were as high as 1 in 2,000. Clay-lined FBC landfills also presented 90th percentile risks above and HQ of 1 for antimony (HQ = 3) and thallium (HQ = 4) and showed excess cancer risks of 3 in 50,000 for arsenic. However, unlined FBC landfills differed in that they only exceeded a 1 in 100,000 excess cancer risk for arsenic.[14] At the 50th percentile, arsenic III from CCW codisposed with

[14] As modeled, unlined FBC units showed less risk than clay-line FBC units.

coal refuse unlined landfills showed an excess cancer risk of 1 in 50,000: all noncarcinogenic constituents were well below an HQ of 1.

- Arsenic and cobalt were the constituents with the highest risks for surface impoundments, with risks as high as 1 in 50 and an HQ of 500, respectively, for unlined units. Clay-lined surface impoundments presented 90th percentile cancer risks above 1 in 100,000 for arsenic (7 in 1,000 cancer risk), HQs above 1 for boron (HQs as high as 4), cadmium (HQ as high as 3), cobalt (HQ as high as 200), molybdenum (HQ as high as 5), and nitrate (an MCL-based HQ as high as 10). When surface impoundments are unlined, they also show risk above an HQ of 1 for lead (HQ of 9) and selenium (HQ of 2). Here, arsenic cancer risks are as high as 1 in 50, and cobalt had HQs as high as 500. The only 50th percentile surface impoundment results that exceeded the risk range or HQ criterion were arsenicand cobalt. Here, unlined units had arsenic cancer risks as high as 6 in 10,000 while clay-lined units had arsenic cancer risks as high as 1 in 5,000. Cobalt HQs were as high as 20 and 6 for unlined and clay-lined surface impoundments, respectively.

- For the groundwater-to-drinking-water pathway, composite liners, as modeled in this assessment, effectively reduce risks from all constituents to below a cancer risk of 1 in 100,000 and an HQ of 1 for both landfills and surface impoundments at the 90th and 50th percentiles.

- For the groundwater-to-drinking-water pathway, arrival times of the peak concentrations at a receptor well are much longer for landfills (hundreds or thousands of years) than for surface impoundments (most less than 100 years).

- For humans exposed via the groundwater-to-surface-water (fish consumption) pathway, unlined and clay-lined surface impoundments posed risks above an excess cancer risk of 1 in 100,000 and an HQ of 1 at the 90th percentile. For CCW managed alone in surface impoundments, these exceedences came from selenium (HQs of 3 and 2), while for CCW comanaged with coal refuse these exceedences came from arsenic (3 in 100,000 and 2 in 100,000 excess cancer risks for unlined and clay-lined units). All 50th percentile surface impoundment risks are below a cancer risk of 1 in 100,000 and an HQ of 1. No constituents pose risks above these risk levels for landfills (including FBC landfills) at the 90th or 50th percentile for the fish consumption pathway.

- Waste type has a much larger effect when wastes are managed in surface impoundments than when they are managed in landfills. In the case of surface impoundments, some constituents (boron, molybdenum, nitrate, and selenium) presented higher risks from CCW managed alone. However, others (arsenic, cadmium, cobalt, and lead) presented higher risks when CCW is comanaged with coal refuse, because of their association with the sulfide minerals concentrated in the refuse.

- The higher risks for surface impoundments than landfills are likely due to higher waste leachate concentrations and the higher hydraulic head from the impounded liquid waste. This is consistent with damage cases reporting wet handling as a factor that can increase risks from CCW management.

- For ecological receptors exposed via surface water, risks for landfills exceed an HQ of 1 for boron (HQ of 281 for unlined and 78 for clay-lined), lead (HQ of 8 for unlined), and selenium, arsenic, and barium (HQs of 2) at the 90th percentile, but 50th percentile HQs are well below 1. For surface impoundments, 90th percentile risks for several constituents (boron, lead, arsenic, selenium, cobalt, and barium) exceed an HQ of 1, with boron showing the highest risks (HQ over 2,000). Only boron exceeds an HQ of 1 at the 50th percentile (HQ = 7 for unlined surface impoundments). The HQs over 1 for boron and selenium are consistent with reported ecological damage cases, which include impacts to waterbodies through the groundwater-to-surface-water pathway.

- For ecological receptors exposed via sediment, 90th percentile risks exceed an HQ of 1 for both landfills and surface impoundments because certain CCW constituents strongly sorb to sediments in the waterbody. Here, the 90th percentile HQ for lead was 58 for unlined landfills and clay-lined surface impoundments, and 311 for unlined surface impoundments. For arsenic, HQs were 11 and 3 for unlined and clay-lined landfills, and 127 and 55 for unlined and clay-lined surface impoundments. Cadmium had HQs of 5 for unlined landfills, and 30 and 9 for unlined and clay-lined surface impoundments. Antimony had an HQ of 2 for unlined landfills. Composite lined surface impoundments also had risks above an HQ of 1 for lead (HQ of 4), arsenic (HQ of 31), and cadmium (HQ of 2). The 50th percentile risks are an order of magnitude or more below an HQ of 1 for ecological receptors exposed via sediments.

Sensitivity analysis results indicate that for most of the scenarios evaluated (over 70 percent), the risk assessment model was most sensitive to parameters related to the contaminant source and groundwater flow and transport: WMU infiltration rate, leachate concentration, and aquifer hydraulic conductivity and gradient. For strongly sorbing contaminants (such as lead and cadmium), variables related to sorption and travel time (adsorption coefficient, depth to groundwater, receptor well distance) are also important.

One of the most sensitive parameters in the risk assessment (infiltration rate) is greatly influenced by whether and how a WMU is lined. The 1994–2004 DOE/EPA survey results (U.S. DOE, 2006) do not include information on how many unlined facilities are still operating today, but do indicate that more facilities are lined today than were in the 1995 EPRI survey data set on which this risk assessment was based. This suggests that the risks from future CCW disposal facilities are likely to be lower than the results presented in this report.

There are uncertainties associated with the CCW risk assessment, but scenario uncertainty (i.e., uncertainty about the environmental setting around the plant) has been minimized by basing the risk assessment on conditions around existing U.S. coal-fired power plants around the United States. Uncertainty in environmental setting parameters has been incorporated into the risk assessment by varying these inputs within reasonable ranges when the exact value is not known. Uncertainty in human exposure factors (such as exposure duration, body weight, and intake rates) has also been addressed through the use of national distributions.

Some uncertainties not addressed explicitly in the risk assessment have been addressed through comparisons with other studies and data sources.

- **Appropriateness of CCW leachate data.** Data on another highly sensitive parameter, leachate (porewater) constituent concentration, were available and used for CCW surface impoundments. However, available data for landfills were mainly TCLP analyses, which may not be representative of actual CCW leachate. Comparisons with recent (2006 and 2008) studies of coal ash leaching processes show very good agreement for arsenic. However, although the selenium CCW data are within the range of the 2006 and 2008 data, some of the higher concentrations in both Vanderbilt data sets are not represented by the TCLP data, and U.S. EPA (2008c) show similar trends for barium and molybdenum. This suggests that risks for these metals may be underestimated, which is consistent with selenium as a common driver of the damage cases.

- **Impacts of mercury rules (CAIR and CAMR).** While CAIR and CAMR will reduce emissions of mercury and other metals from coal-fired power plants, mercury and other more volatile metals will be transferred from the flue gas to fly ash and other air pollution control residues, including the sludge from wet scrubbers. EPA ORD has research underway to evaluate changes to CCW characteristics and leaching of mercury and other metals from CAIR and CAMR. Data from the first report (U.S. EPA, 2006c) suggest that although total mercury will increase in CCW from the use of sorbents as mercury controls, the leachability of mercury may be reduced. Data from U.S. EPA (2008c) add to this assessment by supporting similar findings.

- **Mercury and nondetect analyses.** Because of a high proportion of nondetect values and a limited number of measurements, the risks from mercury in CCW could not be evaluated for either landfills or surface impoundments and for antimony and thallium in surface impoundments. The 2006 leaching study data suggest that mercury levels are fairly low in fly ash from coal combustion, a conclusion generally confirmed by the 2008 study report (U.S. EPA, 2008c), although that study did find higher mercury leachate concentrations from scrubber sludge than other coal wastes and found that blending fly ash and lime can increase mercury leaching from scrubber sludge.

Uncertainties that are more difficult to evaluate with respect to CCW risk results include the following:

- **Well distance.** Nearest well distances were taken from a survey of MSW landfills, as data were not available from CCW sites. EPA believes that this is a protective assumption because MSW landfills generally tend to be in more populated areas, but there are little data available to test this hypothesis.

- **Liner conditions.** Liner design and performance for CCW WMUs were based on data and assumptions EPA developed to be appropriate for nonhazardous industrial waste landfills. EPA believes that CCW landfills should have similar performance characteristics, but does not have the quantitative data to verify that.

- **Data gaps for ecological receptors.** Insufficient data were available to develop screening levels and quantitative risk estimates for terrestrial amphibians, but EPA acknowledges that damage cases indicate risk to terrestrial amphibian and plant communities through exposure to selenium and boron.

- **Ecosystems and receptors at risk.** Certain critical assessment endpoints were not evaluated in this analysis, including impacts on managed lands, critical habitats, and threatened and endangered species.

- **Synergistic risk.** The impact of exposures of multiple contaminants to human and ecological risks was not evaluated in this analysis. EPA recognizes that a single-constituent analysis may underestimate risks associated with multiple chemical exposures.

These are potentially the more significant uncertainties associated with the CCW risk assessment. Other uncertainties are discussed in **Section 4.4**.

Given the results and characterization above, composite liners, as modeled in this risk assessment, effectively reduce risks from all pathways and constituents to levels below an excess cancer risk of 1 in 100,000 or an HQ of 1 for both landfills and surface impoundments. The CCW risk assessment suggests that the management of CCW in unlined landfills and unlined surface impoundments may present risks to human health and the environment. From the perspective of what is known about toxic effects in humans, arsenic, nitrates, cadmium, and selenium appear to be among the constituents that may present risks of concern depending on the specific waste management practices employed. From the perspective of what is known about toxic effects in ecological receptors, arsenic, boron, lead, and selenium emerge as having documented adverse effects on ecological receptors.

The estimated human health arsenic risks from clay-lined units are lower than the risks of unlined units, but are still above a 1 in 100,000 excess cancer risk or an HQ of 1. In addition, surface impoundments typically showed higher risks than landfills, regardless of liner type. These risk results are largely consistent with damage cases compiled by EPA (U.S. EPA, 2000, 2003e, 2007) and others (Lang and Schlictmann, 2004; Zillmer and Fauble, 2004; Carlson and Adriano, 1993; Rowe et al., 2002; Hopkins et al., 2006). These results suggest that with a higher prevalence of composite liners in new CCW disposal facilities, future national risks from onsite CCW disposal are likely to be lower than those presented in this risk assessment (which is based on 1995 CCW WMUs).

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Appendix A. Constituent Data

The coal combustion waste (CCW) risk assessment addressed metals and inorganic constituents identified by EPA as potential constituents of concern in CCW (**Table A-1**). EPA-derived waste concentrations for these constituents from the CCW constituent database, which includes analyte concentration data in three tables representing different types of waste samples: landfill leachate analyses (in mg/L), surface impoundment and landfill porewater analyses (in mg/L), and analyses of whole waste samples (in mg/kg). Each database table specifies, for most samples, the type of waste sampled and the type of coal burned at the facility.

Table A-1. Constituents Addressed in the CCW Risk Assessment

Constituent	CAS ID	Constituent	CAS ID
Metals		***Inorganic Anions***	
Aluminum	7429-90-5	Chloride	16887-00-6
Antimony	7440-36-0	Cyanide	57-12-5
Arsenic	7440-38-2	Fluoride	16984-48-8
Barium	7440-39-3	Total Nitrate Nitrogen	14797-55-8
Beryllium	7440-41-7	Phosphate	14265-44-2
Boron	7440-42-8	Silicon	7631-86-9
Cadmium	7440-43-9	Sulfate	14808-79-8
Chromium	7440-47-3	Sulfide	18496-25-8
Cobalt	7440-48-4	***Inorganic Cations***	
Copper	7440-50-8	Ammonia	7664-41-7
Iron	7439-89-6	Calcium	7440-70-2
Lead	7439-92-1	pH	12408-02-5
Magnesium	7439-95-4	Potassium	7440-09-7
Manganese	7439-96-5	Sodium	7440-23-5
Mercury	7439-97-6	***Nonmetallic Elements***	
Molybdenum	7439-98-7	Inorganic Carbon	7440-44-0
Nickel	7440-02-0	Total Elemental Sulfur	7704-34-9
Selenium	7782-49-2	***Measurements***	
Silver	7440-22-4	Total Dissolved Solids	none
Strontium	7440-24-6	Total Organic Carbon	none
Thallium	7440-28-0	Dissolved Organic Carbon	none
Vanadium	7440-62-2		
Zinc	7440-66-6		

A.1 Data Sources

EPA prepared the CCW constituent database in 2002. The 2002 CCW constituent database includes all of the waste characterization data used by EPA in its risk assessments in support of the March 1999 *Report to Congress: Wastes from the Combustion of Fossil Fuels* (the RTC) (U.S. EPA, 1999). In addition to the data set from the March 1999 RTC, EPA supplemented the database with the following data:

- Data submitted with public comments to EPA on the 1999 RTC
- Data submitted with public comments to EPA concerning the May 22, 2000, Final Regulatory Determination
- Data collected by and provided to EPA since the end of the public comment period on the Final Regulatory Determination
- Data identified from literature searches.

The primary sources of these additional data include the electric power industry, state and federal regulatory agencies, and scientific literature. **Attachment A-1** is a complete list of the sources of data contained in the 2002 CCW constituent database.

The additional data represent a significant expansion in the quantity of characterization data available to EPA for analysis. For example, the data set used for the risk assessments supporting the RTC covered approximately 50 CCW generation and/or disposal sites. With the addition of the supplemental data, the 2002 CCW constituent database now covers more than 160 sites. The 1999 data set included approximately 10,000 individual samples of CCW. The 2002 CCW constituent database now includes more than 35,000 individual samples.

The additional data also represent an expansion in the scope of characterization data available to EPA for analysis. The 1999 data were obtained exclusively from the electric power industry. As shown in Attachment A-1, the 2002 data set includes data from other sources, such as scientific literature and state and federal regulatory agencies. The 1999 data set included analyses of whole waste samples, surface impoundment and landfill porewater analyses, and analyses of extracts obtained using the Toxicity Characteristic Leaching Procedure (TCLP), the Synthetic Precipitation Leaching Procedure (SPLP), and Extraction Procedure (EP) Toxicity leaching methods. The 2002 data set added analyses of actual landfill leachate (e.g., obtained from leachate collection systems), analyses of extracts obtained using other leaching methods (including higher retention time leaching methods), and porewater analyses.

The 2002 CCW constituent database represents CCW characteristics across a broad cross-section of the generating universe. Not only does the database include data from a large number of sites, but these sites are distributed throughout the United States, as shown in **Table A-2**. The database includes data for all major types of CCW (i.e., fly ash, bottom ash, flue gas desulfurization [FGD] sludge, fluidized bed combustion [FBC] fly ash, and FBC bed ash), from mixtures of CCW types that are commonly created during disposal operations (e.g., combined fly ash and bottom ash), and from CCW mixed with coal refuse (a common disposal practice). **Section A.2** discusses waste types in more detail.

Table A-2. States Included in the CCW Constituent Database

Alaska	Illinois	Maryland
Arkansas	Indiana	Michigan
California	Kentucky	Ohio
Colorado	Missouri	Oklahoma
Connecticut	North Carolina	Pennsylvania
Florida	North Dakota	Tennessee
Georgia	Nebraska	Texas
Hawaii	New Mexico	Wisconsin
Iowa	Louisiana	West Virginia

The database also includes data for CCW generated from combustion of all major coal ranks: bituminous, sub-bituminous, lignite, and anthracite. Although the database does include coal type designations for most of the entries, in many cases the type is not specified. In addition, many coal plants mix coal from different sources (e.g., eastern and western coals), depending on prices and the need to reduce sulfur levels. As a result, correlations of risk results with coal types may be difficult and may not produce significant results.

A.2 Data Preparation

Table A-3 lists the waste types evaluated in the CCW risk assessment, along with the number of sites representing each waste type in the CCW constituent database. Key steps in preparing these data for risk assessment include (1) selection and grouping of waste types to be addressed, (2) selection of the analyte data to be used, and (3) processing of these data to develop the analyte concentrations for the screening analysis and full-scale risk assessment.

Table A-3. Waste Streams in CCW Constituent Database

Waste Type **Waste Streams**	**Number of Sites by Waste Type**[a]		
	Landfill Leachate	**Surface Impoundment Porewater**	**Total Waste**
Conventional Combustion Waste	*97*	*13*	*62*
Ash (not otherwise specified)	43	0	30
Fly ash	61	2	33
Bottom ash & slag	24	3	23
Combined fly & bottom ash	7	4	4
FGD sludge	4	6	5
Codisposed Ash & Coal Refuse	9	5	1
Fluidized Bed Combustion Waste	*58*	*0*	*54*
Ash (not otherwise specified)	18	0	10
Fly ash	33	0	32
Bottom and bed ash	26	0	25
Combined fly & bottom ash	20	0	22

[a] Site counts by waste type from leachate, porewater, and whole waste data tables in the 2002 CCW constituent database.

A.2.1 Selection and Grouping of Waste Types of Concern

The CCW constituent database contains a variety of waste types. Some selection and grouping of these types was appropriate so that the risk assessment could evaluate risks consistently for groups of wastes that are expected to behave similarly when disposed in landfills and surface impoundments.

Combustion ash types in the CCW constituent database include fly ash, bottom ash, bed ash, slag, combined fly and bottom ash, and coal ash not otherwise specified. Based on a statistical analysis that showed no significant difference in leachate and porewater chemistry, the analysis combines data for these ash types for landfills and surface impoundments. FGD sludge was also combined with these conventional combustion ash types based on insignificant differences in porewater chemistry and the fact that FGD sludge is usually codisposed with varying amounts of fly ash and bottom ash.

CCW porewater constituent data did show that FBC wastes and codisposed ash and coal refuse (coal waste from coal crushers and other coal preparation and handling operations[1]) differ significantly from coal combustion ash in their composition and leachate chemistry, so these wastes were addressed separately in the risk analysis. FBC waste chemistry is impacted by the limestone injected with coal in FBC units for sulfur capture and tends to be very alkaline with high levels of calcium and sulfate. Coal refuse is high in pyrite, which generates sulfuric acid when disposed. As a result, combustion wastes exhibit a lower pH when codisposed with coal refuse.

A.2.2 Selection of Appropriate Analyte Data

CCW analyte concentration data represent leachate from landfills and surface impoundments and whole waste in landfills, as follows:

- Whole waste analyte concentrations (in mg/kg) represent landfill waste.
- Analyte concentrations (in mg/L) in porewater sampled from surface impoundment sediments represent surface impoundment leachate.
- Analyte concentrations for extracts from leaching methods, analyses of actual landfill leachate, and landfill porewater analyses represent landfill leachate. Because the CCW constituent database includes analyte concentrations from several leaching methods, a decision hierarchy was used to select leachate analyses to use in the risk assessment (**Table A-4**).

As shown in Table A-4, the methods thought to best represent long-term waste monofill porewater composition (i.e., methods with long equilibration times and low liquid-to-solid ratios) represent only a few sites, with most sites having TCLP and/or SPLP measurements. To best represent CCW landfill waste concentration at a wide variety of sites, the hierarchy rank shown in Table A-4 was used to select the best method for a particular site. For sites where two or more

[1] Coal refuse is the waste coal produced from coal handling, crushing, and sizing operations. In the CCW constituent database, codisposed coal refuse includes “combined ash and coal gob”, “combined ash and coal refuse”, and “combined bottom ash and pyrites”.

methods were available in the same rank (which often occurs for SPLP and TCLP analyses), the screening analysis used the method with the highest analyte concentrations. This ensured that the data used in the risk assessment were the best that were available and represent a broad variety of waste disposal conditions.

Table A-4. Comparison/Hierarchy of Leaching Methods for Landfills Represented in CCW Constituent Database

Method (Rank)	Description	Advantages	Disadvantages
Landfill leachate (1)	Direct samples of landfill leachate	Most representative of leachate chemistry	Low number of sites represented
Landfill porewater (1)	Direct porewater samples from landfill	Most representative of leachate chemistry	Low number of sites represented
High retention time and low liquid-to-solid ratio (L:S) methods (2)	Waste extractions with long equilibration times (days to weeks) and low L:S	Better representation of landfill equilibration times and L:S	Low number of sites represented
Low L:S methods (3)	Waste extractions with low L:S	Better representation of landfill L:S	Low number of sites represented; equilibrium times relatively short
High retention time methods (3)	Waste extractions with long equilibration times (days to weeks)	Better representation of landfill equilibration times	Low number of sites represented; L:S relatively high
TCLP (4)	Toxicity Characteristic Leaching Procedure waste extractions	Most representative in terms of number of sites, waste types covered	High L:S (20:1) can dilute leachate concentrations; short equilibration time (18 hours) may not allow equilibrium to develop; Na-acetate buffer can overestimate leaching for some constituents (e.g., Pb)
SPLP (4)	Synthetic Precipitation Leaching Procedure and other dilute water waste extractions	More representative in terms of number of sites, waste types covered; extract similar to precipitation	High L:S (20:1) can dilute leachate concentrations; short equilibration time (18 hours) may not allow equilibrium to develop

A.2.3 Development of Waste Constituent Concentrations

To allow risk assessment results to be organized by waste constituent and waste type, CCW data were processed to produce a single concentration per waste stream (surface impoundment porewater, landfill leachate, and landfill whole waste), analyte, and site for use in the risk assessment. Data processing to prepare these analyte concentrations for the CCW risk assessment involved two steps:

1. **Calculation of average constituent concentrations by site for landfill leachate, surface impoundment porewater, and total ash concentrations.** Site averaging avoids potential bias toward sites with many analyses per analyte. During site averaging, any separate waste disposal scenarios occurring at a site (e.g., non-FBC and FBC ash) were treated as separate “sites” and were averaged independently. This approach is consistent with that used in the 1998 CCW risk analysis. As in 1998, nondetects were averaged at one-half the reported detection limit.

2. **Selection of waste concentrations from site-averaged values.** For the Monte Carlo analysis, the analysis randomly selected, by waste type/waste management unit (WMU) scenario, site-averaged leachate concentrations. For landfills, a corresponding total waste analysis was pulled from the database or calculated from a constituent-specific relationship between landfill leachate and total waste analyses.

A.3 Results

Attachment A-2 provides the site-averaged constituent data used (sampled) in the full-scale CCW risk assessment by waste type/WMU scenario. **Attachment A-3** presents summary statistics, by constituent and WMU type, including the 90th percentile waste concentrations used in the screening analysis. Attachment A-3 also includes figures (**Figures A-3-1** to **A-3-3**) that illustrate the differences between site-averaged and non-site-averaged waste concentrations for surface impoundment porewater (Figure A-3-1), landfill leachate (Figure A-3-2), and total waste analyses (Figure A-3-3).

A.4 References

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Attachment A-2: CCW Constituent Data

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
11 - FBC	LF	Arsenic	0.002916667	3	3	51
11 - FBC	LF	Barium	0.339166667	3	3	174.5
11 - FBC	LF	Cadmium	0.0005	4	4	6.91875
11 - FBC	LF	Lead	0.0025	4	4	39.5
11 - FBC	LF	Mercury	0.00125	4	4	0.1325
11 - FBC	LF	Selenium	0.00225	4	2	45.5
12 - FBC	LF	Aluminum	3.4	1	0	35874.6
12 - FBC	LF	Antimony	0.27	1	0	18
12 - FBC	LF	Arsenic	0.02205	2	0	57.64333333
12 - FBC	LF	Barium	0.196	2	1	203.805
12 - FBC	LF	Boron	0.05	1	1	20.324
12 - FBC	LF	Cadmium	0.005625	2	1	0.279375
12 - FBC	LF	Lead	0.025	1	1	45.66666667
12 - FBC	LF	Mercury	0.00005	2	2	1.2575
12 - FBC	LF	Molybdenum	0.21	1	0	15.5
12 - FBC	LF	Selenium	0.04355	2	0	7.365833333
17 - FBC	LF	Aluminum	4.788	5	0	46194.8
17 - FBC	LF	Antimony	0.0708	5	2	14.60333333
17 - FBC	LF	Arsenic	0.1378	5	0	71.46666667
17 - FBC	LF	Barium	0.3512	5	1	134.975
17 - FBC	LF	Boron	0.4404	5	1	34.06333333
17 - FBC	LF	Cadmium	0.0434	5	2	3.058333333
17 - FBC	LF	Lead	0.2372	5	2	49.65
17 - FBC	LF	Mercury	0.01022	5	5	1.60345
17 - FBC	LF	Molybdenum	0.097	5	1	3.515
17 - FBC	LF	Selenium	0.06315	5	2	3.301666667
18 - FBC	LF	Aluminum	1.333333333	3	0	23501.33333
18 - FBC	LF	Antimony	0.025	3	3	5
18 - FBC	LF	Arsenic	0.025	3	3	53.33333333
18 - FBC	LF	Barium	0.175	3	1	211.3333333
18 - FBC	LF	Boron	1.341666667	3	1	532.3333333
18 - FBC	LF	Cadmium	0.025	3	3	2.5
18 - FBC	LF	Cobalt	0.025	3	3	11
18 - FBC	LF	Lead	0.025	3	3	22
18 - FBC	LF	Mercury	0.0005	3	2	0.268333333
18 - FBC	LF	Molybdenum	0.175	3	1	7.666666667

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
18 – FBC	LF	Selenium	0.108333333	3	1	0.5
18 - FBC	LF	Thallium	0.025	3	3	1
19 - FBC	LF	Arsenic	0.0875	2	1	6.25
19 - FBC	LF	Barium	0.27	2	1	39.2
19 - FBC	LF	Cadmium	0.01375	2	2	2.5
19 - FBC	LF	Lead	0.0675	2	2	3.75
19 - FBC	LF	Mercury	0.00125	2	1	0.125
19 - FBC	LF	Selenium	0.06875	2	2	6.25
20 - FBC	LF	Aluminum	10.81	12	0	34329.16522
20 - FBC	LF	Antimony	0.787	10	0	46.28125
20 - FBC	LF	Arsenic	0.035	12	0	15.03130435
20 - FBC	LF	Barium	0.381818182	11	0	255.4608696
20 - FBC	LF	Boron	0.457142857	7	0	28.0025
20 - FBC	LF	Cadmium	0.03625	8	0	2.089166667
20 - FBC	LF	Lead	0.301111111	9	0	36.20052632
20 - FBC	LF	Mercury	0.29	1	0	0.454
20 - FBC	LF	Molybdenum	0.392857143	7	0	12.10111111
20 - FBC	LF	Selenium	0.088571429	7	0	4.177333333
21 - FBC	LF	Aluminum	1.91	3	0	14677.33167
21 - FBC	LF	Antimony	0.001833333	3	3	1.083333333
21 - FBC	LF	Arsenic	0.012	3	0	10.76666667
21 - FBC	LF	Barium	0.022333333	3	2	176.2666667
21 - FBC	LF	Boron	0.036666667	3	2	14.38333333
21 - FBC	LF	Cadmium	0.002083333	3	3	0.145833333
21 - FBC	LF	Cobalt	0.008333333	3	2	5.756666667
21 - FBC	LF	Lead	0.009166667	3	3	27.3
21 - FBC	LF	Mercury	0.000133333	3	2	0.431666667
21 - FBC	LF	Molybdenum	0.0125	3	3	3.708333333
21 - FBC	LF	Selenium	0.016666667	3	0	10.9
2-18 - Ash	LF	Arsenic	0.41794375	16	3	
2-18 - Ash	LF	Barium	0.4305625	16	0	
2-18 - Ash	LF	Boron	1.0160625	16	0	
2-18 - Ash	LF	Cadmium	0.05825	16	11	
2-18 - Ash	LF	Lead	0.2819375	16	11	
2-18 - Ash	LF	Mercury	0.000115625	16	16	
2-18 - Ash	LF	Selenium	0.01534375	16	8	
22 - FBC	LF	Arsenic	0.055	5	3	
22 - FBC	LF	Barium	0.5405	5	1	
22 - FBC	LF	Cadmium	0.003	5	5	
22 - FBC	LF	Lead	0.015	5	5	
22 - FBC	LF	Mercury	0.0002	5	3	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
22 - FBC	LF	Molybdenum	0.0125	2	2	
22 - FBC	LF	Selenium	0.032	5	5	
23 - FBC	LF	Barium	0.81	4	0	
25 - FBC	LF	Arsenic	0.125	1	1	
25 - FBC	LF	Barium	2.5	1	1	
25 - FBC	LF	Cadmium	0.025	1	1	
25 - FBC	LF	Lead	0.125	1	1	
25 - FBC	LF	Mercury	0.005	1	1	
25 - FBC	LF	Selenium	0.025	1	1	
28 - FBC	LF	Barium	2.525	2	0	235.11875
30 - FBC	LF	Aluminum	6.894555556	18	7	28246.46923
30 - FBC	LF	Antimony	0.548082353	17	2	61.49315385
30 - FBC	LF	Arsenic	0.050694444	18	3	48.55980769
30 - FBC	LF	Barium	0.286388889	18	6	120.0687692
30 - FBC	LF	Boron	0.31759375	16	7	30.83913462
30 - FBC	LF	Cadmium	0.023125	14	3	1.916230769
30 - FBC	LF	Lead	0.240805556	18	4	39.36092308
30 - FBC	LF	Mercury	0.000744444	18	17	10.91689923
30 - FBC	LF	Molybdenum	0.138125	16	10	14.50257692
30 - FBC	LF	Selenium	0.10475	16	10	5.603596154
31 - FBC	LF	Aluminum	0.28	1	0	29437.5
31 - FBC	LF	Antimony	0.00065	1	1	5.0325
31 - FBC	LF	Arsenic	0.0687	4	2	26.825
31 - FBC	LF	Barium	0.58275	4	0	170.25
31 - FBC	LF	Boron	26.7	1	0	930
31 - FBC	LF	Cadmium	0.02775	4	3	5.45
31 - FBC	LF	Cobalt	0.0065	1	0	6.42
31 - FBC	LF	Lead	0.03025	4	3	1.19
31 - FBC	LF	Mercury	0.00095	4	1	0.61
31 - FBC	LF	Molybdenum	0.085	1	0	8
31 - FBC	LF	Selenium	0.06485	4	2	7.54
32 - FBC	LF	Arsenic	0.35	1	1	1.4
32 - FBC	LF	Barium	0.085	1	0	
32 - FBC	LF	Cadmium	0.005	1	1	0.009
32 - FBC	LF	Lead	0.05	1	1	0.45
32 - FBC	LF	Mercury	0.0001	1	1	0.03
32 - FBC	LF	Selenium	0.175	1	1	3.5
33 - FBC	LF	Arsenic	0.015	1	1	
33 - FBC	LF	Barium	42	1	0	
33 - FBC	LF	Boron	0.06	1	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
33 - FBC	LF	Cadmium	0.00125	1	1	
33 - FBC	LF	Cobalt	0.0025	1	1	
33 - FBC	LF	Mercury	0.00005	1	1	
33 - FBC	LF	Selenium	0.01	1	1	
35 - FBC	LF	Arsenic	0.015	1	1	
35 - FBC	LF	Barium	2.6	1	0	
35 - FBC	LF	Cadmium	0.009	1	0	
35 - FBC	LF	Lead	0.035	1	1	
35 - FBC	LF	Mercury	0.00025	1	1	
35 - FBC	LF	Selenium	0.2	1	0	
37 - FBC	LF	Arsenic	0.011102941	17	9	5.79
37 - FBC	LF	Barium	2.104705882	17	2	
37 - FBC	LF	Boron	1.125	5	1	15.9
37 - FBC	LF	Cadmium	0.046176471	17	4	4.183333333
37 - FBC	LF	Cobalt	0.246	5	0	
37 - FBC	LF	Lead	0.287352941	17	6	55
37 - FBC	LF	Mercury	0.001314706	17	4	0.01125
37 - FBC	LF	Selenium	0.01075	17	9	3.42
38 - FBC	LF	Aluminum	2.256666667	9	2	26711.25
38 - FBC	LF	Antimony	0.213069444	9	6	11.27770833
38 - FBC	LF	Arsenic	0.024554444	9	3	25.136075
38 - FBC	LF	Barium	0.178888889	9	4	181.0083333
38 - FBC	LF	Boron	0.346555556	9	2	26.98916667
38 - FBC	LF	Cadmium	0.007388889	9	5	0.71625
38 - FBC	LF	Cobalt	0.008566667	3	2	4.515
38 - FBC	LF	Lead	0.0565	9	6	28.54166667
38 - FBC	LF	Mercury	0.000344444	9	8	0.18195
38 - FBC	LF	Molybdenum	0.177375	8	2	14.1875
38 - FBC	LF	Selenium	0.088561111	9	4	7.682450833
39 - FBC	LF	Arsenic	0.075	1	1	14.5
39 - FBC	LF	Barium	0.395	2	1	590
39 - FBC	LF	Boron	0.76	1	0	
39 - FBC	LF	Cadmium	0.005	1	1	0.5
39 - FBC	LF	Lead	0.025	1	1	15
39 - FBC	LF	Mercury	0.00025	1	1	0.17
39 - FBC	LF	Molybdenum	0.14	1	0	13.5
39 - FBC	LF	Selenium	0.025	1	1	21.5
4 - FBC	LF	Aluminum	13.556	5	0	16084.68429
4 - FBC	LF	Antimony	0.2236	5	2	26.78817857
4 - FBC	LF	Arsenic	0.271	5	0	28.03585714
4 - FBC	LF	Barium	0.6346	5	1	154.95

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
4 - FBC	LF	Boron	0.693	4	0	13.026
4 - FBC	LF	Cadmium	0.0115	5	2	0.646539286
4 - FBC	LF	Mercury	0.00005	5	5	0.087192857
4 - FBC	LF	Lead	0.1834	5	1	18.35671429
4 - FBC	LF	Molybdenum	0.286666667	3	0	16.18257143
4 - FBC	LF	Selenium	0.0620625	4	2	1.505421429
41 - FBC	LF	Antimony	0.025	5	5	1.551333333
41 - FBC	LF	Arsenic	0.035471698	53	50	13.72255319
41 - FBC	LF	Barium	0.095694444	54	25	19.05490196
41 - FBC	LF	Cadmium	0.022355769	52	51	0.427826087
41 - FBC	LF	Lead	0.017548077	52	51	0.935208333
41 - FBC	LF	Mercury	0.000596154	52	50	0.119542553
41 - FBC	LF	Selenium	0.024433962	53	51	1.505744681
41 - FBC	LF	Thallium	0.031	5	4	3.662790698
42 - FBC	LF	Arsenic	0.0125	2	2	
42 - FBC	LF	Barium	0.1625	2	1	
42 - FBC	LF	Cadmium	0.005	2	2	
42 - FBC	LF	Lead	0.0075	2	2	
42 - FBC	LF	Mercury	0.0005	2	2	
42 - FBC	LF	Selenium	0.0125	2	2	
43 - FBC	LF	Arsenic	0.0125	2	2	
43 - FBC	LF	Barium	0.0875	2	1	
43 - FBC	LF	Cadmium	0.005	2	2	
43 - FBC	LF	Lead	0.0075	2	2	
43 - FBC	LF	Mercury	0.0005	2	2	
43 - FBC	LF	Selenium	0.08625	2	1	
6 - FBC	LF	Aluminum	0.1525	2	1	42736.5
6 - FBC	LF	Antimony	0.05	2	2	16.25
6 - FBC	LF	Arsenic	0.09125	2	1	126.6
6 - FBC	LF	Barium	0.285	2	0	221.5
6 - FBC	LF	Boron	0.1425	2	1	73.8
6 - FBC	LF	Cadmium	0.0025	2	2	1.29625
6 - FBC	LF	Lead	0.01375	2	2	8.1125
6 - FBC	LF	Mercury	0.00005	2	2	1.16
6 - FBC	LF	Molybdenum	0.09	2	0	1.425
6 - FBC	LF	Selenium	0.1025	2	1	84.5625
Amerikohl - FBC	LF	Aluminum	0.753333333	3	0	51600
Amerikohl - FBC	LF	Antimony	0.345	3	3	20
Amerikohl - FBC	LF	Arsenic	0.024166667	3	3	114
Amerikohl - FBC	LF	Barium	0.1	3	3	140
Amerikohl - FBC	LF	Boron	0.346666667	3	1	60

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Amerikohl - FBC	LF	Cadmium	0.004166667	3	3	0.15
Amerikohl - FBC	LF	Cobalt	0.175	3	3	30
Amerikohl - FBC	LF	Lead	0.009166667	3	3	23
Amerikohl - FBC	LF	Mercury	0.0005	3	3	0.15
Amerikohl - FBC	LF	Molybdenum	0.266666667	3	1	10
Amerikohl - FBC	LF	Nitrate/Nitrite	3.15	3	3	
Amerikohl - FBC	LF	Selenium	0.044166667	3	3	3.5
Arkwright - Ash	LF	Arsenic	0.07	1	0	
Arkwright - Ash	LF	Barium	0.4	1	0	
Arkwright - Ash	LF	Cadmium	0.01	1	0	
Arkwright - Ash	LF	Lead	0.04	1	0	
Arkwright - Ash	LF	Selenium	0.02	1	0	
Barry - Ash	LF	Arsenic	1	1	0	
Barry - Ash	LF	Barium	0.7	1	0	
Barry - Ash	LF	Cadmium	0.005	1	0	
Barry - Ash	LF	Lead	0.04	1	0	
Barry - Ash	LF	Selenium	0.07	1	0	
Belle Ayr - Ash	LF	Aluminum	0.036666667	3	0	
Belle Ayr - Ash	LF	Antimony	0.021	2	0	
Belle Ayr - Ash	LF	Arsenic	0.181	3	0	
Belle Ayr - Ash	LF	Barium	1.163333333	3	0	
Belle Ayr - Ash	LF	Cobalt	0.0075	2	0	
Belle Ayr - Ash	LF	Molybdenum	0.325	3	0	
Belle Ayr - Ash	LF	Selenium	0.652333333	3	0	
Big Gorilla Pit - FBC	LF	Aluminum	3.774166667	12	0	18440.58824
Big Gorilla Pit - FBC	LF	Antimony	0.037166667	12	1	1.244485294
Big Gorilla Pit - FBC	LF	Arsenic	0.023181818	22	21	7.534117647
Big Gorilla Pit - FBC	LF	Barium	0.243636364	11	3	147.7320588
Big Gorilla Pit - FBC	LF	Boron	0.677916667	12	2	29.64058824
Big Gorilla Pit - FBC	LF	Cadmium	0.015227273	22	22	0.58728125
Big Gorilla Pit - FBC	LF	Cobalt	0.008553571	14	11	2.374214286
Big Gorilla Pit - FBC	LF	Lead	0.08125	12	7	19.51823529
Big Gorilla Pit - FBC	LF	Mercury	0.001704545	22	19	0.302990909
Big Gorilla Pit - FBC	LF	Molybdenum	0.1202	10	1	6.429333333
Big Gorilla Pit - FBC	LF	Nitrate/Nitrite	1.755857143	14	3	
Big Gorilla Pit - FBC	LF	Selenium	0.10975	12	1	7.159397059
Bowen - Ash	LF	Arsenic	0.6	1	0	68
Bowen - Ash	LF	Barium	0.3	1	0	974
Bowen - Ash	LF	Cadmium	0.01	1	0	0.7
Bowen - Ash	LF	Lead	0.04	1	0	63.9
Bowen - Ash	LF	Selenium	0.1	1	0	

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Branch - Ash	LF	Arsenic	0.04	1	0	
Branch - Ash	LF	Barium	0.5	1	0	
Branch - Ash	LF	Cadmium	0.01	1	0	
Branch - Ash	LF	Lead	0.04	1	0	
Branch - Ash	LF	Selenium	0.06	1	0	
Buckheart Mine - Ash	LF	Antimony	0.01854	40	14	
Buckheart Mine - Ash	LF	Arsenic	0.122357143	42	13	
Buckheart Mine - Ash	LF	Barium	0.364809524	42	0	
Buckheart Mine - Ash	LF	Boron	9.998738095	42	0	
Buckheart Mine - Ash	LF	Cadmium	0.0235	42	8	
Buckheart Mine - Ash	LF	Cobalt	0.048047619	42	17	
Buckheart Mine - Ash	LF	Lead	0.27887619	42	9	
Buckheart Mine - Ash	LF	Mercury	0.000107143	42	40	
Buckheart Mine - Ash	LF	Selenium	0.118266667	42	26	
Buckheart Mine - Ash	LF	Thallium	0.017875	40	10	
Buckheart Mine - FBC	LF	Antimony	0.0018125	8	8	
Buckheart Mine - FBC	LF	Arsenic	0.0465	8	5	
Buckheart Mine - FBC	LF	Barium	0.560125	8	1	
Buckheart Mine - FBC	LF	Boron	3.157	8	0	
Buckheart Mine - FBC	LF	Cadmium	0.0033125	8	7	
Buckheart Mine - FBC	LF	Cobalt	0.02875	8	7	
Buckheart Mine - FBC	LF	Lead	0.036	8	4	
Buckheart Mine - FBC	LF	Mercury	0.0005	8	4	
Buckheart Mine - FBC	LF	Selenium	0.050625	8	5	
Buckheart Mine - FBC	LF	Thallium	0.001	8	8	
CAER - Ash	LF	Arsenic	1.132	5	0	77.32222222
CAER - Ash	LF	Barium	0.315	5	0	537.6666667
CAER - Ash	LF	Cadmium	0.0942	5	0	
CAER - Ash	LF	Lead	0.1	5	2	73.62375
CAER - Ash	LF	Mercury	0.00025	5	5	
CAER - Ash	LF	Selenium	0.103	5	0	
Canton Site - Ash	LF	Aluminum	9.818127778	36	0	
Canton Site - Ash	LF	Arsenic	0.0025	2	2	
Canton Site - Ash	LF	Barium	3.0156	10	0	
Canton Site - Ash	LF	Boron	18.62468571	35	0	
Canton Site - Ash	LF	Cadmium	0.0005	2	2	
Canton Site - Ash	LF	Cobalt	0.02	1	1	
Canton Site - Ash	LF	Lead	0.1865	2	0	
Canton Site - Ash	LF	Mercury	0.0001	1	1	
Canton Site - Ash	LF	Molybdenum	30.9359	20	0	
Canton Site - Ash	LF	Nitrate/Nitrite	0.095	1	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Canton Site - Ash	LF	Selenium	0.0374	1	0	
Canton Site - FBC	LF	Aluminum	2.461866667	24	0	
Canton Site - FBC	LF	Arsenic	0.005	1	1	
Canton Site - FBC	LF	Barium	0.02	1	0	
Canton Site - FBC	LF	Boron	1.5602625	16	0	
Canton Site - FBC	LF	Cadmium	0.066	1	0	
Canton Site - FBC	LF	Lead	0.062	1	0	
Canton Site – FBC	LF	Mercury	0.0005	1	1	
Canton Site – FBC	LF	Molybdenum	1.768009524	21	0	
Canton Site – FBC	LF	Selenium	0.005	1	1	
Central Cleaning Plant - Ash	LF	Antimony	0.008205882	17	17	
Central Cleaning Plant - Ash	LF	Arsenic	0.005	17	17	
Central Cleaning Plant - Ash	LF	Barium	0.168164706	17	0	
Central Cleaning Plant - Ash	LF	Boron	7.213823529	17	0	
Central Cleaning Plant - Ash	LF	Cadmium	0.004117647	17	16	
Central Cleaning Plant - Ash	LF	Cobalt	0.019588235	17	15	
Central Cleaning Plant - Ash	LF	Lead	0.022782353	17	11	
Central Cleaning Plant - Ash	LF	Mercury	0.000568824	17	11	
Central Cleaning Plant - Ash	LF	Selenium	0.040211765	17	0	
Central Cleaning Plant - Ash	LF	Thallium	0.005	17	17	
CL - Ash and Coal Refuse	LF	Aluminum	2.58	3	0	
CL - Ash and Coal Refuse	LF	Antimony	0.0041	3	0	
CL - Ash and Coal Refuse	LF	Arsenic	0.121266667	3	0	
CL - Ash and Coal Refuse	LF	Barium	3.63	3	0	
CL - Ash and Coal Refuse	LF	Boron	0.103133333	3	0	
CL - Ash and Coal Refuse	LF	Cadmium	0.001	3	0	
CL - Ash and Coal Refuse	LF	Cobalt	0.006066667	3	1	
CL - Ash and Coal Refuse	LF	Lead	0.003533333	3	0	
CL - Ash and Coal Refuse	LF	Mercury	0.00005	6	6	
CL - Ash and Coal Refuse	LF	Selenium	0.0452	3	0	
CL - Ash and Coal Refuse	LF	Thallium	0.003483333	3	1	
Coal Creek - Ash	LF	Arsenic	0.0109	2	0	0.086
Coal Creek - Ash	LF	Barium	0.6105	2	0	4.76
Coal Creek - Ash	LF	Boron	6.22	2	0	1.1105
Coal Creek - Ash	LF	Cadmium	0.00015	2	2	0.00045
Coal Creek - Ash	LF	Lead	0.001	2	2	0.02025
Coal Creek - Ash	LF	Mercury	0.000005	2	2	0.0006
Coal Creek - Ash	LF	Selenium	0.0555	2	1	0.00505
Colver Site - FBC	LF	Aluminum	0.248333333	6	1	78878.83333
Colver Site - FBC	LF	Antimony	0.196666667	6	2	166.5
Colver Site - FBC	LF	Arsenic	0.0875	6	1	124.2

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Colver Site - FBC	LF	Barium	0.291666667	6	0	443.8333333
Colver Site - FBC	LF	Boron	0.261666667	6	1	62.6
Colver Site - FBC	LF	Cadmium	0.016666667	6	2	9.994166667
Colver Site - FBC	LF	Lead	0.190833333	6	2	192.075
Colver Site - FBC	LF	Mercury	0.00015	6	5	0.586666667
Colver Site - FBC	LF	Molybdenum	0.143333333	6	0	30.65833333
Colver Site - FBC	LF	Selenium	0.48	6	1	68.70833333
Conemaugh - Ash	LF	Aluminum	1.245	2	0	
Conemaugh - Ash	LF	Antimony	0.075	1	1	
Conemaugh - Ash	LF	Arsenic	0.388333333	3	1	
Conemaugh - Ash	LF	Barium	0.331666667	3	0	
Conemaugh - Ash	LF	Boron	0.91	1	0	
Conemaugh - Ash	LF	Cadmium	0.01	3	0	
Conemaugh - Ash	LF	Cobalt	0.026	1	0	
Conemaugh - Ash	LF	Lead	0.1	2	2	
Conemaugh - Ash	LF	Mercury	0.00055	2	2	
Conemaugh - Ash	LF	Molybdenum	0.355	2	0	
Conemaugh - Ash	LF	Selenium	0.295	2	1	
Conemaugh - Ash	LF	Thallium	0.024	1	0	
Conemaugh - Ash and Coal Refuse	LF	Aluminum	1.467666667	3	0	
Conemaugh - Ash and Coal Refuse	LF	Antimony	0.075	3	3	
Conemaugh - Ash and Coal Refuse	LF	Arsenic	0.625	2	2	
Conemaugh - Ash and Coal Refuse	LF	Barium	0.145666667	3	0	
Conemaugh - Ash and Coal Refuse	LF	Boron	0.095	2	0	
Conemaugh - Ash and Coal Refuse	LF	Cadmium	0.002	3	3	
Conemaugh - Ash and Coal Refuse	LF	Cobalt	0.009	1	0	
Conemaugh - Ash and Coal Refuse	LF	Lead	0.073333333	3	2	
Conemaugh - Ash and Coal Refuse	LF	Mercury	0.0004	3	2	
Conemaugh - Ash and Coal Refuse	LF	Molybdenum	0.01	1	0	
Conemaugh - Ash and Coal Refuse	LF	Selenium	0.179833333	3	1	
Conemaugh - Ash and Coal Refuse	LF	Thallium	0.005	1	0	
Crist - Ash	LF	Arsenic	0.02	1	0	

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Crist - Ash	LF	Barium	0.1	1	0	
Crist - Ash	LF	Cadmium	0.02	1	0	
Crist - Ash	LF	Lead	0.003	1	0	
Crist - Ash	LF	Selenium	0.05	1	0	
Crown III - Ash	LF	Antimony	0.071159259	54	10	
Crown III - Ash	LF	Arsenic	0.352503226	62	29	
Crown III - Ash	LF	Barium	0.279112903	62	3	
Crown III - Ash	LF	Boron	22.93277419	62	0	
Crown III - Ash	LF	Cadmium	0.128258065	62	3	
Crown III - Ash	LF	Cobalt	0.101225806	62	17	
Crown III - Ash	LF	Lead	0.605616935	62	19	
Crown III - Ash	LF	Mercury	0.000104839	62	61	
Crown III - Ash	LF	Molybdenum	0.588888889	9	4	
Crown III - Ash	LF	Selenium	0.03946129	62	46	
Crown III - Ash	LF	Thallium	0.0645	54	18	
Crown III - FBC	LF	Antimony	0.0135	17	9	
Crown III - FBC	LF	Arsenic	0.034822581	31	26	3.766666667
Crown III - FBC	LF	Barium	0.346774194	31	2	150
Crown III - FBC	LF	Boron	2.815296296	27	1	
Crown III - FBC	LF	Cadmium	0.011241935	31	22	2.17
Crown III - FBC	LF	Cobalt	0.02475	24	16	
Crown III - FBC	LF	Lead	0.068645161	31	17	8.233333333
Crown III - FBC	LF	Mercury	0.000164516	31	27	0.381
Crown III - FBC	LF	Molybdenum	0.1522	10	2	
Crown III - FBC	LF	Selenium	0.061467742	31	27	3.3
Crown III - FBC	LF	Thallium	0.004941176	17	11	
CTL-V - Ash	LF	Antimony	0.26	1	0	
CTL-V - Ash	LF	Arsenic	0.037	1	0	
CTL-V - Ash	LF	Barium	0.247	1	0	
CTL-V - Ash	LF	Cadmium	0.04	1	0	
CTL-V - Ash	LF	Lead	0.072	1	0	
CTL-V - Ash	LF	Mercury	0.001	1	0	
CTL-V - Ash	LF	Selenium	0.014	1	0	
CTL-V - Ash	LF	Thallium	0.01	1	0	
CY - Ash	LF	Aluminum	4.735	2	0	
CY - Ash	LF	Antimony	0.0078	2	0	
CY - Ash	LF	Arsenic	0.04825	2	0	
CY - Ash	LF	Barium	1.2395	2	0	
CY - Ash	LF	Boron	6.13	2	0	
CY - Ash	LF	Cadmium	0.0002075	2	1	
CY - Ash	LF	Cobalt	0.001915	4	4	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
CY - Ash	LF	Lead	0.003555	2	1	
CY - Ash	LF	Mercury	0.000265	2	0	
CY - Ash	LF	Selenium	0.004825	2	1	
CY - Ash	LF	Thallium	0.00196	4	4	
Dairyland Power Coop - Ash	LF	Arsenic	0.0328625	8	0	
Dairyland Power Coop - Ash	LF	Barium	0.058740741	27	0	
Dairyland Power Coop - Ash	LF	Boron	68.03979592	49	0	
Dairyland Power Coop - Ash	LF	Cadmium	0.00539	34	0	
Dairyland Power Coop - Ash	LF	Lead	0.0046	7	2	
Dairyland Power Coop - Ash	LF	Mercury	0.000223	2	1	
Dairyland Power Coop - Ash	LF	Selenium	0.0696375	8	0	
Daniel - Ash	LF	Arsenic	0.2	1	0	
Daniel - Ash	LF	Barium	0.4	1	0	
Daniel - Ash	LF	Cadmium	0.001	1	1	
Daniel - Ash	LF	Lead	0.001	1	1	
Daniel - Ash	LF	Selenium	0.001	1	1	
Deer Ridge Mine - Ash	LF	Aluminum	0.5941	10	1	64681.487
Deer Ridge Mine - Ash	LF	Arsenic	0.0029	10	6	21.29419
Deer Ridge Mine - Ash	LF	Barium	0.1448	10	2	258.468
Deer Ridge Mine - Ash	LF	Boron	1.228	10	2	179.354
Deer Ridge Mine - Ash	LF	Cadmium	0.01365	10	1	0.94425
Deer Ridge Mine - Ash	LF	Lead	0.0253	10	2	58.48
Deer Ridge Mine - Ash	LF	Mercury	0.00011025	10	10	0.1158
Deer Ridge Mine - Ash	LF	Molybdenum	0.0756	10	4	6.6287
Deer Ridge Mine - Ash	LF	Nitrate/Nitrite	0.095	3	2	
Deer Ridge Mine - Ash	LF	Selenium	0.01022	10	2	13.1061
DPC - Ash	LF	Antimony	0.04	2	1	0.475
DPC - Ash	LF	Arsenic	0.051	2	0	55.085
DPC - Ash	LF	Barium	0.28	2	0	37.7
DPC - Ash	LF	Boron	27.945	2	0	404.05
DPC - Ash	LF	Cadmium	0.005	4	4	0.56
DPC - Ash	LF	Lead	0.025	4	4	28.7
DPC - Ash	LF	Mercury	0.001	2	2	0.127
DPC - Ash	LF	Nitrate/Nitrite	2.5	2	0	0.2425
DPC - Ash	LF	Selenium	0.046	2	0	3.4445
EERC - Ash	LF	Mercury	0.000025	4	4	
Elkhart Mine - Ash	LF	Antimony	0.025192308	52	46	
Elkhart Mine - Ash	LF	Arsenic	0.043571429	77	71	
Elkhart Mine - Ash	LF	Barium	0.495324675	77	23	
Elkhart Mine - Ash	LF	Boron	6.88961039	77	0	
Elkhart Mine - Ash	LF	Cadmium	0.022551948	77	41	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Elkhart Mine - Ash	LF	Cobalt	0.012785714	77	57	
Elkhart Mine - Ash	LF	Lead	0.027987013	77	66	
Elkhart Mine - Ash	LF	Mercury	0.000148052	77	68	
Elkhart Mine - Ash	LF	Selenium	0.036649351	77	64	
Elkhart Mine - Ash	LF	Thallium	0.015942308	52	48	
Elkhart Mine - FBC	LF	Antimony	0.021875	16	15	
Elkhart Mine - FBC	LF	Arsenic	0.034512195	41	37	
Elkhart Mine - FBC	LF	Barium	0.525365854	41	5	
Elkhart Mine - FBC	LF	Boron	13.13829268	41	0	
Elkhart Mine - FBC	LF	Cadmium	0.003536585	41	41	
Elkhart Mine - FBC	LF	Cobalt	0.007219512	41	39	
Elkhart Mine - FBC	LF	Lead	0.017195122	41	34	
Elkhart Mine - FBC	LF	Mercury	0.000104878	41	40	
Elkhart Mine - FBC	LF	Selenium	0.035365854	41	33	
Elkhart Mine - FBC	LF	Thallium	0.02390625	16	15	
FBX - Ash	LF	Arsenic	0.0025	2	2	
FBX - Ash	LF	Barium	29.6225	2	1	
FBX - Ash	LF	Cadmium	0.2	2	2	
FBX - Ash	LF	Lead	0.5	2	2	
FBX - Ash	LF	Mercury	0.00025	2	2	
FBX - Ash	LF	Selenium	0.01375	2	2	
FC - Ash and Coal Refuse	LF	Aluminum	13.8	2	0	
FC - Ash and Coal Refuse	LF	Antimony	0.00105	4	4	
FC - Ash and Coal Refuse	LF	Arsenic	0.005	2	0	
FC - Ash and Coal Refuse	LF	Barium	0.602	2	0	
FC - Ash and Coal Refuse	LF	Boron	2.54	2	0	
FC - Ash and Coal Refuse	LF	Cadmium	0.00015	4	4	
FC - Ash and Coal Refuse	LF	Cobalt	0.0029	2	0	
FC - Ash and Coal Refuse	LF	Lead	0.00345	2	0	
FC - Ash and Coal Refuse	LF	Mercury	0.00005	4	4	
FC - Ash and Coal Refuse	LF	Selenium	0.01765	2	0	
FC - Ash and Coal Refuse	LF	Thallium	0.00185	4	4	
Florence Mine - Ash	LF	Aluminum	0.03	1	0	
Florence Mine - Ash	LF	Antimony	0.005	1	1	
Florence Mine - Ash	LF	Arsenic	0.07	1	0	
Florence Mine - Ash	LF	Barium	2.23	1	0	
Florence Mine - Ash	LF	Boron	0.01	1	1	
Florence Mine - Ash	LF	Cadmium	0.01	1	1	
Florence Mine - Ash	LF	Lead	0.001	1	0	
Florence Mine - Ash	LF	Mercury	0.002	1	0	
Florence Mine - Ash	LF	Molybdenum	0.01	1	1	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Florence Mine - Ash	LF	Nitrate/Nitrite	1.2	1	0	
Florence Mine - Ash	LF	Selenium	0.06	1	0	
Fran Site - FBC	LF	Aluminum	0.32	1	0	
Fran Site - FBC	LF	Antimony	0.005	1	1	
Fran Site - FBC	LF	Arsenic	0.02	1	0	
Fran Site - FBC	LF	Barium	0.08	1	0	
Fran Site - FBC	LF	Boron	0.43	1	0	
Fran Site - FBC	LF	Cadmium	0.005	1	1	
Fran Site - FBC	LF	Lead	0.005	1	1	
Fran Site - FBC	LF	Nitrate/Nitrite	1.22	1	0	
Fran Site - FBC	LF	Selenium	0.03	1	0	
FW - FBC	LF	Arsenic	0.02525	4	3	
FW - FBC	LF	Barium	0.304	4	0	
FW - FBC	LF	Cadmium	0.005	4	4	
FW - FBC	LF	Lead	0.05	4	4	
FW - FBC	LF	Mercury	0.001	4	4	
FW - FBC	LF	Selenium	0.1	4	4	
Gadsden - Ash	LF	Arsenic	0.2	1	0	
Gadsden - Ash	LF	Barium	0.3	1	0	
Gadsden - Ash	LF	Cadmium	0.01	1	0	
Gadsden - Ash	LF	Lead	0.04	1	0	
Gadsden - Ash	LF	Selenium	0.03	1	0	
Gale - Ash	LF	Aluminum	3.1	1	0	13630
Gale - Ash	LF	Antimony	0.03	1	0	3
Gale - Ash	LF	Arsenic	0.42	1	0	51.5
Gale - Ash	LF	Barium	1.7	1	0	143
Gale - Ash	LF	Boron	0.22	1	0	25
Gale - Ash	LF	Cadmium	0.01	1	0	1
Gale - Ash	LF	Lead	0.23	1	0	21
Gale - Ash	LF	Molybdenum	0.05	1	0	5
Gale - Ash	LF	Selenium	0.1	1	0	4.4
Gaston - Ash	LF	Arsenic	1.8	1	0	
Gaston - Ash	LF	Barium	0.3	1	0	
Gaston - Ash	LF	Cadmium	0.01	1	0	
Gaston - Ash	LF	Lead	0.05	1	0	
Gaston - Ash	LF	Selenium	0.003	1	0	
Gorgas - Ash	LF	Arsenic	1.6	1	0	
Gorgas - Ash	LF	Barium	0.3	1	0	
Gorgas - Ash	LF	Cadmium	0.01	1	0	
Gorgas - Ash	LF	Lead	0.04	1	0	
Gorgas - Ash	LF	Selenium	0.002	1	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Greene Co - Ash	LF	Arsenic	1.1	1	0	
Greene Co - Ash	LF	Barium	0.4	1	0	
Greene Co - Ash	LF	Cadmium	0.01	1	0	
Greene Co - Ash	LF	Lead	0.04	1	0	
Greene Co - Ash	LF	Selenium	0.003	1	0	
HA - Ash and Coal Refuse	LF	Aluminum	1.71925	4	0	5666.666667
HA - Ash and Coal Refuse	LF	Antimony	0.003905	4	2	
HA - Ash and Coal Refuse	LF	Arsenic	0.024975	4	0	9.666666667
HA - Ash and Coal Refuse	LF	Barium	1.01675	4	0	186.6666667
HA - Ash and Coal Refuse	LF	Boron	0.64545	4	0	14
HA - Ash and Coal Refuse	LF	Cadmium	0.0039275	4	0	0.25
HA - Ash and Coal Refuse	LF	Cobalt	0.01517875	4	1	
HA - Ash and Coal Refuse	LF	Lead	0.00378	4	2	8.7
HA - Ash and Coal Refuse	LF	Mercury	0.0001	4	0	0.065
HA - Ash and Coal Refuse	LF	Selenium	0.005025	4	0	0.534166667
HA - Ash and Coal Refuse	LF	Thallium	0.00196	8	8	
Hammond - Ash	LF	Arsenic	0.1	1	0	
Hammond - Ash	LF	Barium	0.3	1	0	
Hammond - Ash	LF	Cadmium	0.01	1	0	
Hammond - Ash	LF	Lead	0.05	1	0	
Hammond - Ash	LF	Selenium	0.02	1	0	
Harrim 3019 - Ash	LF	Aluminum	5.21	1	0	46577
Harrim 3019 - Ash	LF	Antimony	0.0058	1	0	646.4
Harrim 3019 - Ash	LF	Arsenic	0.178	1	0	50.43172727
Harrim 3019 - Ash	LF	Barium	0.32	1	0	319.89
Harrim 3019 - Ash	LF	Molybdenum	0.594	1	0	17.9
Harrim 3019 - Ash	LF	Nitrate/Nitrite	1.99	1	0	
Harrim 3019 - Ash	LF	Selenium	0.0468	1	0	1.405714286
Harrim 3019 - FBC	LF	Aluminum	0.67375	8	0	
Harrim 3019 - FBC	LF	Antimony	0.002	1	0	
Harrim 3019 - FBC	LF	Barium	0.465888889	9	0	
Harrim 3019 - FBC	LF	Boron	0.07	1	0	
Harrim 3019 - FBC	LF	Cobalt	0.1385	6	0	
Harrim 3019 - FBC	LF	Lead	0.24	5	0	
Harrim 3019 - FBC	LF	Molybdenum	0.347714286	7	0	
Harrim 3019 - FBC	LF	Nitrate/Nitrite	0.199333333	3	0	
Harrim 3019 - FBC	LF	Selenium	0.019	2	0	
Industry Mine - Ash	LF	Antimony	0.031597143	70	12	
Industry Mine - Ash	LF	Arsenic	0.050248454	97	51	
Industry Mine - Ash	LF	Barium	0.328329897	97	13	
Industry Mine - Ash	LF	Boron	4.719969072	97	0	

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Industry Mine - Ash	LF	Cadmium	0.059061856	97	7	
Industry Mine - Ash	LF	Cobalt	0.120010309	97	30	
Industry Mine - Ash	LF	Lead	3.610544845	97	16	
Industry Mine - Ash	LF	Mercury	0.000284536	97	92	
Industry Mine - Ash	LF	Selenium	0.052408247	97	64	
Industry Mine - Ash	LF	Thallium	0.016984286	70	12	
Industry Mine - FBC	LF	Antimony	0.017077778	9	4	
Industry Mine - FBC	LF	Arsenic	0.031111111	9	7	
Industry Mine - FBC	LF	Barium	9.515666667	9	0	
Industry Mine - FBC	LF	Boron	2.813888889	9	2	
Industry Mine - FBC	LF	Cadmium	0.015888889	9	7	
Industry Mine - FBC	LF	Cobalt	0.029333333	9	8	
Industry Mine - FBC	LF	Lead	0.051877778	9	6	
Industry Mine - FBC	LF	Mercury	0.000222222	9	8	
Industry Mine - FBC	LF	Selenium	0.080388889	9	4	
Industry Mine - FBC	LF	Thallium	0.002288889	9	6	
Key West - Ash	LF	Arsenic	0.005	1	1	
Key West - Ash	LF	Barium	1	2	0	
Key West - Ash	LF	Boron	0.2	1	0	
Key West - Ash	LF	Cadmium	0.07	1	0	
Key West - Ash	LF	Lead	0.4	1	0	
Key West - Ash	LF	Mercury	0.18	1	0	
Key West - Ash	LF	Selenium	0.005	1	1	
Keystone - Ash	LF	Aluminum	2.059	4	0	
Keystone - Ash	LF	Antimony	0.036	1	0	
Keystone - Ash	LF	Arsenic	0.30925	4	0	
Keystone - Ash	LF	Barium	0.40375	4	0	
Keystone - Ash	LF	Boron	0.72	1	0	
Keystone - Ash	LF	Cadmium	0.009625	4	1	
Keystone - Ash	LF	Cobalt	0.023	1	0	
Keystone - Ash	LF	Lead	0.045375	4	1	
Keystone - Ash	LF	Mercury	0.001	1	1	
Keystone - Ash	LF	Molybdenum	0.32	1	0	
Keystone - Ash	LF	Selenium	0.0525	4	2	
Keystone - Ash	LF	Thallium	0.083	1	0	
Keystone - Ash and Coal Refuse	LF	Aluminum	0.842	4	0	
Keystone - Ash and Coal Refuse	LF	Antimony	0.0015	2	2	
Keystone - Ash and Coal Refuse	LF	Arsenic	0.01875	4	4	

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Keystone - Ash and Coal Refuse	LF	Barium	0.1925	4	0	
Keystone - Ash and Coal Refuse	LF	Boron	0.06	1	0	
Keystone - Ash and Coal Refuse	LF	Cadmium	0.00225	4	4	
Keystone - Ash and Coal Refuse	LF	Cobalt	0.022	1	0	
Keystone - Ash and Coal Refuse	LF	Lead	0.01875	4	4	
Keystone - Ash and Coal Refuse	LF	Mercury	0.001	1	1	
Keystone - Ash and Coal Refuse	LF	Molybdenum	0.01	2	2	
Keystone - Ash and Coal Refuse	LF	Selenium	0.02	4	4	
Keystone - Ash and Coal Refuse	LF	Thallium	0.028	1	0	
Kraft - Ash	LF	Arsenic	0.02	1	0	
Kraft - Ash	LF	Barium	0.3	1	0	
Kraft - Ash	LF	Cadmium	0.01	1	0	
Kraft - Ash	LF	Lead	0.04	1	0	
Kraft - Ash	LF	Selenium	0.04	1	0	
LIMB Site - Ash	LF	Aluminum	0.102894737	38	37	
LIMB Site - Ash	LF	Antimony	0.29	5	1	25
LIMB Site - Ash	LF	Arsenic	0.033594737	38	6	63
LIMB Site - Ash	LF	Barium	0.036552632	38	0	255
LIMB Site - Ash	LF	Boron	0.521842105	38	31	400
LIMB Site - Ash	LF	Cadmium	0.001031579	38	33	0.31
LIMB Site - Ash	LF	Cobalt	0.005131579	38	37	
LIMB Site - Ash	LF	Lead	0.012789474	38	25	14.5
LIMB Site - Ash	LF	Mercury	0.0001	2	2	
LIMB Site - Ash	LF	Molybdenum	1.527342105	38	1	2.5
LIMB Site - Ash	LF	Nitrate/Nitrite	26	2	0	
LIMB Site - Ash	LF	Selenium	0.0199	38	24	0.25
LIMB Site - Ash	LF	Thallium	0.05	5	5	
Little Sandy #10 Mine - Ash	LF	Aluminum	1.078	6	2	4541.666667
Little Sandy #10 Mine - Ash	LF	Arsenic	0.032336364	11	8	38.293
Little Sandy #10 Mine - Ash	LF	Barium	0.264454545	11	6	48.81
Little Sandy #10 Mine - Ash	LF	Boron	2.630909091	11	3	157.76
Little Sandy #10 Mine - Ash	LF	Cadmium	0.008290909	11	9	1.198
Little Sandy #10 Mine - Ash	LF	Lead	0.022009091	11	10	56.84
Little Sandy #10 Mine - Ash	LF	Mercury	0.000486364	11	10	0.24435

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Little Sandy #10 Mine - Ash	LF	Molybdenum	0.177272727	11	5	6.354
Little Sandy #10 Mine - Ash	LF	Selenium	0.059527273	11	9	6.531
Lone Mtn - Ash	LF	Aluminum	28.615	2	0	
Lone Mtn - Ash	LF	Antimony	0.033	2	0	
Lone Mtn - Ash	LF	Arsenic	0.185	2	0	76
Lone Mtn - Ash	LF	Barium	0.167	2	0	1483.2
Lone Mtn - Ash	LF	Cadmium	0.572	2	0	11.86
Lone Mtn - Ash	LF	Cobalt	0.142	2	0	87.3
Lone Mtn - Ash	LF	Mercury	0.0019	1	0	
Lone Mtn - Ash	LF	Molybdenum	0.4295	2	0	
Lone Mtn - Ash	LF	Selenium	0.328	2	0	
LS - Ash and Coal Refuse	LF	Aluminum	1.18	7	0	
LS - Ash and Coal Refuse	LF	Antimony	0.0107	4	0	
LS - Ash and Coal Refuse	LF	Arsenic	0.0104525	16	3	
LS - Ash and Coal Refuse	LF	Barium	0.13220625	16	0	
LS - Ash and Coal Refuse	LF	Boron	18.93125	16	0	
LS - Ash and Coal Refuse	LF	Cadmium	0.00148	16	15	
LS - Ash and Coal Refuse	LF	Cobalt	0.011125	4	0	
LS - Ash and Coal Refuse	LF	Lead	0.0025	16	16	
LS - Ash and Coal Refuse	LF	Mercury	0.00007	4	3	
LS - Ash and Coal Refuse	LF	Molybdenum	0.886875	16	0	
LS - Ash and Coal Refuse	LF	Nitrate/Nitrite	3.045	32	16	
LS - Ash and Coal Refuse	LF	Selenium	1.05343125	16	0	
LS - Ash and Coal Refuse	LF	Thallium	0.00185	8	8	
Martins Creek - Ash	LF	Aluminum	3.18335	20	2	114229.3889
Martins Creek - Ash	LF	Antimony	0.005021053	19	11	10.315
Martins Creek - Ash	LF	Arsenic	0.2314	20	1	50.50530556
Martins Creek - Ash	LF	Barium	0.1969	20	2	641.5466667
Martins Creek - Ash	LF	Boron	3.5089	20	1	304.1266667
Martins Creek - Ash	LF	Cadmium	0.0032	20	20	2.025
Martins Creek - Ash	LF	Cobalt	0.024722222	18	18	66.37611111
Martins Creek - Ash	LF	Lead	0.014	20	19	
Martins Creek - Ash	LF	Mercury	0.0001	19	19	
Martins Creek - Ash	LF	Molybdenum	0.195157895	19	10	
Martins Creek - Ash	LF	Nitrate/Nitrite	0.636428571	14	9	
Martins Creek - Ash	LF	Selenium	0.05717	20	8	4.043888889
Martins Creek - Ash	LF	Thallium	0.003263158	19	19	
McCloskey Site - FBC	LF	Aluminum	0.5	2	2	27450
McCloskey Site - FBC	LF	Arsenic	0.001	2	2	45.355
McCloskey Site - FBC	LF	Barium	0.1	2	2	32.55
McCloskey Site - FBC	LF	Boron	0.022	2	1	0.092

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
McCloskey Site - FBC	LF	Cadmium	0.0375	2	1	0.025
McCloskey Site - FBC	LF	Lead	0.05	2	2	50
McCloskey Site - FBC	LF	Mercury	0.25	2	2	0.4465
McCloskey Site - FBC	LF	Molybdenum	0.15	2	2	0.15
McCloskey Site - FBC	LF	Selenium	0.0515675	2	2	52.315
McDonough - Ash	LF	Arsenic	0.9	1	0	
McDonough - Ash	LF	Barium	0.5	1	0	
McDonough - Ash	LF	Cadmium	0.01	1	0	
McDonough - Ash	LF	Lead	0.04	1	0	
McDonough - Ash	LF	Selenium	0.2	1	0	
McIntosh - Ash	LF	Arsenic	0.09	1	0	
McIntosh - Ash	LF	Barium	0.2	1	0	
McIntosh - Ash	LF	Cadmium	0.6	1	0	
McIntosh - Ash	LF	Lead	0.03	1	0	
McIntosh - Ash	LF	Selenium	0.03	1	0	
McKay Site - FBC	LF	Aluminum	0.105	2	0	30000
McKay Site - FBC	LF	Antimony	0.01	2	2	2.5
McKay Site - FBC	LF	Arsenic	0.025	2	2	51.5
McKay Site - FBC	LF	Barium	0.27	2	0	215
McKay Site - FBC	LF	Boron	0.265	2	0	41.5
McKay Site - FBC	LF	Cadmium	0.005	2	2	2.5
McKay Site - FBC	LF	Lead	0.03	2	1	49
McKay Site - FBC	LF	Mercury	0.0001	2	2	0.345
McKay Site - FBC	LF	Molybdenum	0.13	2	0	6.25
McKay Site - FBC	LF	Nitrate/Nitrite	0.0175	2	1	
McKay Site - FBC	LF	Selenium	0.0355	2	1	1
Miller - Ash	LF	Arsenic	1.3	1	0	18
Miller - Ash	LF	Barium	0.1	1	0	7140
Miller - Ash	LF	Cadmium	0.09	1	0	1.6
Miller - Ash	LF	Lead	0.002	1	0	38
Miller - Ash	LF	Selenium	0.03	1	0	
Miller Creek Mine - Ash	LF	Aluminum	4.78597619	42	4	22486.5969
Miller Creek Mine - Ash	LF	Arsenic	0.075817021	47	16	60.54551064
Miller Creek Mine - Ash	LF	Barium	0.147255319	47	0	87.49382979
Miller Creek Mine - Ash	LF	Boron	2.343829787	47	3	167.0508511
Miller Creek Mine - Ash	LF	Cadmium	0.009771277	47	31	1.850959894
Miller Creek Mine - Ash	LF	Lead	0.034382979	47	24	51.50851064
Miller Creek Mine - Ash	LF	Mercury	0.000255319	47	46	0.06780663
Miller Creek Mine - Ash	LF	Molybdenum	0.166808511	47	17	9.819680851
Miller Creek Mine - Ash	LF	Selenium	0.047102128	47	23	6.492617021
Mine 26 - Ash	LF	Antimony	0.0125	6	6	

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Mine 26 - Ash	LF	Arsenic	0.022333333	9	8	
Mine 26 - Ash	LF	Barium	0.388111111	9	1	
Mine 26 - Ash	LF	Boron	9.266666667	9	0	
Mine 26 - Ash	LF	Cadmium	0.008555556	9	4	
Mine 26 - Ash	LF	Cobalt	0.021744444	9	5	
Mine 26 - Ash	LF	Lead	0.148111111	9	6	
Mine 26 - Ash	LF	Mercury	0.0003	9	9	
Mine 26 - Ash	LF	Selenium	0.026388889	9	6	
Mine 26 - Ash	LF	Thallium	0.006833333	6	5	
Mine 26 - Ash and Coal Refuse	LF	Antimony	0.01	2	2	
Mine 26 - Ash and Coal Refuse	LF	Arsenic	0.054285714	7	5	
Mine 26 - Ash and Coal Refuse	LF	Barium	0.615714286	7	0	
Mine 26 - Ash and Coal Refuse	LF	Boron	3.504285714	7	0	
Mine 26 - Ash and Coal Refuse	LF	Cadmium	0.010142857	7	4	
Mine 26 - Ash and Coal Refuse	LF	Cobalt	0.032857143	7	2	
Mine 26 - Ash and Coal Refuse	LF	Lead	0.047142857	7	4	
Mine 26 - Ash and Coal Refuse	LF	Mercury	0.0001	7	7	
Mine 26 - Ash and Coal Refuse	LF	Selenium	0.02	7	7	
Mine 26 - Ash and Coal Refuse	LF	Thallium	0.005	2	2	
Mine 26 - FBC	LF	Arsenic	0.03	1	1	
Mine 26 - FBC	LF	Barium	0.51	1	0	
Mine 26 - FBC	LF	Boron	1.3	1	0	
Mine 26 - FBC	LF	Cadmium	0.0025	1	1	
Mine 26 - FBC	LF	Cobalt	0.005	1	1	
Mine 26 - FBC	LF	Lead	0.01	1	1	
Mine 26 - FBC	LF	Mercury	0.0001	1	1	
Mine 26 - FBC	LF	Selenium	0.08	1	0	
Mitchell - Ash	LF	Arsenic	1.3	1	0	
Mitchell - Ash	LF	Barium	0.3	1	0	
Mitchell - Ash	LF	Cadmium	0.01	1	0	
Mitchell - Ash	LF	Lead	0.06	1	0	
Mitchell - Ash	LF	Selenium	0.06	1	0	
MO - Ash and Coal Refuse	LF	Aluminum	4.49	2	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
MO - Ash and Coal Refuse	LF	Antimony	0.0125	2	0	
MO - Ash and Coal Refuse	LF	Arsenic	0.2855	2	0	
MO - Ash and Coal Refuse	LF	Barium	1.845	2	0	
MO - Ash and Coal Refuse	LF	Boron	0.219	2	0	
MO - Ash and Coal Refuse	LF	Cadmium	0.006	2	0	
MO - Ash and Coal Refuse	LF	Cobalt	0.012	2	0	
MO - Ash and Coal Refuse	LF	Lead	0.0065	2	0	
MO - Ash and Coal Refuse	LF	Mercury	0.00005	4	4	
MO - Ash and Coal Refuse	LF	Selenium	0.1312	2	0	
MO - Ash and Coal Refuse	LF	Thallium	0.01415	2	0	
Murdock Mine - Ash	LF	Antimony	0.0076875	8	8	
Murdock Mine - Ash	LF	Arsenic	0.0080875	8	6	
Murdock Mine - Ash	LF	Barium	0.258625	8	0	
Murdock Mine - Ash	LF	Boron	9.38775	8	0	
Murdock Mine - Ash	LF	Cadmium	0.0458	8	2	
Murdock Mine - Ash	LF	Cobalt	0.0225625	8	2	
Murdock Mine - Ash	LF	Lead	0.00555	8	2	
Murdock Mine - Ash	LF	Mercury	0.0004375	8	8	
Murdock Mine - Ash	LF	Selenium	0.0053875	8	4	
Murdock Mine - Ash	LF	Thallium	0.02325	8	2	
Murdock Mine - FBC	LF	Antimony	0.004	3	3	
Murdock Mine - FBC	LF	Arsenic	0.005	3	3	
Murdock Mine - FBC	LF	Barium	0.368333333	3	0	
Murdock Mine - FBC	LF	Boron	0.436666667	3	0	
Murdock Mine - FBC	LF	Cadmium	0.0015	3	3	
Murdock Mine - FBC	LF	Cobalt	0.0025	3	3	
Murdock Mine - FBC	LF	Lead	0.0015	3	3	
Murdock Mine - FBC	LF	Mercury	0.0004	3	3	
Murdock Mine - FBC	LF	Selenium	0.003533333	3	2	
Murdock Mine - FBC	LF	Thallium	0.005	3	3	
Nepco - FBC	LF	Arsenic	0.025	2	2	21
Nepco - FBC	LF	Cadmium	0.01	1	0	0.5
Nepco - FBC	LF	Lead	0.025	2	2	39
Nepco - FBC	LF	Mercury	0.0002	2	2	0.01
Nepco - FBC	LF	Selenium	0.05	2	2	12.6
No. 1 Contracting Corp - FBC	LF	Aluminum	0.935	2	0	
No. 1 Contracting Corp - FBC	LF	Antimony	0.018	1	0	
No. 1 Contracting Corp - FBC	LF	Arsenic	0.046	2	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
No. 1 Contracting Corp - FBC	LF	Barium	0.1315	2	0	
No. 1 Contracting Corp - FBC	LF	Boron	0.05	1	0	
No. 1 Contracting Corp - FBC	LF	Cadmium	0.005	1	0	
No. 1 Contracting Corp - FBC	LF	Lead	0.06	1	0	
No. 1 Contracting Corp - FBC	LF	Mercury	0.0002	1	0	
No. 1 Contracting Corp - FBC	LF	Molybdenum	0.105	2	0	
No. 1 Contracting Corp - FBC	LF	Selenium	0.1395	2	0	
Northampton40000201 - Ash	LF	Aluminum	0.38	1	0	24500
Northampton40000201 - Ash	LF	Antimony	0.01	1	0	20
Northampton40000201 - Ash	LF	Arsenic	0.005	1	0	40.6
Northampton40000201 - Ash	LF	Barium	0.21	1	0	242
Northampton40000201 - Ash	LF	Boron	0.2	1	0	17.3
Northampton40000201 - Ash	LF	Cadmium	0.012	1	0	0.5
Northampton40000201 - Ash	LF	Lead	0.1	1	0	18
Northampton40000201 - Ash	LF	Mercury	0.0002	1	0	0.535
Northampton40000201 - Ash	LF	Molybdenum	0.1	1	0	10
Northampton40000201 - Ash	LF	Selenium	0.015	1	0	8.9
Nucla - FBC	LF	Aluminum	0.1	2	2	110050
Nucla - FBC	LF	Arsenic	0.0025	4	4	7.4
Nucla - FBC	LF	Barium	0.08	2	1	190
Nucla - FBC	LF	Boron	0.485	2	1	57.5
Nucla - FBC	LF	Cadmium	0.00055	2	2	1.95
Nucla - FBC	LF	Cobalt	0.005	2	2	10
Nucla - FBC	LF	Lead	0.0016	2	1	35.5
Nucla - FBC	LF	Mercury	0.0001	2	2	
Nucla - FBC	LF	Molybdenum	0.2045	2	0	83
Nucla - FBC	LF	Nitrate/Nitrite	0.1125	2	2	
Nucla - FBC	LF	Selenium	0.00485	2	1	9.35

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Nucla2 - FBC	LF	Aluminum	7.18	3	0	100000
Nucla2 - FBC	LF	Antimony	0.1	6	6	46
Nucla2 - FBC	LF	Arsenic	0.00375	6	5	27.93333333
Nucla2 - FBC	LF	Barium	0.093	3	0	246
Nucla2 - FBC	LF	Boron	3.1	3	1	69.16666667
Nucla2 - FBC	LF	Cadmium	0.000475	6	4	0.263333333
Nucla2 - FBC	LF	Cobalt	0.012	3	1	6.1
Nucla2 - FBC	LF	Lead	0.0062	3	0	8.296666667
Nucla2 - FBC	LF	Mercury	0.000566667	6	5	0.214166667
Nucla2 - FBC	LF	Molybdenum	0.303333333	3	0	3.316666667
Nucla2 - FBC	LF	Nitrate/Nitrite	6.591666667	6	4	
Nucla2 - FBC	LF	Selenium	0.048666667	6	2	1.395
Nucla2 - FBC	LF	Thallium	0.05	3	3	6.416666667
OK - Ash	LF	Aluminum	11.895	2	0	
OK - Ash	LF	Antimony	0.001575	2	1	
OK - Ash	LF	Arsenic	0.003225	2	1	
OK - Ash	LF	Barium	0.686	2	0	
OK - Ash	LF	Boron	2.68	2	0	
OK - Ash	LF	Cadmium	0.00027	2	1	
OK - Ash	LF	Cobalt	0.00745	2	0	
OK - Ash	LF	Lead	0.00355	2	0	
OK - Ash	LF	Mercury	0.0001	2	1	
OK - Ash	LF	Selenium	0.037	2	0	
OK - Ash	LF	Thallium	0.00185	4	4	
P4 - Ash	LF	Aluminum	6.2196875	8	0	
P4 - Ash	LF	Antimony	0.00105	4	4	
P4 - Ash	LF	Arsenic	0.00420375	8	5	
P4 - Ash	LF	Barium	0.254375	8	0	
P4 - Ash	LF	Boron	1.142697917	8	0	
P4 - Ash	LF	Cadmium	0.00125	8	8	
P4 - Ash	LF	Cobalt	0.00315	2	0	
P4 - Ash	LF	Lead	0.0025	8	8	
P4 - Ash	LF	Mercury	0.00005	4	4	
P4 - Ash	LF	Molybdenum	0.2114375	8	4	
P4 - Ash	LF	Nitrate/Nitrite	1.92075	16	8	
P4 - Ash	LF	Selenium	0.01	8	8	
P4 - Ash	LF	Thallium	0.002775	2	2	
PA - Ash	LF	Aluminum	26.16153846	13	0	
PA - Ash	LF	Antimony	0.0031	2	0	
PA - Ash	LF	Arsenic	0.005991923	13	9	
PA - Ash	LF	Barium	1.043838462	13	0	

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CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
PA - Ash	LF	Boron	0.736153846	13	0	
PA - Ash	LF	Cadmium	0.001758462	13	12	
PA - Ash	LF	Cobalt	0.001915	2	2	
PA - Ash	LF	Lead	0.005993077	13	10	
PA - Ash	LF	Mercury	0.000175	2	0	
PA - Ash	LF	Molybdenum	0.138461538	13	4	
PA - Ash	LF	Nitrate/Nitrite	2.544596154	26	15	
PA - Ash	LF	Selenium	0.084376923	13	5	
PA - Ash	LF	Thallium	0.00196	4	4	
Pitt - FBC	LF	Antimony	0.0219	1	0	
Pitt - FBC	LF	Arsenic	0.05	1	1	
Pitt - FBC	LF	Barium	1.167333333	3	1	
Pitt - FBC	LF	Cadmium	0.033333333	3	3	
Pitt - FBC	LF	Lead	0.183333333	3	3	
Pitt - FBC	LF	Mercury	0.005	1	1	
Pitt - FBC	LF	Selenium	0.05	1	1	
Pitt - FBC	LF	Thallium	0.0025	3	3	
Plant 10 - FBC	LF	Arsenic	0.14875	4	0	71.3
Plant 10 - FBC	LF	Cadmium	0.05425	4	1	2.418181818
Plant 10 - FBC	LF	Lead	0.2965	4	1	39.63636364
Plant 10 - FBC	LF	Mercury	0.05005	4	4	1.174
Plant 10 - FBC	LF	Selenium	0.1285	4	0	4.011818182
Plant 12 - FBC	LF	Arsenic	0.004125	8	4	98.62222222
Plant 12 - FBC	LF	Cadmium	0.02	8	8	2.188888889
Plant 12 - FBC	LF	Lead	0.28375	8	2	47.83333333
Plant 12 - FBC	LF	Mercury	0.0004	8	8	1.047777778
Plant 12 - FBC	LF	Selenium	0.006125	8	8	4.263888889
Plant 8 - FBC	LF	Arsenic	0.019868421	19	18	42.04210526
Plant 8 - FBC	LF	Cadmium	0.016826923	52	43	2.288947368
Plant 8 - FBC	LF	Lead	0.007211538	52	37	27.62105263
Plant 8 - FBC	LF	Mercury	0.000289474	19	19	0.065789474
Plant 8 - FBC	LF	Selenium	0.053026316	19	9	33.02263158
Plant 9 - FBC	LF	Arsenic	0.058666667	3	0	2.8
Plant 9 - FBC	LF	Lead	0.105454545	11	8	57.67142857
Plant 9 - FBC	LF	Mercury	0.00025	11	11	0.604285714
Plant 9 - FBC	LF	Selenium	0.065333333	3	0	5.115714286
Portland - Ash	LF	Aluminum	2.648555556	9	0	
Portland - Ash	LF	Antimony	0.075	2	2	
Portland - Ash	LF	Arsenic	0.178666667	9	6	
Portland - Ash	LF	Barium	0.28475	8	0	
Portland - Ash	LF	Boron	4.799333333	3	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Portland - Ash	LF	Cadmium	0.006	9	7	
Portland - Ash	LF	Cobalt	0.014	2	1	
Portland - Ash	LF	Lead	0.058333333	9	8	
Portland - Ash	LF	Mercury	0.001	4	4	
Portland - Ash	LF	Molybdenum	0.178666667	3	1	
Portland - Ash	LF	Selenium	0.25625	4	4	
Portland - Ash	LF	Thallium	0.005	4	4	
PP - Ash	LF	Aluminum	2.422	2	0	
PP - Ash	LF	Antimony	0.00245	2	0	
PP - Ash	LF	Arsenic	0.0273375	2	1	
PP - Ash	LF	Barium	0.2435	2	0	
PP - Ash	LF	Boron	6.605	2	0	
PP - Ash	LF	Cadmium	0.0023975	2	1	
PP - Ash	LF	Cobalt	0.0049575	2	1	
PP - Ash	LF	Lead	0.001155	2	1	
PP - Ash	LF	Mercury	0.00028	2	0	
PP - Ash	LF	Selenium	0.0364	2	0	
PP - Ash	LF	Thallium	0.01518	2	1	
Revloc Site - FBC	LF	Aluminum	0.58	2	1	
Revloc Site - FBC	LF	Antimony	0.002	2	2	
Revloc Site - FBC	LF	Arsenic	0.002	2	1	
Revloc Site - FBC	LF	Barium	0.44	2	2	
Revloc Site - FBC	LF	Boron	0.2585	2	1	
Revloc Site - FBC	LF	Cadmium	0.02	2	2	
Revloc Site - FBC	LF	Cobalt	0.0825	2	1	
Revloc Site - FBC	LF	Lead	0.25	2	0	
Revloc Site - FBC	LF	Mercury	0.0005	2	2	
Revloc Site - FBC	LF	Molybdenum	0.0545	2	1	
Revloc Site - FBC	LF	Selenium	0.0025	2	1	
Scherer - Ash	LF	Arsenic	0.01	1	0	
Scherer - Ash	LF	Barium	0.7	1	0	
Scherer - Ash	LF	Cadmium	0.001	1	0	
Scherer - Ash	LF	Lead	0.001	1	0	
Scherer - Ash	LF	Selenium	0.06	1	0	
Scholz - Ash	LF	Arsenic	0.02	1	0	
Scholz - Ash	LF	Barium	0.2	1	0	
Scholz - Ash	LF	Cadmium	0.04	1	0	
Scholz - Ash	LF	Lead	0.04	1	0	
Scholz - Ash	LF	Selenium	0.02	1	0	
Scrubgrass - FBC	LF	Arsenic	0.025	2	2	59
Scrubgrass - FBC	LF	Cadmium	0.0025	1	0	0.7

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Scrubgrass - FBC	LF	Lead	0.025	2	2	50
Scrubgrass - FBC	LF	Mercury	0.0002	2	2	0.01
Scrubgrass - FBC	LF	Selenium	0.05	2	2	21.7
Seward - Ash	LF	Aluminum	2.965	2	0	
Seward - Ash	LF	Antimony	0.075	2	2	
Seward - Ash	LF	Arsenic	0.288666667	3	2	
Seward - Ash	LF	Barium	0.473333333	3	0	
Seward - Ash	LF	Boron	0.57	1	0	
Seward - Ash	LF	Cadmium	0.005833333	3	1	
Seward - Ash	LF	Cobalt	0.014	1	0	
Seward - Ash	LF	Lead	0.1875	1	1	
Seward - Ash	LF	Mercury	0.003733333	3	3	
Seward - Ash	LF	Molybdenum	0.53	1	0	
Seward - Ash	LF	Selenium	0.196666667	3	2	
Seward - Ash	LF	Thallium	0.012	1	0	
Shawnee - FBC	LF	Aluminum	0.231	5	3	38240
Shawnee - FBC	LF	Antimony	0.296	5	2	15.6
Shawnee - FBC	LF	Arsenic	0.219	10	6	17.3
Shawnee - FBC	LF	Barium	2.001	10	0	799.4
Shawnee - FBC	LF	Boron	0.97	5	3	116.2
Shawnee - FBC	LF	Cadmium	0.005555	10	7	0.622
Shawnee - FBC	LF	Cobalt	0.07	5	2	2.75
Shawnee - FBC	LF	Lead	0.0897	10	5	6.4
Shawnee - FBC	LF	Mercury	0.00029	10	8	0.365
Shawnee - FBC	LF	Molybdenum	0.382	5	0	6.4
Shawnee - FBC	LF	Nitrate/Nitrite	3.786666667	8	4	
Shawnee - FBC	LF	Selenium	0.13005	10	6	0.73
Shawnee - FBC	LF	Thallium	0.197	5	3	8.9
Shawville - Ash	LF	Aluminum	2.0958	5	0	
Shawville - Ash	LF	Antimony	0.075	2	2	
Shawville - Ash	LF	Arsenic	0.4384	5	1	
Shawville - Ash	LF	Barium	0.2172	5	0	
Shawville - Ash	LF	Boron	0.56	1	0	
Shawville - Ash	LF	Cadmium	0.0059	5	2	
Shawville - Ash	LF	Cobalt	0.021	1	0	
Shawville - Ash	LF	Lead	0.1875	1	1	
Shawville - Ash	LF	Mercury	0.001	2	2	
Shawville - Ash	LF	Molybdenum	0.09	1	0	
Shawville - Ash	LF	Selenium	0.191	5	2	
Shawville - Ash	LF	Thallium	0.005	2	2	
Sibley Quarry - Ash	LF	Aluminum	0.6	4	4	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Sibley Quarry - Ash	LF	Arsenic	0.018	4	0	
Sibley Quarry - Ash	LF	Barium	0.265	4	4	
Sibley Quarry - Ash	LF	Cadmium	0.00114125	4	2	
Sibley Quarry - Ash	LF	Lead	0.00305	4	4	
Sibley Quarry - Ash	LF	Mercury	0.0001	4	4	
Sibley Quarry - Ash	LF	Molybdenum	0.725	3	1	
Sibley Quarry - Ash	LF	Selenium	0.18425	4	1	
Silverton - Ash	LF	Aluminum	3.1	1	0	16870
Silverton - Ash	LF	Arsenic	0.375	2	0	48.5
Silverton - Ash	LF	Barium	1.7	1	0	181.5
Silverton - Ash	LF	Boron	0.22	1	0	20.5
Silverton - Ash	LF	Lead	0.23	1	0	29.5
Silverton - Ash	LF	Molybdenum	0.1	1	0	5
Silverton - Ash	LF	Selenium	0.12	2	0	6.7
Smith - Ash	LF	Arsenic	0.02	1	0	
Smith - Ash	LF	Barium	0.2	1	0	
Smith - Ash	LF	Cadmium	0.04	1	0	
Smith - Ash	LF	Lead	0.01	1	0	
Smith - Ash	LF	Selenium	0.01	1	0	
SW - Ash	LF	Arsenic	0.006679487	195	53	29.495189
SW - Ash	LF	Barium	0.81082716	243	0	2538.862069
SW - Ash	LF	Cadmium	0.003400769	195	47	1.230670103
SW - Ash	LF	Lead	0.001570707	99	97	35.39886598
SW - Ash	LF	Mercury	0.000217677	99	98	0.039255034
SW - Ash	LF	Selenium	0.003534884	172	46	0.6
SX - Ash	LF	Aluminum	1.862	2	0	
SX - Ash	LF	Antimony	0.003275	2	1	
SX - Ash	LF	Arsenic	0.0365	2	0	
SX - Ash	LF	Barium	0.959	2	0	
SX - Ash	LF	Boron	4.5223	2	0	
SX - Ash	LF	Cadmium	0.04425	2	0	
SX - Ash	LF	Cobalt	0.0167	2	0	
SX - Ash	LF	Lead	0.00675	2	0	
SX - Ash	LF	Mercury	0.00005	4	4	
SX - Ash	LF	Selenium	0.048725	2	1	
SX - Ash	LF	Thallium	0.013625	2	1	
Tidd - FBC	LF	Aluminum	0.105	3	1	
Tidd - FBC	LF	Antimony	0.03	5	5	
Tidd - FBC	LF	Arsenic	0.028333333	3	2	
Tidd - FBC	LF	Barium	0.184	2	0	
Tidd - FBC	LF	Boron	0.82	3	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Tidd - FBC	LF	Cadmium	0.0015	3	3	
Tidd - FBC	LF	Cobalt	0.021	3	0	
Tidd - FBC	LF	Lead	0.015833333	3	3	
Tidd - FBC	LF	Mercury	0.006733333	3	3	
Tidd - FBC	LF	Molybdenum	0.082	3	0	
Tidd - FBC	LF	Selenium	0.101666667	3	2	
Titus - Ash	LF	Aluminum	4.4135	4	0	
Titus - Ash	LF	Antimony	0.04375	4	4	
Titus - Ash	LF	Arsenic	0.346	2	1	
Titus - Ash	LF	Barium	0.3	4	0	
Titus - Ash	LF	Boron	7.345	2	0	
Titus - Ash	LF	Cadmium	0.0115	4	0	
Titus - Ash	LF	Cobalt	0.027	2	0	
Titus - Ash	LF	Lead	0.19375	2	2	
Titus - Ash	LF	Mercury	0.001	2	2	
Titus - Ash	LF	Molybdenum	0.34	2	0	
Titus - Ash	LF	Selenium	0.144	4	3	
Titus - Ash	LF	Thallium	0.01	2	0	
Tracy Vein Slope - Ash	LF	Aluminum	0.533833333	6	0	11090
Tracy Vein Slope - Ash	LF	Antimony	0.05	5	0	24.215
Tracy Vein Slope - Ash	LF	Arsenic	0.065166667	6	0	61.33333333
Tracy Vein Slope - Ash	LF	Barium	0.148833333	6	0	99.31666667
Tracy Vein Slope - Ash	LF	Boron	1.4486	5	0	122.4333333
Tracy Vein Slope - Ash	LF	Cadmium	0.044833333	6	0	1.070166667
Tracy Vein Slope - Ash	LF	Lead	0.075	6	0	18.90833333
Tracy Vein Slope - Ash	LF	Mercury	0.001	2	0	1.5888
Tracy Vein Slope - Ash	LF	Molybdenum	0.1662	5	0	7.721666667
Tracy Vein Slope - Ash	LF	Selenium	0.0524	5	0	8.608
Tracy Vein Slope - FBC	LF	Aluminum	1.32	1	0	7240
Tracy Vein Slope - FBC	LF	Arsenic	0.052	1	0	6.97
Tracy Vein Slope - FBC	LF	Barium	0.056	1	0	68.9
Tracy Vein Slope - FBC	LF	Boron	0.043	1	0	7.43
Tracy Vein Slope - FBC	LF	Molybdenum	0.027	1	0	0.84
Tracy Vein Slope - FBC	LF	Selenium	0.039	1	0	3.22
UAPP - Ash	LF	Arsenic	0.0025	2	2	
UAPP - Ash	LF	Barium	0.4	2	1	
UAPP - Ash	LF	Cadmium	0.04	2	2	
UAPP - Ash	LF	Lead	0.1	2	2	
UAPP - Ash	LF	Mercury	0.025	2	2	
UAPP - Ash	LF	Selenium	0.00275	2	1	
Universal - Ash	LF	Aluminum	2.057777778	9	0	6000.222222

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Universal - Ash	LF	Arsenic	0.277818182	11	2	41.50909091
Universal - Ash	LF	Barium	0.090181818	11	1	71
Universal - Ash	LF	Boron	2.754545455	11	0	180.2954545
Universal - Ash	LF	Cadmium	0.003227273	11	9	2.115909091
Universal - Ash	LF	Lead	0.022145455	11	7	33.00909091
Universal - Ash	LF	Mercury	0.000386364	11	11	0.137272727
Universal - Ash	LF	Molybdenum	0.134363636	11	1	3.554545455
Universal - Ash	LF	Selenium	0.160090909	11	2	7.106363636
Wansley - Ash	LF	Arsenic	0.05	1	0	
Wansley - Ash	LF	Barium	0.2	1	0	
Wansley - Ash	LF	Cadmium	0.09	1	0	
Wansley - Ash	LF	Lead	0.02	1	0	
Wansley - Ash	LF	Selenium	0.06	1	0	
WEPCO CALEDONIA LANDFILL - Ash	LF	Barium	0.225	2	0	
WEPCO CALEDONIA LANDFILL - Ash	LF	Boron	16.90454545	22	0	
WEPCO CALEDONIA LANDFILL - Ash	LF	Cadmium	0.000045	3	3	
WEPCO CALEDONIA LANDFILL - Ash	LF	Lead	0.003566667	3	3	
WEPCO CALEDONIA LANDFILL - Ash	LF	Molybdenum	0.77500575	4	3	
WEPCO CALEDONIA LANDFILL - Ash	LF	Selenium	0.046794118	34	0	
WEPCO HWY 32 LANDFILL - Ash	LF	Boron	83.41666667	12	0	
WEPCO HWY 32 LANDFILL - Ash	LF	Selenium	0.006675	12	4	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Arsenic	0.0055	2	0	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Barium	0.1195	2	0	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Boron	14.02134483	29	0	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Cadmium	0.010266667	3	1	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Lead	0.00625	2	1	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Mercury	0.0002	1	0	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Molybdenum	0.000022375	4	4	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Nitrate/Nitrite	1.866666667	3	0	
WEPCO SYSTEMS CONTROL CENTER A - Ash	LF	Selenium	0.06332275	28	0	
Wilton Site - Ash	LF	Aluminum	3	1	0	
Wilton Site - Ash	LF	Arsenic	0.027	1	0	
Wilton Site - Ash	LF	Barium	0.51	1	0	
Wilton Site - Ash	LF	Boron	25	1	0	
Wilton Site - Ash	LF	Cadmium	0.0025	2	2	
Wilton Site - Ash	LF	Lead	0.0025	2	2	
Wilton Site - Ash	LF	Mercury	0.001	2	2	
Wilton Site - Ash	LF	Molybdenum	0.34	1	0	
Wilton Site - Ash	LF	Nitrate/Nitrite	0.5	1	1	
Wilton Site - Ash	LF	Selenium	0.09	1	0	
WIS PUBLIC SERV CORP-WESTON AS - Ash	LF	Arsenic	0.0014	3	2	
WIS PUBLIC SERV CORP-WESTON AS - Ash	LF	Barium	0.183025	4	1	
WIS PUBLIC SERV CORP-WESTON AS - Ash	LF	Boron	6.363333333	21	1	
WIS PUBLIC SERV CORP-WESTON AS - Ash	LF	Cadmium	0.0047595	8	0	
WIS PUBLIC SERV CORP-WESTON AS - Ash	LF	Lead	0.00668375	8	0	
WIS PUBLIC SERV CORP-WESTON AS - Ash	LF	Mercury	0.000082	5	5	
WIS PUBLIC SERV CORP-WESTON AS - Ash	LF	Selenium	0.011077619	21	1	
Yates1 - Ash	LF	Arsenic	0.1	1	0	
Yates1 - Ash	LF	Barium	0.3	1	0	
Yates1 - Ash	LF	Cadmium	0.02	1	0	
Yates1 - Ash	LF	Lead	0.05	1	0	
Yates1 - Ash	LF	Selenium	0.02	1	0	
Yates2 - Ash	LF	Arsenic	0.09	1	0	
Yates2 - Ash	LF	Barium	0.2	1	0	
Yates2 - Ash	LF	Cadmium	0.02	1	0	
Yates2 - Ash	LF	Lead	0.03	1	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
Yates2 - Ash	LF	Selenium	0.05	1	0	
AP - Ash	SI	Aluminum	0.553384615	13	0	
AP - Ash	SI	Antimony	0.01	1	1	
AP - Ash	SI	Arsenic	0.070933333	15	0	
AP - Ash	SI	Barium	0.063066667	15	1	
AP - Ash	SI	Boron	12.50986667	15	0	
AP - Ash	SI	Cadmium	0.001042857	14	7	
AP - Ash	SI	Cobalt	0.01	1	1	
AP - Ash	SI	Lead	0.001723333	15	14	
AP - Ash	SI	Molybdenum	0.486733333	15	2	
AP - Ash	SI	Nitrate/Nitrite	0.254809524	29	22	
AP - Ash	SI	Selenium	0.044326667	15	1	
AP - Ash	SI	Thallium	0.0025	1	1	
BR - Ash and Coal Refuse	SI	Aluminum	89.12777778	18	0	
BR - Ash and Coal Refuse	SI	Arsenic	0.775383333	15	4	
BR - Ash and Coal Refuse	SI	Barium	0.188055556	18	14	
BR - Ash and Coal Refuse	SI	Boron	3.857694444	18	2	
BR - Ash and Coal Refuse	SI	Cadmium	0.175	18	7	
BR - Ash and Coal Refuse	SI	Cobalt	0.204722222	18	11	
BR - Ash and Coal Refuse	SI	Molybdenum	0.5	18	18	
C - Ash	SI	Aluminum	4.192307692	13	0	
C - Ash	SI	Antimony	0.07	10	10	
C - Ash	SI	Arsenic	0.15	10	0	
C - Ash	SI	Barium	0.113769231	13	0	
C - Ash	SI	Boron	10.96428571	14	0	
C - Ash	SI	Cadmium	0.0025	10	10	
C - Ash	SI	Cobalt	0.005	10	10	
C - Ash	SI	Lead	0.00229	10	5	
C - Ash	SI	Molybdenum	0.585384615	13	0	
C - Ash	SI	Nitrate/Nitrite	10.85474359	16	3	
C - Ash	SI	Selenium	0.0175	10	2	
C - Ash	SI	Thallium	0.05	10	10	
CADK - Ash	SI	Aluminum	0.165	2	0	
CADK - Ash	SI	Arsenic	0.0075	2	2	
CADK - Ash	SI	Barium	0.02	2	2	
CADK - Ash	SI	Boron	60.05	2	0	
CADK - Ash	SI	Cadmium	0.001	2	2	
CADK - Ash	SI	Lead	0.1	2	2	
CADK - Ash	SI	Molybdenum	1.165	2	0	
CADK - Ash	SI	Nitrate/Nitrite	11.135	4	0	
CADK - Ash	SI	Selenium	0.125	2	0	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
CASJ - Ash	SI	Aluminum	0.1108	5	4	
CASJ - Ash	SI	Arsenic	5.37225	4	0	
CASJ - Ash	SI	Barium	0.0214	5	2	
CASJ - Ash	SI	Boron	46.02	5	0	
CASJ - Ash	SI	Cadmium	0.0156	5	3	
CASJ - Ash	SI	Lead	0.21	5	4	
CASJ - Ash	SI	Molybdenum	0.13	5	5	
CASJ - Ash	SI	Nitrate/Nitrite	1.882	10	8	
CASJ - Ash	SI	Selenium	0.40575	4	0	
CATT - Ash	SI	Aluminum	0.28	2	0	
CATT - Ash	SI	Arsenic	0.206	2	0	
CATT - Ash	SI	Barium	0.085	2	0	
CATT - Ash	SI	Boron	110.5	2	0	
CATT - Ash	SI	Cadmium	0.002	2	1	
CATT - Ash	SI	Lead	0.2275	2	0	
CATT - Ash	SI	Molybdenum	0.655	2	0	
CATT - Ash	SI	Nitrate/Nitrite	0.01	2	0	
CATT - Ash	SI	Selenium	1.025	2	0	
CL - Ash and Coal Refuse	SI	Aluminum	4.680970556	30	2	
CL - Ash and Coal Refuse	SI	Arsenic	0.493663408	30	2	
CL - Ash and Coal Refuse	SI	Barium	0.550251717	30	0	
CL - Ash and Coal Refuse	SI	Boron	1.092075	30	0	
CL - Ash and Coal Refuse	SI	Cadmium	0.001680507	30	27	
CL - Ash and Coal Refuse	SI	Lead	0.003384333	30	29	
CL - Ash and Coal Refuse	SI	Molybdenum	0.377590556	30	0	
CL - Ash and Coal Refuse	SI	Nitrate/Nitrite	0.6303	60	13	
CL - Ash and Coal Refuse	SI	Selenium	0.147525085	30	9	
CY - Ash	SI	Aluminum	6.0975	4	0	
CY - Ash	SI	Arsenic	0.1975	4	0	
CY - Ash	SI	Barium	0.179725	4	0	
CY - Ash	SI	Boron	0.025	4	4	
CY - Ash	SI	Cadmium	0.0040625	4	4	
CY - Ash	SI	Lead	0.008125	4	4	
CY - Ash	SI	Molybdenum	0.655	4	0	
CY - Ash	SI	Nitrate/Nitrite	750.2625	8	5	
CY - Ash	SI	Selenium	0.086575	4	1	
FC - Ash and Coal Refuse	SI	Aluminum	11.433	10	0	
FC - Ash and Coal Refuse	SI	Arsenic	0.00752	10	8	
FC - Ash and Coal Refuse	SI	Barium	0.14918	10	0	
FC - Ash and Coal Refuse	SI	Boron	0.7445	10	1	
FC - Ash and Coal Refuse	SI	Cadmium	0.001956	10	9	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
FC - Ash and Coal Refuse	SI	Lead	0.0025	10	10	
FC - Ash and Coal Refuse	SI	Molybdenum	0.2275	10	10	
FC - Ash and Coal Refuse	SI	Nitrate/Nitrite	0.2	20	20	
FC - Ash and Coal Refuse	SI	Selenium	0.02174	10	0	
HA - Ash	SI	Aluminum	2.830833333	9	2	
HA - Ash	SI	Arsenic	0.086774333	9	2	
HA - Ash	SI	Barium	0.471945556	9	0	
HA - Ash	SI	Boron	2.283583333	9	0	
HA - Ash	SI	Cadmium	0.00125	9	9	
HA - Ash	SI	Lead	0.003503333	9	8	
HA - Ash	SI	Molybdenum	0.107333333	9	4	
HA - Ash	SI	Nitrate/Nitrite	1.968222222	18	10	
HA - Ash	SI	Selenium	0.01	9	9	
HA - Ash and Coal Refuse	SI	Aluminum	0.65	1	0	
HA - Ash and Coal Refuse	SI	Arsenic	0.18	1	0	
HA - Ash and Coal Refuse	SI	Barium	0.11	1	0	
HA - Ash and Coal Refuse	SI	Boron	1.7	1	0	
HA - Ash and Coal Refuse	SI	Cadmium	0.0025	1	1	
HA - Ash and Coal Refuse	SI	Lead	0.025	1	1	
HA - Ash and Coal Refuse	SI	Mercury	0.00025	1	1	
HA - Ash and Coal Refuse	SI	Molybdenum	0.075	1	1	
HA - Ash and Coal Refuse	SI	Selenium	0.0025	1	1	
L - Ash	SI	Aluminum	0.015	2	2	
L - Ash	SI	Barium	0.001	2	2	
L - Ash	SI	Boron	0.62	2	0	
L - Ash	SI	Cadmium	0.001	2	2	
L - Ash	SI	Molybdenum	0.1675	2	1	
MO - Ash	SI	Aluminum	0.894458333	6	0	
MO - Ash	SI	Arsenic	0.011755993	6	3	
MO - Ash	SI	Barium	0.019379487	6	0	
MO - Ash	SI	Boron	0.085041667	6	2	
MO - Ash	SI	Cadmium	0.00125	6	6	
MO - Ash	SI	Lead	0.003666667	6	5	
MO - Ash	SI	Molybdenum	0.928770833	6	3	
MO - Ash	SI	Nitrate/Nitrite	0.1205	12	10	
MO - Ash	SI	Selenium	0.005	6	6	
MO - Ash and Coal Refuse	SI	Aluminum	296.2888026	19	6	
MO - Ash and Coal Refuse	SI	Arsenic	11.67554177	20	0	
MO - Ash and Coal Refuse	SI	Barium	0.039930301	20	1	
MO - Ash and Coal Refuse	SI	Boron	15.49313158	19	2	
MO - Ash and Coal Refuse	SI	Cadmium	0.124406392	27	9	

(continued)

CCW Constituent Data (continued)

Site/Waste Type	WMU Type	Chemical	Leachate (mg/L)	No. of Leachate Measure-ments	No. of Leachate Non-detects	Total (mg/kg)
MO - Ash and Coal Refuse	SI	Cobalt	4.8377	20	7	
MO - Ash and Coal Refuse	SI	Lead	0.321181411	20	11	
MO - Ash and Coal Refuse	SI	Molybdenum	0.402184211	19	15	
MO - Ash and Coal Refuse	SI	Nitrate/Nitrite	5.165	39	37	
MO - Ash and Coal Refuse	SI	Selenium	0.103823054	20	9	
O - Ash	SI	Arsenic	0.234766667	3	0	
O - Ash	SI	Boron	6.166666667	3	0	
O - Ash	SI	Molybdenum	0.0179	1	0	
O - Ash	SI	Nitrate/Nitrite	461	1	0	
O - Ash	SI	Selenium	0.0029	3	0	
OK - Ash	SI	Aluminum	40.45955556	9	0	
OK - Ash	SI	Arsenic	0.060628889	9	2	
OK - Ash	SI	Barium	0.159055556	9	1	
OK - Ash	SI	Boron	3.148333333	9	0	
OK - Ash	SI	Cadmium	0.01	9	9	
OK - Ash	SI	Lead	0.02	9	9	
OK - Ash	SI	Molybdenum	0.721694444	9	0	
OK - Ash	SI	Nitrate/Nitrite	7.62	18	17	
OK - Ash	SI	Selenium	0.282377778	9	2	
SX - Ash	SI	Aluminum	3.866609827	15	0	
SX - Ash	SI	Arsenic	0.054834273	15	2	
SX - Ash	SI	Barium	0.079191593	15	0	
SX - Ash	SI	Boron	32.70433889	15	0	
SX - Ash	SI	Cadmium	0.019243353	15	5	
SX - Ash	SI	Lead	0.001228153	15	5	
SX - Ash	SI	Molybdenum	11.40518778	15	0	
SX - Ash	SI	Nitrate/Nitrite	1.6328	30	12	
SX - Ash	SI	Selenium	0.239368793	15	6	

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Attachment A-3: CCW Constituent Data Used in Screening Analysis

Table A-3-1. CCW Landfill Waste Analyte Concentrations Used in Screening: Total Waste Analyses (mg/kg)

Analyte	Sites[1]	ND Sites[2]	2002 CCW Total Waste Concentrations						1998 Total Waste 95th
			Minimum	Maximum	50th	75th	90th	95th	
Aluminum	71	0	1.45E+01	1.37E+05	2.53E+04	4.17E+04	8.57E+04	9.76E+04	1.43E+05
Antimony	64	19	1.25E-01	3.10E+02	1.56E+01	2.94E+01	4.62E+01	7.93E+01	4.67E+01
Arsenic	111	3	4.70E-02	3.70E+02	2.79E+01	6.18E+01	1.05E+02	1.25E+02	1.54E+02
Barium	94	1	4.76E+00	7.14E+03	2.22E+02	4.49E+02	1.05E+03	2.59E+03	8.38E+03
Beryllium	37	6	1.19E-01	2.85E+01	4.10E+00	1.00E+01	1.76E+01	2.25E+01	1.56E+01
Boron	70	4	2.50E-02	2.47E+03	5.35E+01	1.50E+02	3.46E+02	5.54E+02	4.17E+02
Cadmium	102	21	1.65E-04	7.60E+02	1.08E+00	2.26E+00	5.43E+00	1.12E+01	2.37E+01
Chromium	108	2	5.00E-03	1.38E+03	4.45E+01	7.62E+01	1.66E+02	1.81E+02	2.91E+02
Cobalt	67	8	5.00E-03	1.35E+02	1.02E+01	3.26E+01	6.22E+01	7.93E+01	4.16E+01
Copper	95	3	5.00E-03	8.90E+02	3.61E+01	8.24E+01	2.28E+02	2.99E+02	1.55E+02
Cyanide	2	1	1.25E-01	2.48E-01	1.86E-01	2.17E-01	2.35E-01	2.41E-01	-
Fluoride	8	0	2.50E+00	7.61E+02	1.08E+01	2.07E+01	2.49E+02	5.05E+02	-
Lead	107	6	1.30E-02	1.37E+03	2.87E+01	4.97E+01	8.06E+01	1.25E+02	1.52E+02
Manganese	87	2	5.00E-02	9.81E+03	1.11E+02	2.41E+02	5.10E+02	6.37E+02	8.17E+02
Mercury	86	12	6.00E-04	6.43E+01	3.28E-01	6.00E-01	1.63E+00	8.22E+00	-
Molybdenum	73	7	4.43E-02	1.26E+02	1.20E+01	2.23E+01	3.47E+01	5.38E+01	4.31E+01
Nickel	106	5	4.90E-02	5.41E+04	4.23E+01	1.30E+02	3.29E+02	6.79E+02	1.55E+02
Nitrate	1	1	2.43E-01	2.43E-01	2.43E-01	2.43E-01	2.43E-01	2.43E-01	-
Nitrite	0	0	-	-	-	-	-	-	-
Selenium	94	11	5.05E-03	6.73E+02	5.12E+00	1.03E+01	2.14E+01	4.79E+01	3.24E+02
Silver	69	26	5.00E-02	1.90E+03	1.72E+00	3.30E+00	1.37E+01	2.66E+01	1.36E+01
Strontium	15	1	5.60E+00	1.23E+03	2.63E+02	7.63E+02	1.05E+03	1.20E+03	4.76E+03
Thallium	20	10	9.00E-02	1.00E+02	3.23E+00	1.05E+01	2.08E+01	4.21E+01	4.80E+01
Vanadium	43	1	3.30E+00	4.55E+03	2.24E+02	3.48E+02	9.07E+02	2.95E+03	3.46E+02
Zinc	98	1	3.40E-02	1.82E+04	4.58E+01	1.44E+02	2.93E+02	1.43E+03	8.56E+02

[1] Number of sites with analyte data (2002)

[2] Number of sites with only nondetect analyte data (2002)

Table A-3-2. CCW Surface Impoundment Waste Analyte Concentrations Used in Screening: Porewater Analyses (mg/L)

Analyte	Sites[1]	ND Sites[2]	2002 SI Porewater Concentrations						1998 Porewater 95th[3]
			Minimum	Maximum	50th	75th	90th	95th	
Aluminum	17	2	1.50E-02	8.91E+01	1.18E+00	4.68E+00	2.30E+01	5.02E+01	2.70E+02
Antimony	2	2	1.00E-02	7.00E-02	4.00E-02	5.50E-02	6.40E-02	6.70E-02	-
Arsenic	17	2	7.50E-03	6.77E+00	1.80E-01	4.94E-01	5.18E+00	5.65E+00	9.64E+00
Barium	17	2	1.00E-03	5.50E-01	1.10E-01	1.59E-01	3.02E-01	4.88E-01	2.74E+01
Beryllium	2	1	1.00E-03	6.20E-03	3.60E-03	4.90E-03	5.68E-03	5.94E-03	-
Boron	18	1	2.50E-02	3.37E+02	5.01E+00	2.92E+01	7.52E+01	1.44E+02	3.42E+02
Cadmium	17	9	1.00E-03	2.50E-01	2.50E-03	1.56E-02	1.31E-01	1.90E-01	1.56E-01
Chromium	18	8	9.00E-04	5.78E-01	3.56E-02	1.13E-01	3.66E-01	5.29E-01	7.46E-01
Cobalt	4	2	5.00E-03	8.87E+00	1.07E-01	2.37E+00	6.27E+00	7.57E+00	-
Copper	16	5	6.40E-04	7.22E-01	3.63E-02	1.26E-01	2.84E-01	4.90E-01	6.90E-01
Cyanide	0	0	-	-	-	-	-	-	-
Fluoride	15	2	5.05E-02	4.10E+02	8.96E-01	4.99E+00	1.91E+01	1.39E+02	4.10E+02
Lead	14	5	1.23E-03	2.28E-01	5.90E-03	4.53E-02	1.77E-01	2.16E-01	4.68E-01
Manganese	16	2	4.24E-03	1.82E+02	1.69E-01	1.20E+00	7.67E+00	5.15E+01	1.03E+02
Mercury	1	1	2.50E-04	2.50E-04	2.50E-04	2.50E-04	2.50E-04	2.50E-04	7.96E-04
Molybdenum	18	6	1.79E-02	1.14E+01	4.73E-01	6.55E-01	1.00E+00	2.70E+00	1.14E+01
Nickel	17	4	5.00E-03	1.23E+01	4.61E-02	2.75E-01	7.49E-01	3.09E+00	8.33E+00
Nitrate	13	3	8.05E-02	1.17E+03	1.85E+00	4.73E+00	6.02E+02	9.17E+02	1.17E+03
Nitrite	15	4	7.00E-03	4.61E+02	1.89E-01	1.39E+00	5.22E+00	1.43E+02	4.61E+02
Selenium	15	3	2.50E-03	1.03E+00	6.97E-02	1.93E-01	3.56E-01	5.92E-01	1.03E+00
Silver	8	8	5.00E-05	5.00E-03	2.06E-03	4.25E-03	5.00E-03	5.00E-03	
Strontium	17	0	4.20E-01	1.61E+01	4.25E+00	7.00E+00	8.74E+00	1.06E+01	1.61E+01
Thallium	2	2	2.50E-03	5.00E-02	2.63E-02	3.81E-02	4.53E-02	4.76E-02	
Vanadium	15	1	1.25E-03	6.61E-01	1.03E-01	3.15E-01	4.78E-01	5.81E-01	8.00E-01
Zinc	17	5	1.16E-02	2.34E+01	1.00E-01	1.20E-01	6.70E-01	5.40E+00	2.31E+01

[1] Number of sites with analyte data (2002)
[2] Number of sites with only nondetect analyte data (2002)
[3] Includes both landfill and surface impoundment (SI) porewater data

Table A-3-3. CCW Landfill Waste Analyte Concentrations Used in Screening: Leachate Analyses (mg/L)

Analyte	Sites[1]	ND Sites[2]	Leachate Concentrations						1998 TCLP 95th
			Minimum	Maximum	50th	75th	90th	95th	
Aluminum	54	3	3.00E-02	2.86E+01	2.06E+00	4.47E+00	1.05E+01	1.36E+01	-
Antimony	60	27	6.50E-04	7.87E-01	2.19E-02	7.50E-02	2.61E-01	2.98E-01	-
Arsenic	119	26	1.00E-03	1.80E+00	3.65E-02	1.31E-01	3.94E-01	1.01E+00	2.40E-01
Barium	115	7	2.00E-02	4.20E+01	3.04E-01	5.71E-01	1.60E+00	2.55E+00	-
Beryllium	47	15	5.00E-05	2.80E-01	2.14E-03	5.37E-03	1.58E-02	2.96E-02	-
Boron	72	3	1.00E-02	2.79E+01	1.07E+00	4.57E+00	1.06E+01	2.07E+01	-
Cadmium	117	38	1.50E-04	6.00E-01	1.00E-02	2.24E-02	4.94E-02	9.00E-02	-
Chromium	118	17	1.00E-03	7.64E-01	3.40E-02	1.00E-01	2.00E-01	3.50E-01	5.90E-02
Cobalt	51	10	1.92E-03	2.46E-01	1.52E-02	2.55E-02	8.25E-02	1.31E-01	-
Copper	72	13	1.60E-03	3.27E+00	4.14E-02	9.46E-02	1.50E-01	4.55E-01	-
Cyanide	24	14	3.50E-03	1.20E-01	7.23E-03	2.03E-02	6.32E-02	8.67E-02	-
Fluoride	33	1	8.00E-02	5.99E+01	8.19E-01	1.90E+00	6.34E+00	3.09E+01	-
Lead	116	38	1.00E-03	3.61E+00	3.23E-02	7.23E-02	2.39E-01	2.90E-01	-
Manganese	72	13	1.25E-03	3.27E+00	1.63E-01	4.39E-01	1.37E+00	1.56E+00	-
Mercury	97	60	5.00E-06	2.90E-01	2.89E-04	1.00E-03	2.69E-03	1.32E-02	-
Molybdenum	49	5	1.00E-02	3.09E+01	1.77E-01	3.40E-01	6.16E-01	1.27E+00	-
Nickel	80	19	2.00E-03	3.88E+00	5.17E-02	1.41E-01	3.09E-01	5.70E-01	5.00E-02
Nitrate	17	3	1.75E-02	2.60E+01	1.59E+00	2.50E+00	2.83E+00	7.72E+00	-
Nitrite	5	4	5.00E-02	5.00E+00	8.33E-01	1.17E+00	3.47E+00	4.23E+00	-
Selenium	119	23	1.00E-03	1.05E+00	4.87E-02	8.74E-02	1.76E-01	2.06E-01	4.40E-01
Silver	109	60	0.00E+00	2.50E-01	8.70E-03	1.75E-02	3.95E-02	5.02E-02	-
Strontium	20	0	6.35E-02	4.28E+01	2.95E+00	4.87E+00	9.70E+00	1.36E+01	-
Thallium	40	18	1.00E-03	1.97E-01	8.29E-03	2.34E-02	5.00E-02	6.54E-02	-
Vanadium	40	5	1.00E-03	1.20E+01	1.07E-01	1.82E-01	4.50E-01	1.50E+00	-
Zinc	75	9	2.00E-03	5.83E+01	1.30E-01	6.09E-01	1.94E+00	1.01E+01	-

[1] Number of sites with analyte data (2002)
[2] Number of sites with only nondetect analyte data (2002)
TCLP = Toxicity Characteristic Leaching Procedure

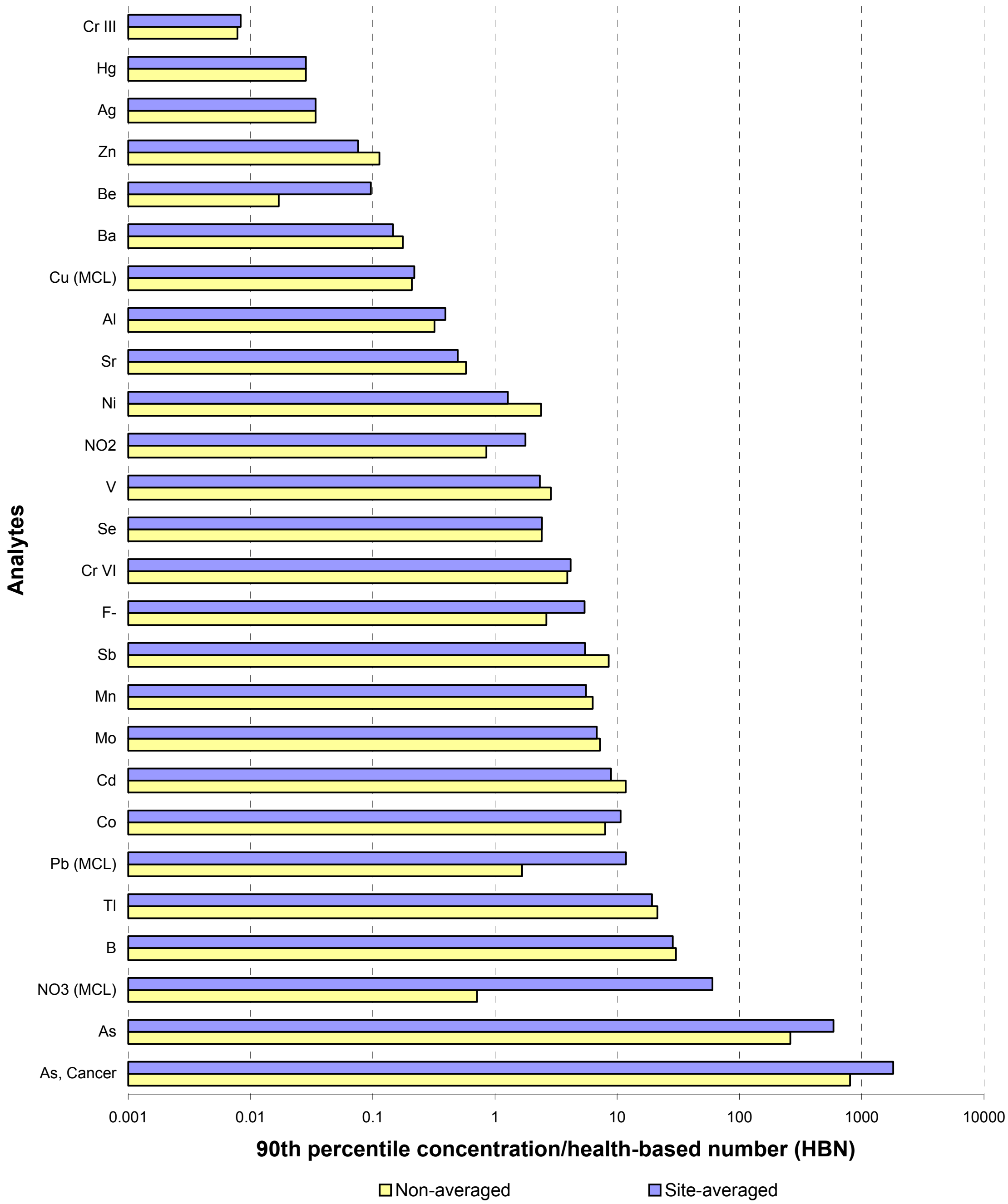

Figure A-3-1. Comparison of site-averaged and nonaveraged results for surface impoundment porewater screening, groundwater-to-drinking-water pathway.

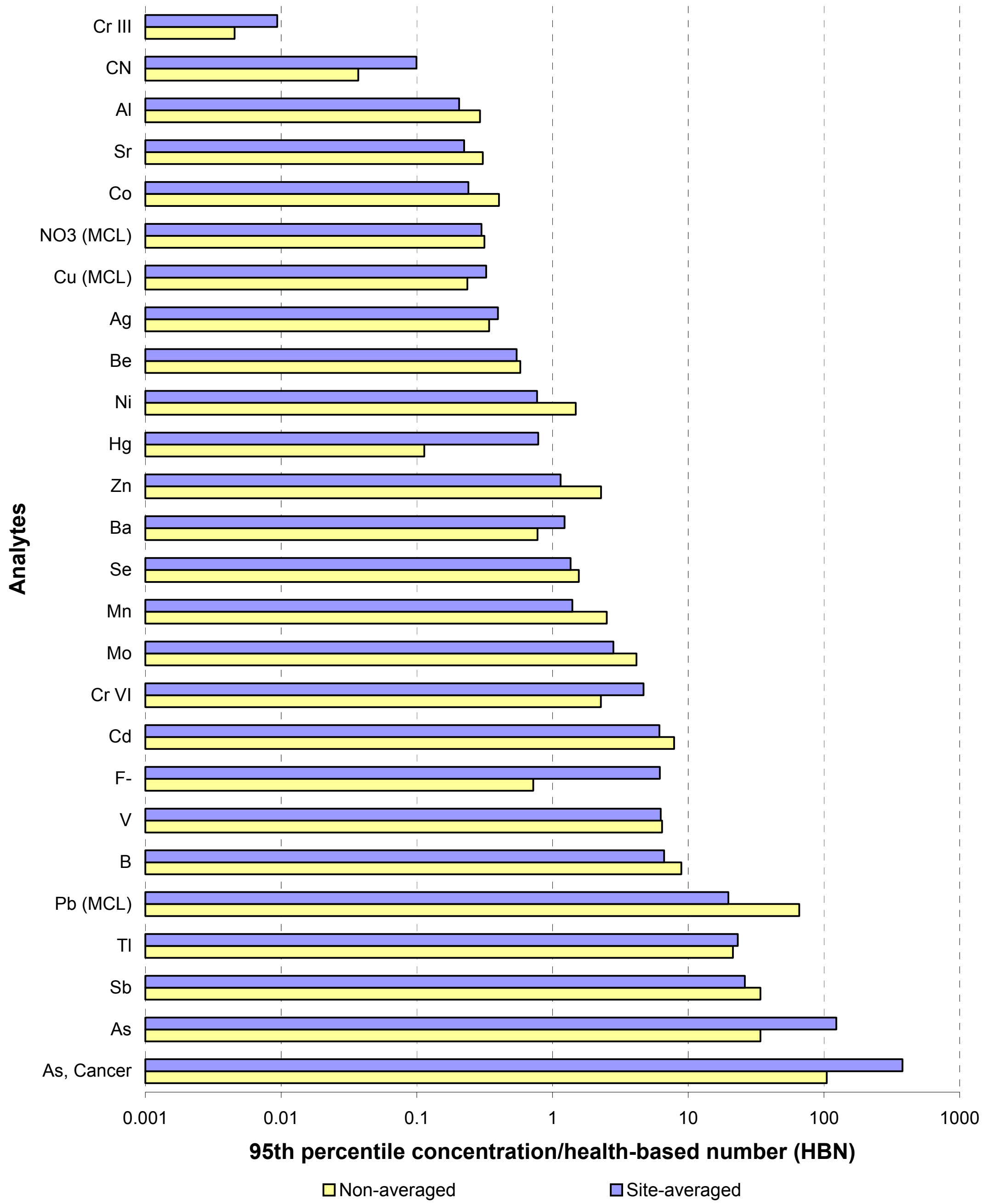

Figure A-3-2. Comparison of site-averaged and nonaveraged results for landfill leachate screening, groundwater-to-drinking-water pathway.

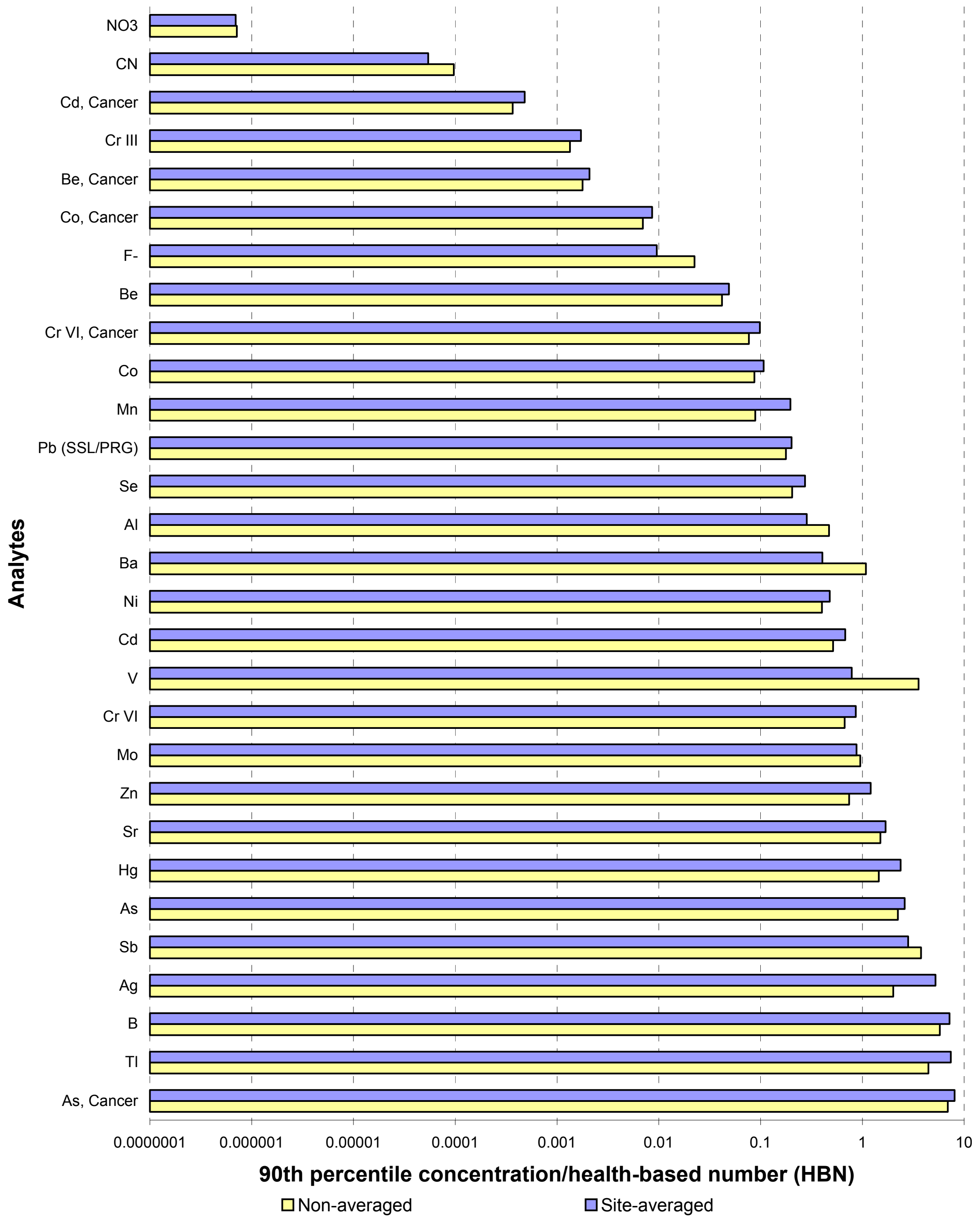

Figure A-3-3. Comparison of site-averaged and nonaveraged results for landfill total waste screening, aboveground pathways.

Appendix B. Waste Management Units

The source models supporting the CCW risk assessment require inputs describing the characteristics of CCW waste management units (WMUs). To satisfy this requirement, the assessment used a data set of WMU area, capacity, liner type, geometry, and waste type managed for a set of individual CCW landfills and surface impoundments that are representative of the national population of coal combustion facilities that are managing their wastes onsite.

The sources for these data sets were responses to two voluntary industry surveys: an Electric Power Research Institute (EPRI) comanagement survey (for conventional utility coal combustion WMUs units) and a Council of Industrial Boiler Owners (CIBO) fluidized bed combustion (FBC) survey (for FBC WMUs). In addition to the individual WMU data, certain assumptions were required regarding (1) liner types and characteristics, (2) surface impoundment operating life, and (3) above- and below-grade geometries for WMUs. The sections below describe the two industry surveys, then discuss the data sources and assumptions made. **Attachment B-1** lists the 181 CCW disposal sites modeled in this risk assessment and their locations. **Attachment B-2** presents the WMU data used in the CCW risk assessment for each of the 108 landfills and 96 surface impoundments at these coal combustion facilities.

B.1 EPRI Comanagement Survey

For conventional utility coal combustion WMUs, the source of data for area, capacity, liner type, and waste type managed was the EPRI Coal Combustion By-Products and Low-Volume Wastes Comanagement Survey (EPRI, 1997a). In 1995, EPRI sent a 4-page questionnaire to all electric utilities with more than 100 megawatts (MW) of coal-fired generating capacity. The survey gathered data on the design of coal combustion management units and the types and volumes of waste managed. From the survey responses, EPRI prepared an electronic database and provided it to EPA in support of the March 1999 *Report to Congress: Wastes from the Combustion of Fossil Fuels* (the RTC) (U.S. EPA, 1999a). EPRI also published a report (EPRI, 1997a) documenting the survey format and providing a brief summary of the results.

The EPRI survey responses include information on 323 waste management facilities serving 238 power plants located in 36 states. The total annual volume of CCW reported disposed by respondents to the EPRI comanagement survey was nearly 62 million tons. This quantity was two-thirds of the total generation of CCW in 1995. Therefore, the survey sample encompasses the majority of CCW disposed in terms of volume. Based on comparison with data from other sources, the EPRI survey sample appears representative of the population of coal combustion WMUs in terms of the types of units included (i.e., landfills and surface impoundments). The EPRI survey sample also is believed to be generally geographically representative of the population of conventional utility WMUs, although it may under-represent certain management practices in a few states. The EPA document, *Technical Background Document for the Supplemental Report to Congress on Remaining Fossil Fuel Combustion*

Wastes: Industry Statistics and Waste Management Practices (U.S. EPA, 1999b), discusses the representativeness of the EPRI survey in greater detail and provides extensive summary statistics on the survey responses.

The EPRI comanagement survey included questions requesting the respondent to report the location of the WMU (by state) and the WMU area, capacity, liner type, and waste type managed. Therefore, the data set used for modeling these variables was extracted directly from the EPRI database for all active landfills and surface impoundments responding to the EPRI survey. Mine placement sites and closed WMUs were excluded from the data set. Also excluded from the data set were three responding WMUs that managed FBC waste. Data for these units were instead combined with the data set for FBC WMUs from the CIBO FBC survey (described below).

The EPRI survey data were provided in blinded form. That is, the original database did not report the identity of each respondent and identified WMU location only by state. To provide a more complete identification of the EPRI waste management locations, each unit in the EPRI database had to be matched with a specific electric utility facility. This matching was accomplished by applying professional judgment in comparing the state, waste quantity, and waste management practice information in the EPRI database with similar data from responses to the U.S. Department of Energy's Energy Information Administration (EIA) Form EIA-767 (Steam-Electric Plant Operation and Design Report) for the same year as the EPRI survey (1995). The latitude and longitude plant locations in the EIA database allowed the pairing of the EPRI WMU data with environmental setting information.

B.2 CIBO Fluidized Bed Combustion Survey

For FBC WMUs, the primary source of data for area, capacity, liner type, and waste type managed was the CIBO Fossil Fuel Fluidized Bed Combustion (FBC) Survey. In 1996, CIBO sent a voluntary questionnaire to every fossil-fuel-fired FBC plant, both utility and nonutility, in the United States. This survey collected general facility information, characterized process inputs and outputs, gathered data on waste generation and characteristics, and captured details of FBC waste management practices. From the survey responses, CIBO prepared an electronic database and provided it to EPA in support of the March 1999 RTC. CIBO also published a report (CIBO, 1997) that includes documentation of the survey format and provides a brief summary of the results.

CIBO reports a total of 84 facilities using FBC technology. Forty-five of these responded to the CIBO FBC survey, with 20 of the respondents providing information about waste management practices. The facilities with waste management data cover 24 percent of all U.S. facilities using FBC. The CIBO sample is geographically representative of the full population, with the exception of two states that appear under-represented in the sample—Pennsylvania and Illinois. EPA's technical background document on industry statistics and waste management practices (U.S. EPA, 1999b) discusses the representativeness of the EPRI survey in greater detail and provides extensive summary statistics on the survey responses.

The CIBO survey includes questions requesting the respondent to report WMU area, capacity, liner type, and waste type managed. Therefore, the data set used for modeling these variables was extracted directly from the CIBO database. The CIBO respondents included both utility and nonutility (i.e., industrial or institutional facilities that burn coal, but are not primarily engaged in the business of selling electricity) facilities. Because nonutilities are outside the scope of this risk assessment, nonutilities were excluded from the data set. Three additional utility facilities were excluded from the data set because their responses contained insufficient data on the variables of interest (area, capacity, liner type, and waste type). Mine placement sites also were excluded from the data set. Data for the FBC units responding to the EPRI survey (see **Section B.1**) were added to the data set. This resulted in a sample of seven FBC landfills and one FBC surface impoundment for modeling. **Table B-1** compares this sample to the waste management practices of the full utility FBC population.

As shown in Table B-1, FBC facilities frequently avoid waste disposal units by directing all of their waste to mine placement or beneficial use. Therefore, although only 8 of the 41 utility FBC facilities were included in the model data set, these 8 facilities represent nearly all of the known FBC landfills and surface impoundments.

Table B-1. Utility FBC Waste Management Practices and Units Modeled

Number of Facilities...	Total	Landfill	Surface Impoundment	Minefill or Beneficial Use	Unknown
in the full population	41	11	1	16	13
modeled	8	7	1	Not applicable	Not applicable

The CIBO survey database identified the location of each WMU in detail (latitude and longitude). Therefore, no additional analysis was necessary to pair the WMU data with environmental setting information.

B.3 Liner Type

The EPRI survey data included information on the liner (if any) for each WMU. For this assessment, the WMUs were assigned to one of three liner scenarios based on the EPRI liner data: an unlined (no liner) scenario, a compacted clay liner, and a composite liner that combines a plastic (e.g., high-density polyethylene (HDPE) membrane) over either geosynthetic or natural clays. These three scenarios correspond to the following conceptual liner scenarios, developed in support of EPA’s Industrial Subtitle D guidance (U.S. EPA, 2002), which can be selected in the landfill and surface impoundment models used in this assessment.

- **Unlined Scenario.** For landfills, waste is placed directly on local soils, either on grade or excavated to some design depth and without a leachate collection system. After the landfill has been filled to capacity, a 2-foot native soil cover (the minimum required by Subtitle D regulations) is installed and assumed to support vegetation. For surface impoundments, wastewater is placed directly on local soils, and the depth of water is constant over the entire life of the impoundment, pre- and post-closure. Sediments accumulate and consolidate at the bottom of the impoundment and migrate into the underlying native soils, where they clog pore spaces and provide some barrier to flow.

- **Clay Liner Scenario.** For landfills, waste is placed directly on a 3-foot compacted clay liner, which is installed on the local soils, either on grade or excavated to some design depth and without a leachate collection system. After the landfill has been filled to capacity, a 3-foot clay cover is installed and covered with 1 foot of loam to support vegetation and drainage. The hydraulic conductivity of both the liner and cover clays is assumed to be $1x10^{-7}$ cm/sec. For surface impoundments, wastewater is placed on a compacted clay liner, which is installed on the local soils. The assumptions for an unlined impoundment also apply to the compacted clay liner scenario, except that a compacted clay liner filters out the sediments that clog the native soils in the unlined case, so the effect of clogging the native materials is not included in the calculation of the infiltration rate. The thickness of the compacted clay liner was assumed to be 3 feet and the hydraulic conductivity was assumed to be $1x10^{-7}$ cm/sec.

- **Composite Liner Scenario.** For landfills, wastes are placed on a liner system that consists of a 60 mil HDPE membrane with either an underlying geosynthetic clay liner with a maximum hydraulic conductivity of $5x10^{-9}$ cm/sec, or a 3-foot compacted clay liner with a maximum hydraulic conductivity of $1x10^{-7}$ cm/sec. A leachate collection system is also assumed to exist between the waste and the liner system. After the landfill has been filled to capacity, a 3-foot clay cover is assumed to be installed and covered with 1 foot of loam to support vegetation and drainage. For surface impoundments, wastewater is placed on a synthetic membrane with an underlying geosynthetic or natural compacted clay liner with a hydraulic conductivity of $1x10^{-7}$ cm/sec. The membrane liner was assumed to have a number of pinhole leaks of uniform size (6 mm^2). The number of these leaks was based on an empirical distribution of membrane leak density values obtained from TetraTech (2001), as described in the *IWEM Technical Background Document* (U.S. EPA, 2002).

Table B-2 shows the crosswalk used to assign one of the three liner scenarios to each facility based on the liner data in the EPRI survey data (EPRI, 1997a). **Attachment B-2** provides these assignments, along with the original EPRI liner type, for each CCW landfill facility modeled.

Table B-2. Crosswalk Between EPRI and CCW Source Model Liner Types

EPRI Liner Type	Model Liner Code	Description
Compacted ash	0	no liner
Compacted clay	1	clay
Composite clay/membrane	2	composite
Double	2	composite
Geosynthetic membrane	2	composite
None/natural soils	0	no liner

B.4 Surface Impoundment Operating Life

The model runs for surface impoundments required a general assumption about the length of the operating life for these WMUs. Of the surface impoundments in the EPRI comanagement survey, 86 provided responses to questions about both the unit's opening date and expected closure date. From these two dates, an expected operating life for each impoundment could be calculated. An additional 30 impoundments provided an opening date, but no closure date. One possible interpretation of these responses is that these facilities do not expect to close in the foreseeable future, corresponding to a very long or indefinite operating life with dredging of waste to maintain capacity. **Figure B-1** shows the distribution of the calculated operating lives, along with a bar showing the facilities with no closure date.

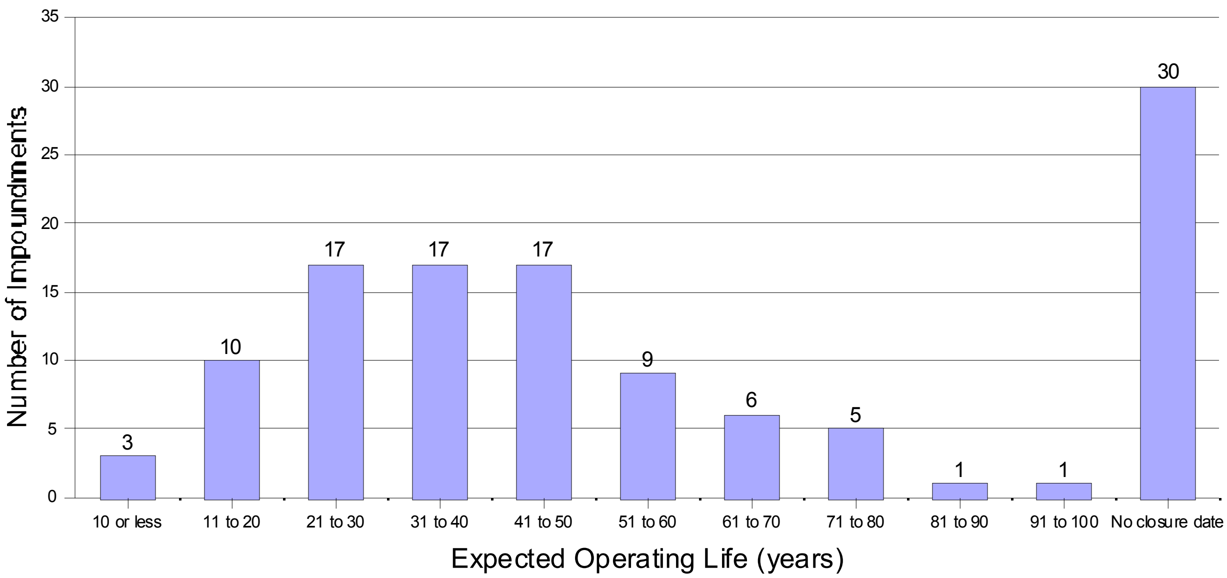

Figure B-1. Operating life of impoundments in the EPRI survey.

Based on these data, a 75-year operating life was chosen. This value corresponds to the 95th percentile of the observed distribution. While the use of a 95th percentile value may appear conservative, if many of the facilities with no closure date do, in fact, plan to operate indefinitely, 75 years would correspond to a much lower percentile in the distribution. More significantly, many CCW surface impoundments close with wastes in place. The selection of 75 years minimizes the underestimation of chronic risks for this scenario, given that EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) surface impoundment model assumes clean closure after the operating life.

B.5 Above- and Below-Grade Geometry

The model runs for surface impoundments and landfills required general assumptions about the geometry of these units with respect to the ground surface (i.e., how much of the unit's depth is below grade). The CIBO FBC survey included data on this geometry, so, for FBC units, these data were extracted directly from the database along with the other individual WMU data (e.g., capacity). The EPRI comanagement survey did not contain data describing above- and below-grade geometry. Therefore, for conventional utility coal combustion WMUs, EPA reviewed 17 site-characterization reports published by EPRI (EPRI 1991; 1992; 1994a,b; 1996a,b; 1997b-k) and determined an above- versus below-grade geometry for each unit described in those reports based on schematic diagrams and site descriptions. EPA also extracted data from another CIBO voluntary survey that covered conventional (non-FBC) nonutility coal combustors. **Figures B-2** and **B-3** display the distributions of the data thus collected.

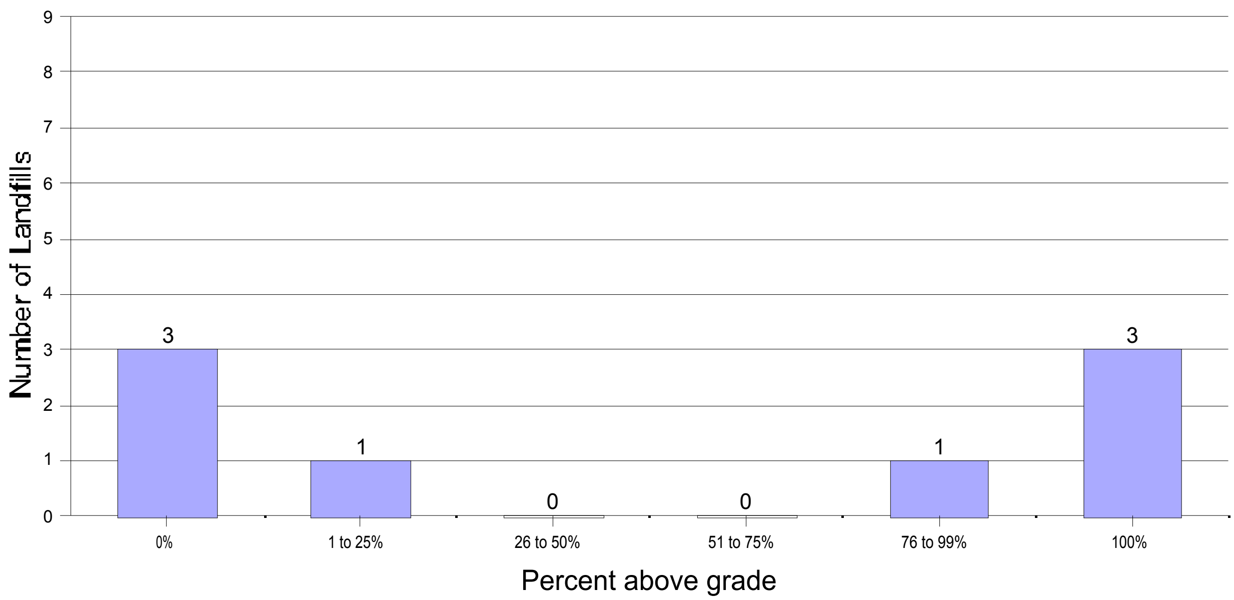

Figure B-2. Above- and below-grade geometry for landfills.

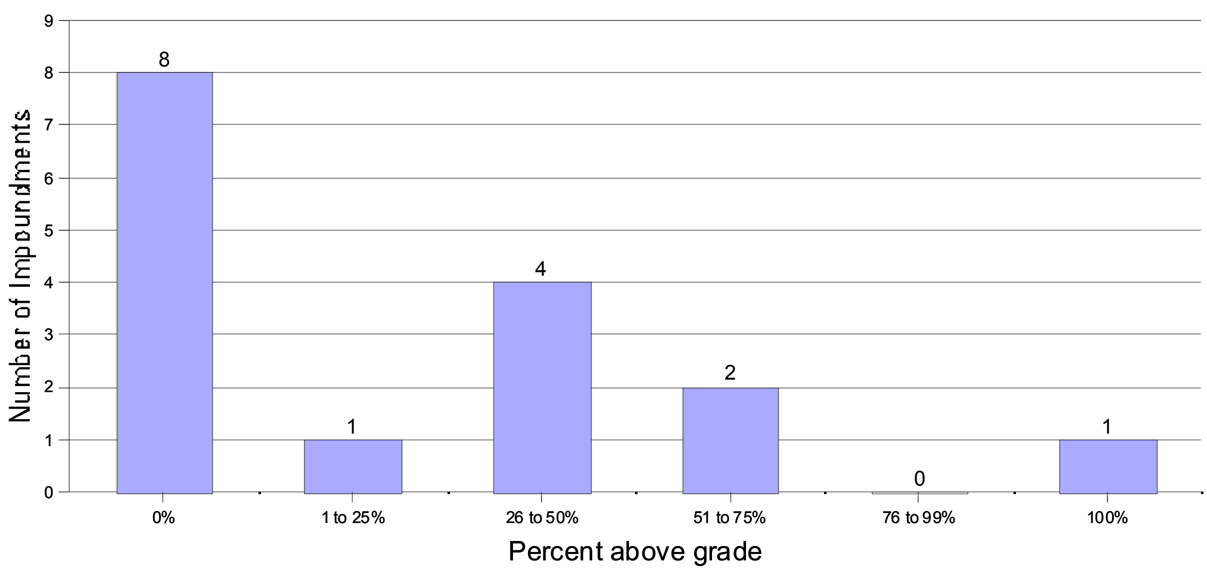

Figure B-3. Above- and below-grade geometry for impoundments.

For landfills, because the data were limited (8 sites), the model runs assumed that the percent below grade ranged from 1 to 100 and was uniformly distributed. For each landfill iteration, a random value for percent below grade was picked and applied to the landfill depth to determine depth below ground surface. This value was constrained to be no deeper than the water table and was checked to see that EPACMTP groundwater mounding constraints were not violated.

For surface impoundments, more data were available (16 sites), with 8 sites being constructed entirely below grade and the remaining 8 sites ranging from 7.5 to 45 feet above grade. For each surface impoundment iteration, height above grade at these 15 sites was randomly sampled as an empirical distribution and applied to the overall surface impoundment depth to determine depth below ground surface.

B.6 Calculation of WMU Depth and Imputation of Missing WMU Data

The EPRI survey includes information on the total area and total waste capacity of each landfill and surface impoundment included in the survey. To calculate average depth for each WMU (a necessary EPACMTP model input), the total waste capacity was divided by the area. The resulting depths were then checked for reasonableness. For surface impoundments, one depth (1 foot) was culled as being unrealistically low and one (700 feet) as too high. Two landfill depths less than 2 feet and one depth greater than 350 feet were also removed from the database. In these cases the EPRI waste capacity data were culled and replaced using the regressions described below (i.e., WMU areas are considered more reliable than the capacity estimates in the survey data), and new capacities were estimated as described below.

In addition, four landfills and six surface impoundments had neither area nor capacity data in the EPRI survey. In these cases, the EIA facility locations were used to find the plants and their WMUs on aerial photos from the Terraserver Web site (http://terraserver-usa.com/geographic.aspx), and a geographic information system (GIS) was used to measure the areas of the units in question. Capacities were then estimated as described below.

To impute data for facilities missing either area or capacity data in the EPRI survey, linear regression equations were developed based on WMUs with both area and capacity data, one to predict area from capacity, and one to predict capacity from area. The final regression equations are shown in **Figures B-4** and **B-5** for landfills and **Figures B-6** and **B-7** for surface impoundments. In each case, a standard deviation around the regression line was also computed and used during source data file preparation to randomly vary the area or capacity from iteration to iteration within the bounds of the existing data set.

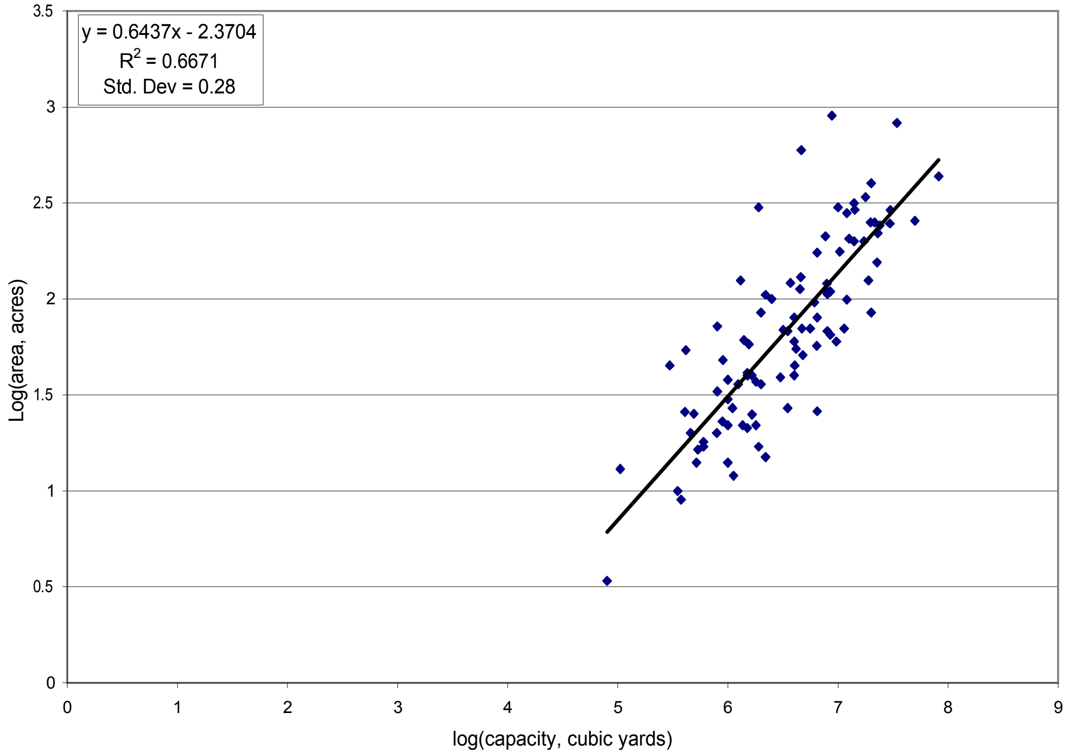

Figure B-4. Linear regression to impute landfill area from capacity.

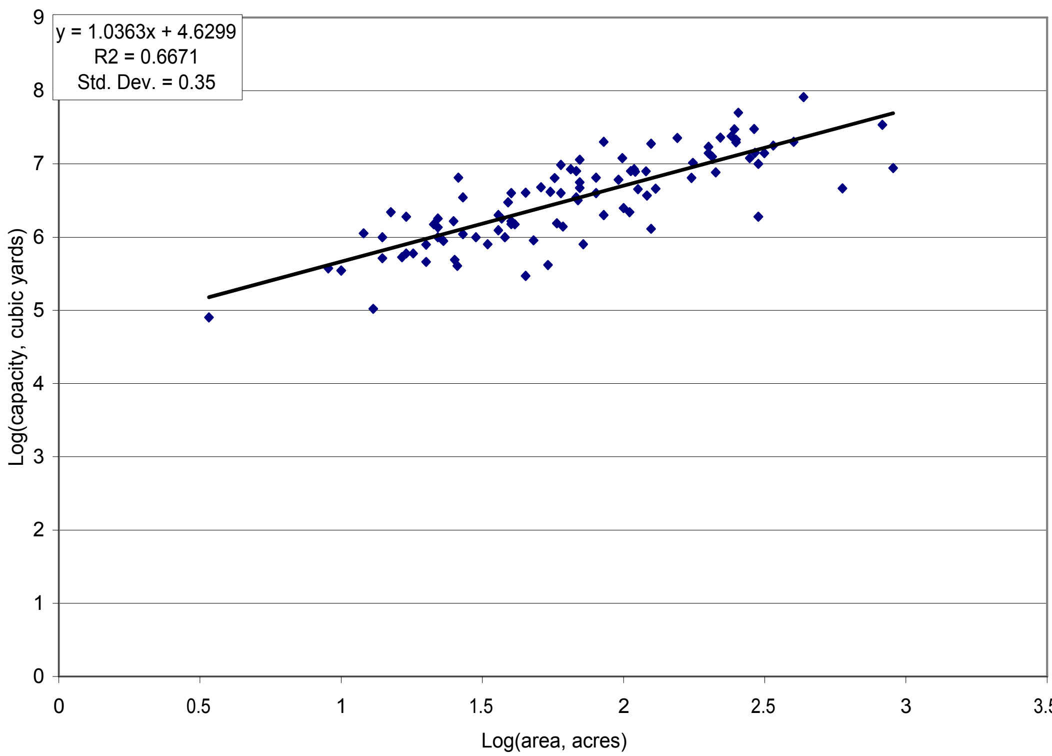

Figure B-5. Linear regression to impute landfill capacity from area.

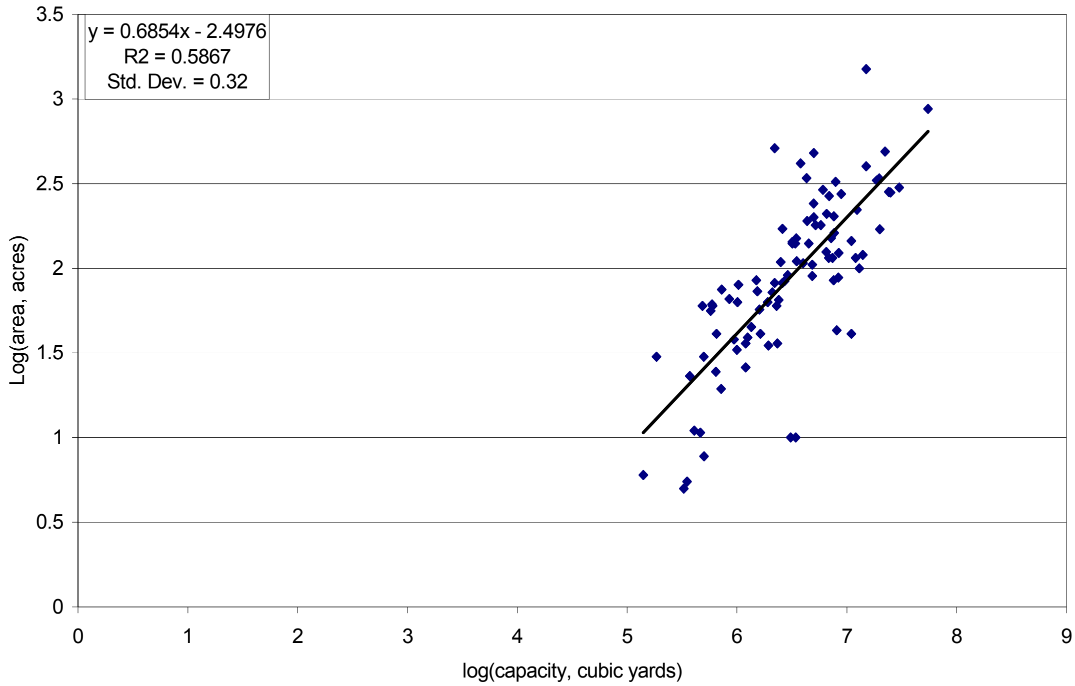

Figure B-6. Linear regression to impute surface impoundment area from capacity.

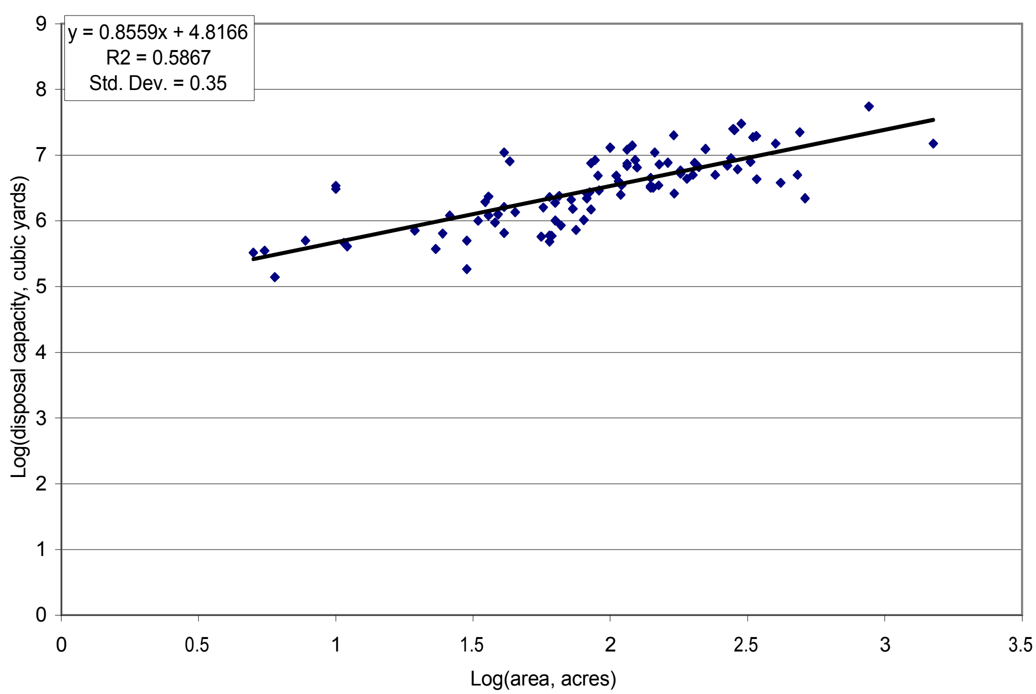

Figure B-7. Linear regression to impute surface impoundment capacity from area.

B.7 Results

Attachment B-1 lists the 181 CCW disposal sites modeled in this risk assessment and their locations. The WMU data used in the CCW risk assessment for each of the 108 landfills and 96 surface impoundments at these coal combustion facilities are presented in **Attachment B-2**. Missing data that were randomly replaced as described above are not represented in the table (i.e., the fields are left blank).

B.8 References

CIBO (Council of Industrial Boiler Owners). 1997. *Report to the U.S. Environmental Protection Agency on Fossil Fuel Combustion Byproducts from Fluidized Bed Boilers.* Prepared by the CIBO Special Project on Non-Utility Fossil Fuel Ash Classification and ICF Kaiser Consulting Group. November.

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Attachment B-1: CCW Disposal Sites (Plants)

Plant Name	Utility Name	County	State	Latitude	Longitude
A B Brown	Southern Indiana Gas & Elec. Co.	Posey	IN	37.9053	87.715
A/C Power - Ace Operations	A.C.E. Cogeneration Co.	San Bernardino	CA	35.75	117.3667
Allen	Tennessee Valley Authority	Shelby	TN	35.0742	90.1492
Alma	Dairyland Power Coop	Buffalo	WI	44.3078	91.905
Antelope Valley	Basin Electric Power Coop	Mercer	ND	47.37	101.8353
Arkwright	Georgia Power Co.	Bibb	GA	32.9269	83.6997
Asheville	Carolina Power & Light Co.	Buncombe	NC	35.4714	82.5431
Baldwin	Illinois Power Co.	Randolph	IL	38.205	89.8544
Barry	Alabama Power Co.	Mobile	AL	31.0069	88.0103
Bay Front	Northern States Power Co.	Ashland	WI	43.4833	89.4
Bay Shore	Toledo Edison Co.	Lucas	OH	41.6925	83.4375
Belews Creek	Duke Power Co.	Stokes	NC	36.2811	80.0603
Ben French	Black Hills Corp.	Pennington	SD	44.0872	103.2614
Big Cajun 2	Cajun Electric Power Coop, Inc.	Pointe Coupee	LA	30.7283	91.3686
Big Sandy	Kentucky Power Co.	Lawrence	KY	38.1686	82.6208
Big Stone	Otter Tail Power Co.	Grant	SD	45.3047	96.5083
Black Dog Steam Plant	Northern States Power Company	Dakota	MN	44.8167	93.25
Blue Valley	Independence, City of	Jackson	MO	39.0919	94.3364
Bowen	Georgia Power Co.	Bartow	GA	34.1256	84.9192
Brandon Shores	Baltimore Gas & Electric Co.	Anne Arundel	MD	39.18	76.5333
Buck	Duke Power Co.	Rowan	NC	35.7133	80.3767
Bull Run	Tennessee Valley Authority	Anderson	TN	36.0211	84.1567
C D McIntosh Jr.	Lakeland, City of	Polk	FL	28.075	81.9292
C P Crane	Baltimore Gas & Electric Co.	Baltimore City	MD	39.2845	76.6207
Cape Fear	Carolina Power & Light Co.	Chatham	NC	35.5989	79.0492
Carbon	PacifiCorp	Carbon	UT	39.7264	110.8639
Cardinal	Cardinal Operating Co.	Jefferson	OH	40.2522	80.6486
Cayuga	PSI Energy, Inc.	Vermillion	IN	39.9008	87.4136
Chalk Point	Potomac Electric Power Co.	Prince Georges	MD	38.5639	76.6806
Cholla	Arizona Public Service Co.	Navajo	AZ	34.9414	110.3003
Cliffside	Duke Power Co.	Cleveland	NC	35.22	81.7594
Clover	Virginia Electric & Power Co.	Halifax	VA	36.8667	78.7
Coal Creek	Coop Power Assn.	McLean	ND	47.3789	101.1572
Coleto Creek	Central Power & Light Co.	Goliad	TX	28.7128	97.2142

(continued)

CCW Disposal Sites (Plants) (continued)

Plant Name	Utility Name	County	State	Latitude	Longitude
Colstrip	Montana Power Co.	Rosebud	MT	45.8844	106.6139
Conemaugh	GPU Service Corporation	Indiana	PA	40.3842	79.0611
Conesville	Columbus Southern Power Co.	Coshocton	OH	40.1842	81.8811
Council Bluffs	MidAmerican Energy Co.	Pottawattamie	IA	41.18	95.8408
Crawford	Commonwealth Edison Co.	Cook	IL	39.8225	90.5681
Crist	Gulf Power Co.	Escambia	FL	30.5658	87.2239
Cross	South Carolina Pub Serv. Auth.	Berkeley	SC	33.3694	80.1119
Cumberland	Tennessee Valley Authority	Stewart	TN	36.3942	87.6539
Dale	East Kentucky Power Coop, Inc.	Clark	KY	37.875	84.25
Dallman	Springfield, City of	Sangamon	IL	39.7547	89.6008
Dan E Karn	Consumers Energy Co.	Bay	MI	43.645	83.8414
Dan River	Duke Power Co.	Rockingham	NC	36.4861	79.7244
Danskammer	Central Hudson Gas & Elec. Corp.	Orange	NY	41.5719	73.9664
Dave Johnston	PacifiCorp	Converse	WY	42.8333	105.7667
Dickerson	Potomac Electric Power Co.	Montgomery	MD	39.144	77.2059
Dolet Hills	CLECO Corporation	De Soto	LA	32.0308	93.5644
Duck Creek	Central Illinois Light Co.	Fulton	IL	40.4644	89.9825
Dunkirk	Niagara Mohawk Power Corp.	Chautauqua	NY	42.4919	79.3469
E D Edwards	Central Illinois Light Co.	Peoria	IL	40.5961	89.6633
E W Brown	Kentucky Utilities Co.	Mercer	KY	37.7911	84.7147
Eckert Station	Lansing, City of	Ingham	MI	42.7189	84.5583
Edgewater	Wisconsin Power & Light Co.	Sheboygan	WI	43.7181	87.7092
Elmer W Stout	Indianapolis Power & Light Co.	Marion	IN	39.7122	86.1975
F B Culley	Southern Indiana Gas & Elec. Co.	Warrick	IN	37.91	87.3267
Fayette Power Prj.	Lower Colorado River Authority	Fayette	TX	29.9172	96.7506
Flint Creek	Southwestern Electric Power Co.	Benton	AR	36.2625	94.5208
Fort Martin	Monongahela Power Co.	Monongalia	WV	39.7	79.9167
Frank E Ratts	Hoosier Energy R E C, Inc.	Pike	IN	38.5186	87.2725
G G Allen	Duke Power Co.	Gaston	NC	35.1897	81.0122
Gadsden	Alabama Power Co.	Etowah	AL	34.0136	85.9703
Gallatin	Tennessee Valley Authority	Sumner	TN	36.3156	86.4006
Gen J M Gavin	Ohio Power Co.	Gallia	OH	38.9358	82.1164
Genoa	Dairyland Power Coop	Vernon	WI	43.5592	91.2333
Gibson	PSI Energy, Inc.	Gibson	IN	38.3589	87.7783
Gorgas	Alabama Power Co.	Walker	AL	33.5111	87.235
Green River	Kentucky Utilities Co.	Muhlenberg	KY	37.3636	87.1214
Greene County	Alabama Power Co.	Greene	AL	32.6	87.7667
H B Robinson	Carolina Power & Light Co.	Darlington	SC	34.4	80.1667
Hammond	Georgia Power Co.	Floyd	GA	34.3333	85.2336

(continued)

CCW Disposal Sites (Plants) (continued)

Plant Name	Utility Name	County	State	Latitude	Longitude
Harllee Branch	Georgia Power Co.	Putnam	GA	33.1942	83.2994
Harrison	Monongahela Power Co.	Harrison	WV	39.3833	80.3167
Hatfield's Ferry	West Penn Power Co.	Greene	PA	39.85	79.9167
Hennepin	Illinois Power Co.	Putnam	IL	41.3028	89.315
Heskett	Montana-Dakota Utilities Co.	Morton	ND	46.8669	100.8839
Holcomb	Sunflower Electric Power Corp.	Finney	KS	37.9319	100.9719
Homer City	GPU Service Corporation	Indiana	PA	40.5142	79.1969
Hoot Lake	Otter Tail Power Co.	Otter Tail	MN	46.29	96.0428
Hugo	Western Farmers Elec. Coop, Inc.	Choctaw	OK	34.0292	95.3167
Hunter	PacifiCorp	Emery	UT	39.1667	111.0261
Huntington	PacifiCorp	Emery	UT	39.3792	111.075
Intermountain	Los Angeles, City of	Millard	UT	39.5108	112.5792
J H Campbell	Consumers Energy Co.	Ottawa	MI	42.9103	86.2031
J M Stuart	Dayton Power & Light Co.	Adams	OH	38.6364	83.7422
J R Whiting	Consumers Energy Co.	Monroe	MI	41.7914	83.4486
Jack McDonough	Georgia Power Co.	Cobb	GA	33.8244	84.475
Jack Watson	Mississippi Power Co.	Harrison	MS	30.4392	89.0264
James H Miller Jr.	Alabama Power Co.	Jefferson	AL	33.6319	87.0597
Jim Bridger	PacifiCorp	Sweetwater	WY	41.75	108.8
John E Amos	Appalachian Power Co.	Putnam	WV	38.4731	81.8233
John Sevier	Tennessee Valley Authority	Hawkins	TN	36.3767	82.9639
Johnsonville	Tennessee Valley Authority	Humphreys	TN	36.0278	87.9861
Joliet 29	Commonwealth Edison Co.	Will	IL	41.4892	88.0844
Keystone	GPU Service Corporation	Armstrong	PA	40.6522	79.3425
Killen Station	Dayton Power & Light Co.	Adams	OH	38.6903	83.4803
Kingston	Tennessee Valley Authority	Roane	TN	35.8992	84.5194
Kraft	Savannah Electric & Power Co	Chatham	GA	32.1333	81.1333
L V Sutton	Carolina Power & Light Co.	New Hanover	NC	34.2831	77.9867
Lansing	Interstate Power Co.	Allamakee	IA	43.3386	91.1667
Laramie R Station	Basin Electric Power Coop	Platte	WY	42.1086	104.8711
Lawrence EC	KPL Western Resources Co.	Douglas	KS	39.0078	95.2681
Lee	Carolina Power & Light Co.	Wayne	NC	35.3778	78.1
Leland Olds	Basin Electric Power Coop	Mercer	ND	47.2833	101.4
Lon Wright	Fremont, City of	Dodge	NE	41.45	96.5167
Louisa	MidAmerican Energy Co.	Louisa	IA	41.3181	91.0931
Marion	Southern Illinois Power Coop	Williamson	IL	37.6167	88.95
Marshall	Duke Power Co.	Catawba	NC	35.5975	80.9658
Martin Lake	Texas Utilities Electric Co.	Rusk	TX	32.2606	94.5708
Mayo	Carolina Power & Light Co.	Person	NC	36.5278	78.8919
Meramec	Union Electric Co.	St Louis	MO	38.6522	90.2397

(continued)

CCW Disposal Sites (Plants) (continued)

Plant Name	Utility Name	County	State	Latitude	Longitude
Merom	Hoosier Energy R E C, Inc.	Sullivan	IN	39.0694	87.5108
Miami Fort	Cincinnati Gas & Electric Co.	Hamilton	OH	39.1111	84.8042
Milton R Young	Minnkota Power Coop, Inc.	Oliver	ND	47.0664	101.2139
Mitchell - PA	West Penn Power Co.	Washington	PA	40.2167	79.9667
Mitchell - WV	Ohio Power Co.	Marshall	WV	39.8297	80.8153
Mohave	Southern California Edison Co.	Clark	NV	35.1667	114.6
Monroe	Detroit Edison Co.	Monroe	MI	41.8911	83.3444
Morgantown	Potomac Electric Power Co.	Charles	MD	38.3611	76.9861
Mountaineer (1301)	Appalachian Power Co.	Mason	WV	38.9794	81.9344
Mt Storm	Virginia Electric & Power Co.	Grant	WV	39.2014	79.2667
Muscatine Plant #1	Muscatine, City of	Muscatine	IA	41.3917	91.0569
Muskogee	Oklahoma Gas & Electric Co.	Muskogee	OK	35.7653	95.2883
Neal North	MidAmerican Energy Co.	Woodbury	IA	42.3167	96.3667
Neal South	MidAmerican Energy Co.	Woodbury	IA	42.3022	96.3622
Nebraska City	Omaha Public Power District	Otoe	NE	40.625	95.7917
New Castle	Pennsylvania Power Co.	Lawrence	PA	40.9383	80.3683
Newton	Central Illinois Pub Serv. Co.	Jasper	IL	38.9364	88.2778
North Omaha	Omaha Public Power District	Douglas	NE	41.33	95.9467
Northeastern	Public Service Co. of Oklahoma	Rogers	OK	36.4222	95.7047
Nucla	Tri-State G & T Assn., Inc.	Montrose	CO	38.2386	108.5072
Oklaunion	West Texas Utilities Co.	Wilbarger	TX	34.0825	99.1753
Paradise	Tennessee Valley Authority	Muhlenberg	KY	37.2608	86.9783
Petersburg	Indianapolis Power & Light Co.	Pike	IN	38.5267	87.2522
Pleasant Prairie	Wisconsin Electric Power Co.	Kenosha	WI	42.5381	87.9033
Port Washington	Wisconsin Electric Power Co.	Ozaukee	WI	43.3908	87.8686
Portland	Metropolitan Edison Co.	Northampton	PA	40.7525	75.3324
Possum Point	Virginia Electric & Power Co.	Prince William	VA	38.5367	77.2806
Potomac River	Potomac Electric Power Co.	Alexandria	VA	38.8078	77.0372
Presque Isle	Wisconsin Electric Power Co.	Marquette	MI	46.5694	87.3933
R Gallagher	PSI Energy, Inc.	Floyd	IN	38.2631	85.8378
R M Schahfer	Northern Indiana Pub. Serv. Co.	Jasper	IN	41.2167	87.0222
Reid Gardner	Nevada Power Co.	Clark	NV	36.6606	114.625
Richard Gorsuch	American Mun. Power-Ohio, Inc.	Washington	OH	39.3672	81.5208
Riverbend	Duke Power Co.	Gaston	NC	35.36	80.9742
Rodemacher	CLECO Corporation	Rapides	LA	31.395	92.7167
Roxboro	Carolina Power & Light Co.	Person	NC	36.4831	79.0711
Sandow	Texas Utilities Electric Co.	Milam	TX	30.5642	97.0639
Scherer	Georgia Power Co.	Monroe	GA	33.0583	83.8072
Shawnee	Tennessee Valley Authority	McCracken	KY	37.1517	88.775
Shawville	GPU Service Corporation	Clearfield	PA	41.0681	78.3661

(continued)

CCW Disposal Sites (Plants) (continued)

Plant Name	Utility Name	County	State	Latitude	Longitude
Sheldon	Nebraska Public Power District	Lancaster	NE	40.5589	96.7842
South Oak Creek	Wisconsin Electric Power Co.	Milwaukee	WI	42.8014	87.8314
Springerville	Tucson Electric Power Co	Apache	AZ	34.3186	109.1636
St Johns River Power	JEA	Duval	FL	30.4308	81.5508
Stanton Energy Ctr.	Orlando Utilities Comm.	Orange	FL	28.4822	81.1678
Stockton Cogen Company	Stockton Cogen Co (operator: Air Products)	San Joaquin	CA	37.9778	121.2667
Syl Laskin	Minnesota Power, Inc.	St Louis	MN	47.53	92.1617
Tecumseh EC	KPL Western Resources Co.	Shawnee	KS	39.0528	95.5683
Texas-New Mexico	Texas-New Mexico Power Company/Sempra Energy	Robertson	TX	31.0928	96.6933
Titus	Metropolitan Edison Co.	Berks	PA	40.3047	75.9072
Trimble County	Louisville Gas & Electric Co.	Trimble	KY	38.5678	85.4139
Tyrone	Kentucky Utilities Co.	Woodford	KY	38.0213	84.7456
Valley	Wisconsin Electric Power Co.	Milwaukee	WI	43.0303	87.925
Vermilion	Illinois Power Co.	Vermilion	IL	40.1781	87.7481
Victor J Daniel Jr.	Mississippi Power Co.	Jackson	MS	30.5322	88.5569
W A Parish	Houston Lighting & Power Co.	Fort Bend	TX	29.4833	95.6331
W H Weatherspoon	Carolina Power & Light Co.	Robeson	NC	34.5889	78.975
W S Lee	Duke Power Co.	Anderson	SC	34.6022	82.435
Wabash River	PSI Energy, Inc.	Vigo	IN	39.5278	87.4222
Walter C Beckjord	Cincinnati Gas & Electric Co.	Clermont	OH	38.9917	84.2972
Wansley	Georgia Power Co.	Heard	GA	33.4167	85.0333
Warrick	Southern Indiana Gas & Elec. Co.	Warrick	IN	37.915	87.3319
Waukegan	Commonwealth Edison Co.	Lake	IL	42.3833	87.8083
Weston	Wisconsin Public Service Corp.	Marathon	WI	44.8617	89.655
Widows Creek	Tennessee Valley Authority	Jackson	AL	34.8825	85.7547
Will County	Commonwealth Edison Co.	Will	IL	38.8639	90.1347
Wyodak	PacifiCorp	Campbell	WY	44.2833	105.4
Yates	Georgia Power Co.	Coweta	GA	33.4631	84.955

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Attachment B-2: CCW WMU Data

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
A B Brown	42	LF	176	10360000	Ash	compacted clay	clay
A/C Power - Ace Operations	3000	LF	18	1030815	FBC	none/natural soils	no liner
Allen	293	SI	85	1500000	Ash	none/natural soils	no liner
Alma	7	LF	85	2000000	Ash and Coal Waste	composite clay/membrane	composite
Antelope Valley	57	LF	27	3500000	Ash	none/natural soils	no liner
Arkwright	198	LF	54	415907	Ash and Coal Waste	none/natural soils	no liner
Asheville	159	SI	140	3200000	Ash	none/natural soils	no liner
Baldwin	2	SI	107	4000000	Ash and Coal Waste	none/natural soils	no liner
Barry	301	SI	63	1900000	Ash and Coal Waste	none/natural soils	no liner
Bay Front	81	LF	10	350000	Ash	none/natural soils	no liner
Bay Shore	32	LF	85		Ash	none/natural soils	no liner
Belews Creek	167	SI	512	2200000	Ash and Coal Waste	none/natural soils	no liner
Belews Creek	168	LF	315	14000000	Ash	compacted ash	no liner
Ben French	14	LF	4.61		Ash	compacted clay	clay
Big Cajun 2	186	SI	241	4990003	Ash	compacted clay	clay
Big Sandy	138	SI	115	12052100	Ash and Coal Waste	none/natural soils	no liner
Big Stone	15	LF	3.4	80000	Ash	compacted clay	clay
Big Stone	41	LF	106	8000000	Ash	none/natural soils	no liner
Black Dog Steam Plant	2700	LF	96	8936296	FBC	compacted clay	clay
Blue Valley	176	SI	23.1	372000	Ash and Coal Waste	compacted clay	clay
Bowen	143	LF	25.24	491400	Ash	compacted ash	no liner
Bowen	144	LF	25.77	406971	Ash	compacted ash	no liner
Brandon Shores	339	LF	246	5600000	Ash and Coal Waste	none/natural soils	no liner

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Buck	235	SI	90	4840000	Ash and Coal Waste	none/natural soils	no liner
Bull Run	296	SI	41	650000	Ash and Coal Waste	none/natural soils	no liner
C D McIntosh Jr.	223	LF	26		Ash and Coal Waste	compacted ash	no liner
C P Crane	338	LF	35	800000	Ash	none/natural soils	no liner
Cape Fear	161	SI	60	2300000	Ash	none/natural soils	no liner
Carbon	263	lf	11.7739066		Ash and Coal Waste	none/natural soils	no liner
Cardinal	126	SI	123	8437500	Ash	none/natural soils	no liner
Cayuga	325	SI	280	25000000	Ash and Coal Waste	none/natural soils	no liner
Chalk Point	292	LF	596	4634000	Ash and Coal Waste	none/natural soils	no liner
Cholla	107	SI	171	2600000	Ash	none/natural soils	no liner
Cliffside	163	SI	82	2200000	Ash	compacted clay	clay
Clover	139	LF	22	1000000	Ash	geosynthetic membrane	composite
Coal Creek	29	LF	70	4700000	Ash	compacted clay	clay
Coal Creek	30	LF	220	23000000	Ash	composite clay/membrane	composite
Coleto Creek	190	si	314.6135409		Ash and Coal Waste	compacted clay	clay
Colstrip	89	LF	9		Ash	none/natural soils	no liner
Conemaugh	101	LF	434	82000000	Ash	geosynthetic membrane	composite
Conesville	250	LF	300	10000000	Ash	compacted clay	clay
Conesville	251	LF	100	2500000	Ash and Coal Waste	none/natural soils	no liner
Council Bluffs	94	SI	200		Ash	none/natural soils	no liner
Crawford	272	SI	24.5	642000	Ash and Coal Waste	compacted clay	clay
Crist	157	LF	12		Ash and Coal Waste	none/natural soils	no liner
Cross	264	LF	320		Ash	compacted ash	no liner
Cross	265	LF	30		Ash and Coal Waste	none/natural soils	no liner
Cross	266	LF	30		Ash and Coal Waste	none/natural soils	no liner
Cross	267	LF	230		Ash and Coal Waste	none/natural soils	no liner
Cross	268	LF	60		Ash and Coal Waste	compacted clay	clay

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Cumberland	294	SI	75	1750000	Ash and Coal Waste	none/natural soils	no liner
Cumberland	303	SI	295	9500000	Ash	none/natural soils	no liner
Dale	151	SI	115	7408274	Ash and Coal Waste	none/natural soils	no liner
Dallman	178	LF	22	1800000	Ash	compacted clay	clay
Dallman	179	SI	417	3800000	Ash	none/natural soils	no liner
Dan E Karn	6	LF	40	1650000	Ash and Coal Waste	geosynthetic membrane	composite
Dan River	234	SI	72	2097000	Ash and Coal Waste	none/natural soils	no liner
Danskammer	24	LF	14	517265	Ash and Coal Waste	geosynthetic membrane	composite
Dave Johnston	13	LF	45	296100	Ash	compacted clay	clay
Dickerson	290	LF	206	12600000	Ash	none/natural soils	no liner
Dolet Hills	245	SI	66	850000	Ash and Coal Waste	none/natural soils	no liner
Dolet Hills	246	LF	109	8500000	Ash	compacted clay	clay
Duck Creek	11	LF	21.3	1500000	Ash	compacted clay	clay
Dunkirk	49	LF	12	1126080	Ash	compacted clay	clay
E D Edwards	276	SI	145	11000000	Ash and Coal Waste	none/natural soils	no liner
E W Brown	313	SI	33	1000000	Ash	none/natural soils	no liner
E W Brown	314	SI	84	2710000	Ash	none/natural soils	no liner
Eckert Station	113	LF	174	6460000	Ash	none/natural soils	no liner
Eckert Station	114	SI	151	7200000	Ash	none/natural soils	no liner
Edgewater	289	LF	25	1655700	Ash and Coal Waste	none/natural soils	no liner
Elmer W Stout	130	SI	10	3420000	Ash	geosynthetic membrane	composite
F B Culley	183	SI	82	2600000	Ash and Coal Waste	none/natural soils	no liner
Fayette Power Prj.	195	SI	190	4351644	Ash	compacted clay	clay
Fayette Power Prj.	196	LF	23	890560	Ash	geosynthetic membrane	composite
Flint Creek	191	LF	40	1508250	Ash and Coal Waste	none/natural soils	no liner
Flint Creek	192	si	35.73857178		Ash and Coal Waste	none/natural soils	no liner
Fort Martin	213	LF	17	1900000	Ash	none/natural soils	no liner

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Fort Martin	214	LF	61	1400000	Ash	double	composite
Fort Martin	215	LF	121	3700000	Ash and Coal Waste	composite clay/membrane	composite
Frank E Ratts	182	SI	39	1250000	Ash and Coal Waste	none/natural soils	no liner
G G Allen	237	SI	210	6545000	Ash and Coal Waste	none/natural soils	no liner
Gadsden	283	SI	60	484000	Ash and Coal Waste	compacted clay	clay
Gallatin	304	SI	341	4300000	Ash and Coal Waste	none/natural soils	no liner
Gen J M Gavin	135	LF	255	50000000	Ash	composite clay/membrane	composite
Gen J M Gavin	136	SI	300	30000000	Ash and Coal Waste	none/natural soils	no liner
Gen J M Gavin	137	LF	99	12000000	Ash	compacted clay	clay
Genoa	244	LF	100		Ash and Coal Waste	none/natural soils	no liner
Gibson	327	SI	875	55000000	Ash and Coal Waste	none/natural soils	no liner
Gibson	329	LF	85	20000000	Ash	compacted clay	clay
Gorgas	280	SI	250		Ash and Coal Waste	compacted clay	clay
Gorgas	281	SI	283	24100000	Ash and Coal Waste	compacted clay	clay
Gorgas	282	SI	1500	15000000	Ash and Coal Waste	compacted clay	clay
Green River	147	SI	36	2331219	Ash and Coal Waste	none/natural soils	no liner
Greene County	279	SI	480	5000000	Ash	compacted clay	clay
H B Robinson	169	SI	30		Ash and Coal Waste	none/natural soils	no liner
Hammond	203	SI	56	576256	Ash and Coal Waste	none/natural soils	no liner
Harllee Branch	204	SI	324	7898277	Ash and Coal Waste	none/natural soils	no liner
Harllee Branch	205	SI	203	7634000	Ash and Coal Waste	none/natural soils	no liner
Harrison	211	LF	79	18000000	Ash and Coal Waste	composite clay/membrane	composite
Harrison	330	SI	300	28000000	Ash	none/natural soils	no liner
Hatfield's Ferry	112	LF	20	790000	Ash and Coal Waste	compacted ash	no liner
Hennepin	274	SI	150	3460600	Ash and Coal Waste	none/natural soils	no liner
Heskett	87	LF	58	1550000	FBC	compacted clay	clay
Holcomb	65	LF	8		Ash	compacted ash	no liner

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Homer City	118	LF	247	29636550	Ash and Coal Waste	geosynthetic membrane	composite
Hoot Lake	40	LF	72	800000	Ash and Coal Waste	none/natural soils	no liner
Hugo	193	LF	40	4000000	Ash	compacted ash	no liner
Hugo	194	si	151.0232271		Ash and Coal Waste	compacted clay	clay
Hunter	256	LF	280	12000000	Ash	none/natural soils	no liner
Huntington	255	LF	70	11400000	Ash	none/natural soils	no liner
Intermountain	224	SI	105	4840000	Ash and Coal Waste	geosynthetic membrane	composite
Intermountain	225	LF	339	17800000	Ash	compacted ash	no liner
Intermountain	226	SI	180	5200000	Ash	geosynthetic membrane	composite
J H Campbell	115	SI	267	6900000	Ash and Coal Waste	none/natural soils	no liner
J M Stuart	125	SI	88	8357000	Ash	none/natural soils	no liner
J R Whiting	129	SI	6	140000	Ash	none/natural soils	no liner
Jack McDonough	202	SI	73	1531893	Ash and Coal Waste	none/natural soils	no liner
Jack Watson	220	SI	100		Ash	none/natural soils	no liner
James H Miller Jr.	300	SI	200	5500000	Ash	compacted clay	clay
Jim Bridger	257	LF	120	7940941	Ash	none/natural soils	no liner
Jim Bridger	258	LF	241	24000000	Ash and Coal Waste	none/natural soils	no liner
Jim Bridger	259	SI	140	3400000	Ash and Coal Waste	none/natural soils	no liner
Jim Bridger	262	SI	125	6500000	Ash and Coal Waste	none/natural soils	no liner
John E Amos	120	SI	100	13000000	Ash	none/natural soils	no liner
John E Amos	121	LF	200	14000000	Ash and Coal Waste	compacted clay	clay
John E Amos	122	SI	10	3078000	Ash	none/natural soils	no liner
John Sevier	297	SI	57	1600000	Ash and Coal Waste	none/natural soils	no liner
John Sevier	298	LF	51	4800000	Ash	compacted clay	clay
John Sevier	309	SI	105	7000000	Ash and Coal Waste	none/natural soils	no liner
Johnsonville	306	SI	91	2900000	Ash and Coal Waste	none/natural soils	no liner
Joliet 29	275	SI	63.1	1012000	Ash and Coal Waste	none/natural soils	no liner

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Keystone	106	LF	155	22663120	Ash and Coal Waste	none/natural soils	no liner
Killen Station	254	SI		99935	Ash and Coal Waste	compacted clay	clay
Kingston	311	SI	41	11000000	Ash and Coal Waste	none/natural soils	no liner
Kingston	312	SI	275	8900000	Ash and Coal Waste	none/natural soils	no liner
Kraft	206	si	59.87027428		Ash and Coal Waste	none/natural soils	no liner
L V Sutton	231	SI	162	7696000	Ash and Coal Waste	none/natural soils	no liner
Lansing	64	SI	15		Ash	compacted clay	clay
Laramie R Station	260	SI	10.7	464156	Ash and Coal Waste	compacted clay	clay
Laramie R Station	261	SI	38	939605	Ash	geosynthetic membrane	composite
Lawrence EC	109	LF	825	34300000	Ash	compacted clay	clay
Lawrence EC	110	LF	22	1360000	Ash	compacted clay	clay
Lawrence EC	111	LF	30	1000000	Ash	compacted clay	clay
Lee	240	SI	35	1936000	Ash and Coal Waste	none/natural soils	no liner
Leland Olds	103	LF	37	1800000	Ash	compacted clay	clay
Leland Olds	104	LF	20	458000	Ash and Coal Waste	none/natural soils	no liner
Lon Wright	98	LF		170000	Ash	none/natural soils	no liner
Louisa	63	SI	30	500000	Ash	compacted clay	clay
Marion	52	LF	105	2200000	Ash	none/natural soils	no liner
Marion	53	LF	38	1000000	Ash	compacted clay	clay
Marshall	232	LF	110	7826000	Ash	none/natural soils	no liner
Marshall	233	SI	340	19689000	Ash and Coal Waste	none/natural soils	no liner
Martin Lake	152	LF	290	30000000	Ash	compacted clay	clay
Mayo	171	SI	30	185000	Ash	none/natural soils	no liner
Mayo	172	SI	65	2400000	Ash	none/natural soils	no liner
Meramec	175	SI	61.1	591200	Ash and Coal Waste	none/natural soils	no liner
Merom	184	LF	65	8500000	Ash	none/natural soils	no liner
Miami Fort	39	LF	80	4000000	Ash	compacted clay	clay

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Milton R Young	100	LF	80	6500000	Ash	compacted clay	clay
Mitchell - PA	208	LF	70	5600000	Ash	none/natural soils	no liner
Mitchell - WV	131	SI		12030000	Ash and Coal Waste	none/natural soils	no liner
Mohave	72	LF	250	21500000	Ash	none/natural soils	no liner
Monroe	26	LF	400	20000000	Ash and Coal Waste	none/natural soils	no liner
Monroe	27	SI	400	15000000	Ash	none/natural soils	no liner
Morgantown	291	LF	212	7700000	Ash and Coal Waste	none/natural soils	no liner
Mountaineer (1301)	212	LF	60	9700000	Ash	composite clay/membrane	composite
Mt Storm	73	LF	125	18920000	Ash	composite clay/membrane	composite
Mt Storm	134	LF	900	8800000	Ash and Coal Waste	compacted clay	clay
Muscatine Plant #1	70	LF	36	2000000	Ash	compacted clay	clay
Muskogee	51	LF	36	1247112	Ash	compacted clay	clay
Neal North	92	SI	150		Ash and Coal Waste	none/natural soils	no liner
Neal North	93	LF	200		Ash	none/natural soils	no liner
Neal South	284	LF	150		Ash	none/natural soils	no liner
Nebraska City	20	LF	17	600000	Ash and Coal Waste	compacted clay	clay
New Castle	66	LF	27	1100000	Ash and Coal Waste	geosynthetic membrane	composite
Newton	180	LF	309		Ash	none/natural soils	no liner
North Omaha	17	LF	13	105000	Ash and Coal Waste	compacted clay	clay
Northeastern	142	LF	69	3185190	Ash	none/natural soils	no liner
Nucla	96	LF	41.2	1500000	FBC	none/natural soils	no liner
Oklaunion	228	SI	11	408940	Ash and Coal Waste	none/natural soils	no liner
Oklaunion	229	SI	19.4	718060	Ash	none/natural soils	no liner
Oklaunion	230	SI	290.8	6056820	Ash	none/natural soils	no liner
Paradise	146	SI	85	7582510	Ash	composite clay/membrane	composite
Paradise	316	SI	200	5000000	Ash	none/natural soils	no liner
Petersburg	155	LF	250	19750000	Ash	compacted clay	clay

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Petersburg	156	si	156.6901408		Ash	none/natural soils	no liner
Pleasant Prairie	243	LF	26	6500000	Ash and Coal Waste	geosynthetic membrane	composite
Port Washington	242	LF	300	1900000	Ash and Coal Waste	compacted clay	clay
Portland	67	LF	15	2200000	Ash and Coal Waste	none/natural soils	no liner
Possum Point	77	SI	56		Ash and Coal Waste	none/natural soils	no liner
Potomac River	140	LF	33	802000	Ash	geosynthetic membrane	composite
Presque Isle	116	LF	292	14200000	Ash	none/natural soils	no liner
R Gallagher	326	SI	170	20000000	Ash and Coal Waste	compacted clay	clay
R M Schahfer	84	SI	80	1030000	Ash and Coal Waste	none/natural soils	no liner
R M Schahfer	85	LF	200	17200000	Ash	none/natural soils	no liner
Reid Gardner	95	LF	112.5	4520000	Ash	none/natural soils	no liner
Richard Gorsuch	36	LF		3003600	Ash	compacted clay	clay
Riverbend	165	SI	143	3200000	Ash	none/natural soils	no liner
Rodemacher	247	SI	36	1200000	Ash	compacted clay	clay
Rodemacher	248	SI	109	2500000	Ash	compacted clay	clay
Roxboro	239	LF	55	4165000	Ash	none/natural soils	no liner
Sandow	153	LF	125	1300000	Ash	compacted clay	clay
Sandow	187	LF	48	903467	Ash and Coal Waste	none/natural soils	no liner
Sandow	188	SI	45	1351973	Ash and Coal Waste	none/natural soils	no liner
Scherer	199	SI	490	22262030	Ash and Coal Waste	none/natural soils	no liner
Shawnee	317	SI	180	5810000	Ash and Coal Waste	none/natural soils	no liner
Shawnee	318	LF	96	6100000	FBC	none/natural soils	no liner
Shawville	209	LF	68	8000000	Ash	none/natural soils	no liner
Sheldon	23	LF	9	375000	Ash	compacted clay	clay
South Oak Creek	3	LF	45	4050000	Ash and Coal Waste	compacted clay	clay
South Oak Creek	4	LF	130	4600000	Ash	none/natural soils	no liner
Springerville	154	LF	57	6400000	Ash	none/natural soils	no liner

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
St Johns River Power	158	lf	128.624166		Ash and Coal Waste	compacted clay	clay
Stanton Energy Ctr.	117	LF	312		Ash	none/natural soils	no liner
Stockton Cogen Company	2000	LF	4	533333	FBC	composite clay/membrane	composite
Syl Laskin	68	SI	75	726000	Ash and Coal Waste	none/natural soils	no liner
Tecumseh EC	177	LF	540		Ash	compacted clay	clay
Texas-New Mexico	3900	LF	61	6142473	FBC	compacted clay	clay
Titus	207	LF	39	3000000	Ash and Coal Waste	composite clay/membrane	composite
Trimble County	69	SI	115	6856667	Ash	compacted clay	clay
Tyrone	148	SI	5.5	351699	Ash	none/natural soils	no liner
Tyrone	149	SI	5	327500	Ash and Coal Waste	none/natural soils	no liner
Tyrone	150	SI	7.75	500123	Ash and Coal Waste	none/natural soils	no liner
Valley	8	LF	16.4	534000	Ash and Coal Waste	compacted clay	clay
Vermilion	55	SI	43	8100000	Ash and Coal Waste	none/natural soils	no liner
Victor J Daniel Jr	287	lf	49.20163084		Ash	compacted clay	clay
Victor J Daniel Jr	288	si	20.03879417		Ash and Coal Waste	composite clay/membrane	composite
W A Parish	189	lf	28.68322214		Ash	compacted clay	clay
W H Weatherspoon	236	SI	26	1200000	Ash and Coal Waste	none/natural soils	no liner
W S Lee	238	SI	41	1634000	Ash and Coal Waste	none/natural soils	no liner
Wabash River	324	SI	120	14000000	Ash and Coal Waste	none/natural soils	no liner
Walter C Beckjord	123	LF	14	1000000	Ash	compacted ash	no liner
Walter C Beckjord	124	SI		2000000	Ash	none/natural soils	no liner
Wansley	200	SI	330	18712850	Ash and Coal Waste	none/natural soils	no liner
Wansley	201	SI	43		Ash	none/natural soils	no liner
Warrick	181	SI	140	4500000	Ash and Coal Waste	compacted clay	clay
Waukegan	54	LF	60	4000000	Ash and Coal Waste	compacted clay	clay
Weston	241	LF	18	600000	Ash	none/natural soils	no liner
Widows Creek	320	SI	110	3500000	Ash and Coal Waste	none/natural soils	no liner

(continued)

CCW WMU Data (continued)

Plant	Facility ID	WMU Type	Area (acres)	Capacity (cubic yards)	Waste Type	Original Liner	Liner Type
Widows Creek	321	SI	222	12400000	Ash	compacted clay	clay
Will County	277	SI	60	599256	Ash and Coal Waste	compacted clay	clay
Wyodak	71	LF	68	3500000	Ash	geosynthetic membrane	composite
Yates	197	SI	4.7	115000	Ash	composite clay/membrane	composite

Appendix C. Site Data

The site characteristics used in this analysis were based on site-specific, regional, and national data sources to provide the environmental parameters necessary for modeling the fate and transport of coal combustion waste (CCW) constituents released in landfill or surface impoundment leachate. Site-specific data were collected for the area in the immediate vicinity of the waste management unit (WMU), and included the geographic relationship among important features such as the WMU boundary, residential well location, and streams and lakes. These data were collected at each of the 181 coal-fired power plants selected for the analysis. These 181 locations across the continental United States were intended to represent the geographic distribution of onsite WMUs used for disposal of CCW and were used to capture national variability in meteorology, soils, climate, aquifers, and surface waterbodies at the disposal sites.

C.1 Data Collection Methodology

The CCW risk assessment employed site-specific, regional, and national data. Site-specific data were collected around CCW plant locations from the Energy Information Administration (EIA) database to obtain data for each facility that were representative of the environment immediately surrounding the plant. When site-specific data were not available, regional or national scale data sources were used. Where appropriate, distributions were used in the Monte Carlo analysis to capture site-to-site, within-site, and national variability in the parameters collected.

Data were collected around each CCW site using a geographic information system (GIS) that allowed (1) site-specific data to be assembled from the area immediately surrounding the facility and (2) the site to be assigned to a region to collect regional data. To account for locational uncertainty for the CCW WMUs[1], a 5-km radius was used to define the data collection area for aquifer type and soil data. If multiple soil or aquifer types occurred within this radius, multiple types were sent to the model, weighted by the fraction of the collection area that they occupied. Surface waterbody type and stream flows also were collected for each site by identifying the nearest stream segment.

Climate and water quality data were collected by assigning each site to a Hydrologic Evaluation of Landfill Performance (HELP) model climate station and a U.S. Geological Survey (USGS) hydrologic region. The EPA STOrage and RETrieval (STORET) database was used as the source for water quality data, with parameters selected from distributions queried from this database for each region.

Because the EIA locations were not exact for the WMUs being modeled, a national distribution of stream distances was developed by manually measuring the distance between the

[1] The EIA latitudes and longitudes usually represent a facility centroid or front-gate location for each power plant. Because these facilities are often large, the WMUs are frequently located some distance from the plant itself and not at the EIA location.

WMU and the waterbody at a random sample of the CCW sites. Similarly, a national distribution was used to represent the distance of the nearest residential wells from the CCW WMUs being modeled.

C.2 Receptor Location (National Data)

The residential scenario for the CCW groundwater pathway analysis calculates exposure through use of well water as drinking water. During the Monte Carlo analysis, the receptor well was placed at a distance of up to 1 mile from the edge of the WMU, by sampling a nationwide distribution of nearest downgradient residential well distances taken from a survey of municipal solid waste landfills (U.S. EPA, 1988).

EPA believes that this MSW well-distance distribution (presented in **Table C-1**) is protective for onsite CCW landfills and surface impoundments at coal-fired utility power plants, but recognizes that this is an uncertainty in this analysis. Because CCW plants tend to be in more isolated areas than MSW landfills and because CCW WMUs tend to be larger than municipal landfills, EPA believes that the MSW well distance distribution is a protective representation of actual well distances at CCW disposal sites. As discussed in **Section 3.4.3**, the groundwater model used in the CCW risk assessment placed limits on the lateral direction from the plume centerline (i.e., angle off plume centerline) and depth below the water table to ensure that the well remained within the plume and at a depth appropriate for surficial aquifers across the United States. These limits were consistent with other recent national risk assessments conducted by EPA OSW and provided a protective approach to siting wells for this analysis.

Table C-1. Distribution of Receptor Well Distance

Percentile	x-distance (m)
Minimum	0.6
10	104
20	183
30	305
40	366
50 (Median)	427
60	610
70	805
80	914
90	1,220
Maximum	1,610

Source: U.S. EPA (1988).

C.2.1 Recreational Fisher and Ecological Risk Scenario (Distance to Waterbody)

The recreational fisher scenario was used to estimate risks to recreational fishers and their children who live in the vicinity of the CCW landfills and surface impoundments and catch and consume fish from a waterbody located adjacent to the buffer. The waterbody was assumed to be a stream or lake located downwind of the WMU, beginning where the buffer area ends (see Figure 2-4), and was also used as the reasonable worst case aquatic system for the ecological risk assessment. Waterbody characteristics were determined based on site-specific, regional, or national data (as described in **Section C.6**), except for stream length, which was determined by the width of the plume as it intersects the waterbody.

The downgradient distance to the surface water body was determined from a national distribution developed by measuring this distance at 59 CCW landfill and surface impoundment sites randomly selected from the 204 WMUs modeled in this risk assessment. **Table C-2** presents this distribution. **Figure C-1** provides a map and aerial photo of one of the facilities used to develop this distribution. The development of this distribution is described in **Section C.6.4**.

Table C-2. Distribution of Surface Water Distances

Percentile	Distance (m)
Minimum	10
0.03	10
0.05	20
0.07	20
0.09	20
0.10	20
0.13	20
0.15	30
0.20	40
0.25	50
0.30	50
0.35	60
0.40	70
0.45	100
0.50 (Median)	120
0.55	130
0.60	150
0.65	250
0.70	400
0.75	440
0.80	500
0.85	700
0.87	775
0.90	800
0.91	1,000
0.93	1,500
0.95	2,125
0.97	2,750
Maximum	3,000

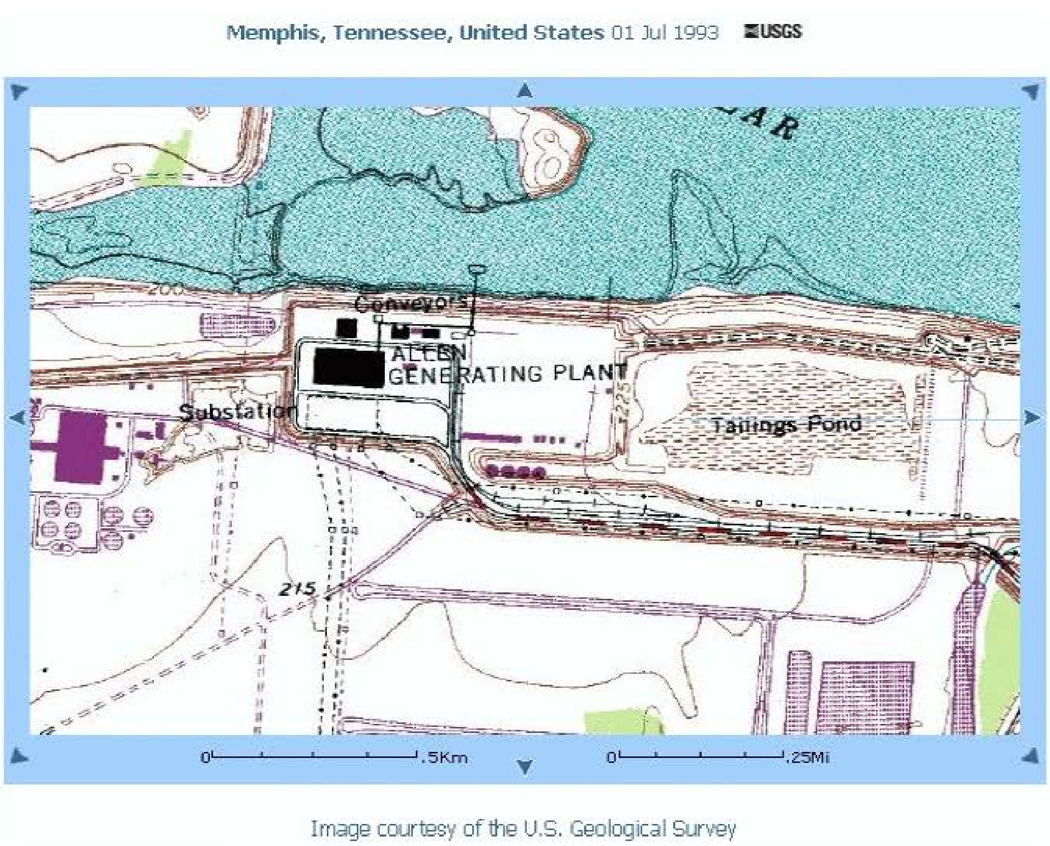

Figure C-1. Example CCW site used to develop waterbody distance distribution.

C.3 Soil Data

The groundwater model used in the CCW risk assessment—EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP)—requires soil properties for the entire soil column to model leachate transport through the vadose zone to groundwater. As with aquifer type, soil data were collected within a 5-km radius of each CCW plant. A GIS was used to identify soil map units within a 20-mile radius around each meteorological station. Database programs were then used to assemble and process soil texture, pH, and soil organic matter data for these map units from the State Soil Geographic (STATSGO) database. Both pH and soil organic matter were processed and indexed by the soil textures present within the 5-km radius. Soil properties are listed by texture for each of the 181 CCW plants in **Attachment C-1**.

C.3.1 Data Sources

The primary data source for soil properties was the STATSGO database. STATSGO is a repository of nationwide soil properties compiled primarily by the U.S. Department of Agriculture (USDA) from county soil survey data (USDA, 1994). STATSGO includes a 1:250,000-scale GIS coverage that delineates soil map units and an associated database containing soil data for each STATSGO map unit. (Map units are areas used to spatially represent soils in the database.)

In addition, two compilations of STATSGO data, each keyed to the STATSGO map unit GIS coverage, were used in the analysis as a convenient source of average soil properties:

- **USSOILS.** The USSOILS data set (Schwarz and Alexander, 1995) averages STATSGO data over the entire soil column for each map unit.
- **CONUS.** The Conterminous United States Multi-Layer Soil Characteristics (CONUS) data set (Miller and White, 1998) provides average STATSGO data by map unit and a set of 11 standardized soil layers.

Soil organic matter and pH were derived directly from USSOILS and STATSGO data. A complete set of hydrological soil properties[2] was not available from STATSGO. To ensure consistent and realistic values, EPACMTP relies on established, nationwide relationships between hydrologic properties and soil texture. Peer-reviewed publications by Carsel and Parrish (1988) and Carsel et al. (1988) provide a consistent set of correlated hydrologic properties for each soil texture. Soil texture data for the entire soil column were collected from the CONUS database.

C.3.2 Methodology

The soil data collection methodology began with GIS programs (in Arc Macro Language [AML]). These programs overlaid a 5-km radius around each CCW plant location on the STATSGO map unit coverage to determine the STATSGO map units and their area within the radius. These data were then passed to data processing programs that derive soil properties for

[2] Hydrological soil properties required by EPACMTP include bulk density, saturated water content, saturated hydraulic conductivity, and the van Genuchten soil moisture retention parameters alpha and beta.

each site, either through direct calculations or by applying established relationships in lookup tables.

EPACMTP utilizes three soil textures to represent variability in hydrologic soil properties and (along with climate data) to assign infiltration rates to each site. Because STATSGO soils are classified into the 12 U.S. Soil Conservation Service (SCS) soil textures, the crosswalk shown in **Table C-3** was used to assign the SCS textures to the EPACMTP megatextures and to calculate the percentage of each megatexture within the 5-km data collection radius. These percentages were sampled for each site when preparing the source data file for each site.

Both soil pH and soil organic matter were derived for each EPACMTP soil megatexture at a site. During source data file preparation, when a megatexture was picked for a particular iteration of a site, the corresponding pH and organic matter values were selected as well.

Table C-3. EPACMTP Soil Texture Crosswalk

STATSGO Texture	EPACMTP Megatexture
Sand	Sandy loam
Loamy sand	
Sandy loam	
Silt loam	Silt loam
Silt	
Loam	
Sandy clay loam	
Clay loam	
Silty clay loam	Silty clay loam
Sandy clay	
Silty clay	
Clay	

C.3.3 Results

Attachment C-1 lists the STATSGO soil textures and EPACMTP megatexture assignments and percentages for each CCW disposal site.

C.4 Hydrogeologic Environments (Aquifer Type)

To assign aquifer properties used by EPACMTP, it was necessary to designate hydrogeologic environments (or aquifer types) for each of the locations modeled so that correlated, national aquifer property data could be used in the analysis. EPACMTP uses the Hydrogeologic Database (HGDB) developed by the American Petroleum Institute (API) (Newell et al., 1989; Newell et al., 1990) to specify correlated probability distributions, which were used to populate the following four hydrogeologic parameters during the Monte Carlo analysis:

- Unsaturated zone thickness
- Aquifer thickness

- Hydraulic gradient
- Saturated hydraulic conductivity.

The HGDB provides correlated data on these hydrogeologic parameters and an aquifer classification for approximately 400 hazardous waste sites nationwide, grouped according to 12 hydrogeologic environments described in Newell et al. (1990). The *EPACMTP User's Guide* (U.S. EPA, 1997) provides the empirical distributions of the four hydrogeologic parameters for each of the hydrogeologic environments.

Average aquifer/vadose zone temperature was also required for the groundwater model and was obtained from a digitized map of groundwater temperatures for the continental United States from the *Water Encyclopedia* (van der Leeden et al., 1990).

The hydrogeologic environment approach to assigning EPACMTP aquifer variables relied upon a hydrogeologic framework originally developed for an attempt by EPA to classify and score groundwater environments according to their potential to be polluted by pesticide application. Although this DRASTIC[3] scoring system was not widely applied to determining groundwater vulnerability to pesticide pollution, the hydrogeologic framework established for the effort has proven very useful in categorizing geologic settings in terms of the aquifer characteristics needed for groundwater modeling. The major components of this modeling framework are Groundwater Regions, hydrogeologic settings, and hydrogeologic environments, as described below:

- The fifteen **Groundwater Regions**, defined by Heath (1984), provide a regional framework that groups hydrogeologic features (i.e., nature and extent of dominant aquifers and their relationship to other geologic units) that influence groundwater occurrence and availability.
- **Hydrogeologic settings** were developed within each Heath region by Aller et al. (1987)[4] to create mappable geological units that are at the proper scale to capture differences in aquifer conditions. Note that there may be the same or similar settings across different regions (e.g., the alluvial settings). Within each region, Aller et al. (1987) describe each setting with a written narrative and provide a block diagram to visualize the geology, geomorphology, and hydrogeology.
- **Hydrogeologic environments** were developed by Newell et al. (1990) as the geologic framework for the API's HGDB. To create the 12 environments, Newell et al. rolled up similar hydrologic settings across the Groundwater Regions to group settings with similar aquifer characteristics (hydraulic conductivity, gradient, thickness, and depth-to-water). **Table C-4** shows the crosswalk between hydrologic environment and hydrogeologic setting, organized by Groundwater Region.

[3] The DRASTIC scoring factors are Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone media, and aquifer hydraulic Conductivity.

[4] Aller et al. (1987, p. 14) did not develop settings for Region 15 (Puerto Rico and the Virgin Islands) and reincorporated Region 12 (Alluvial Valleys) into each of the other regions as "river alluvium with overbank deposits" and "river alluvium without overbank deposits."

Because EPACMTP uses the HGDB for national and regional analyses (using a regional site-based approach), it was necessary to assign the CCW sites to a hydrogeologic environment so that the correct HGDB data set would be used for modeling each site. The data sources and methodology used to make these assignments are described below.

C.4.1 Data Sources

Data sources used to make hydrogeologic assignments for the sites included:

- A USGS inventory of state groundwater resources (Heath, 1985)
- GIS coverages from *Digital Data Sets Describing Principal Aquifers, Surficial Geology, and Ground-Water Regions of the Conterminous United States* (Clawges and Price, 1999a-d)
- GIS coverages of principal aquifers from the USGS *Groundwater Atlas* (Miller, 1998)
- STATSGO soil texture data (described in Section C.3.2).

These coverages were used in a GIS overlay process to determine the principal aquifers, surficial geologic units, groundwater region, productive aquifers, and general hydrogeologic settings for a 5-km radius around each CCW facility location. Attributes for each of these items were passed to a database for use in assigning hydrogeologic environments.

C.4.2 Assignment Methodology

For each CCW site, hydrogeologic environments were assigned by a professional geologist as follows:

- Determine Heath Groundwater Region (for the Alluvial Valleys region, determine the region in which the alluvial valley is located)
- Assign hydrogeologic setting using state geological descriptions from Heath (1985); aquifer, soil, and surficial geology information obtained using GIS; and narratives and block diagrams from Aller et al. (1987)
- Using the look-up table from Newell et al. (1990), determine hydrogeologic environment from hydrogeologic setting.

In general, the surficial geology coverage had better resolution than the aquifer coverages and was used to develop setting percentages for the 5-km radius. In most cases, there were two settings per site. In cases where a single setting accounted for over 80 percent of the 5-km area, a single setting was assigned.

Because Newell et al. (1990) define two alluvial environments (6, River alluvium with overbank deposits, and 7, River alluvium without overbank deposits), it was necessary to determine which environment an alluvial site fell into. The survey soil layer information was used to distinguish between these two settings by determining whether there were significant fine-grained overbank deposits in the soil column.

Quality assurance/quality control (QA/QC) measures included independent review of the assignments by other geologists with expertise in assigning settings.

C.4.3 Data Processing

HGDB hydrogeologic environment fractions (i.e., the portion of the region assigned to each of the 12 hydrogeological environments) were defined and used in the CCW risk assessment as follows. If the 5-km radius around a site contained only one HGDB environment, the fraction assigned was 1.0 and all groundwater model runs for that location were associated with that hydrological environment. If more than one HGDB environment was present, each environment was assigned a fraction based on the areal percentages of each setting within the 5-km radius.

These fractions were used to generate the hydrogeologic environment for that location for each iteration of the Monte Carlo groundwater modeling analysis. For example, if two hydrogeologic environments were assigned to a CCW site with a fraction of 0.5, half of the realizations were modeled with the first hydrogeologic environment and half with the second.

Once the hydrogeologic environments were assigned, a preprocessing run of EPACMTP was conducted to construct a set of randomly generated but correlated hydrogeologic parameter values for each occurrence of the hydrogeologic environments in the source data files. Missing values in the HGDB data set were filled using correlations, as described in U.S. EPA (1997).

C.4.4 Results

Attachment C-2 lists the hydrogeologic environment assignments for each CCW disposal site. **Table C-4** summarizes these results, showing the crosswalk between Groundwater Regions, hydrogeologic settings, and hydrogeologic environments used to make the assignments, along with the number of CCW sites for each setting. **Table C-5** totals the number of CCW disposal sites for each hydrogeologic environment sent to EPACMTP.

Table C-4. Groundwater Regions, Hydrogeologic Settings, and Hydrogeologic Environments: CCW Disposal Sites

Hydrogeologic Setting		Hydrogeologic Environment	Number of CCW Sites
Alluvial Basins			
2C	Alluvial Fans	5	1
2E	Playa Lakes	5	1
2Ha	River Alluvium With Overbank Deposits	6	1
Colorado Plateau and Wyoming Basin			
4B	Consolidated Sedimentary Rock	2	7
4C	River Alluvium	7	3
High Plains			
5Gb	River Alluvium Without Overbank Deposits	7	1

(continued)

Groundwater Regions, Hydrogeologic Settings, and Hydrogeologic Environments: CCW Disposal Sites. (continued)

Hydrogeologic Setting		Hydrogeologic Environment	Number of CCW Sites
Nonglaciated Central Region			
6Da	Alternating Sandstone, Limestone, and Shale – Thin Soil	2	22
6Db	Alternating Sandstone, Limestone, and Shale – Deep Regolith	2	6
6E	Solution Limestone	12	9
6Fa	River Alluvium With Overbank Deposits	6	37
6Fb	River Alluvium Without Overbank Deposits	7	4
6H	Triassic Basins	2	4
Glaciated Central Region			
7Aa	Glacial Till Over Bedded Sedimentary Rock	3	12
7Ac	Glacial Till Over Solution Limestone	12	6
7Ba	Outwash	8	1
7Bb	Outwash Over Bedded Sedimentary Rock	2	3
7Bc	Outwash Over Solution Limestone	12	2
7D	Buried Valley	4	11
7Ea	River Alluvium With Overbank Deposits	6	24
7Eb	River Alluvium Without Overbank Deposits	7	6
7F	Glacial Lake Deposits	4	3
7G	Thin Till Over Bedded Sedimentary Rock	3	5
7H	Beaches, Beach Ridges, and Sand Dunes	11	1
Piedmont and Blue Ridge			
8B	Alluvial Mountain Valleys	5	1
8C	Mountain Flanks	2	2
8D	Regolith	1	13
8E	River Alluvium	6	6
Northeast and Superior Uplands			
9E	Outwash	8	3
9F	Moraine	4	1
9Ga	River Alluvium With Overbank Deposits	6	1
Atlantic and Gulf Coastal Plain			
10Aa	Regional Aquifers	4	1
10Ab	Unconsolidated/Semiconsolidated Shallow Surficial Aquifers	10	20
10Ba	River Alluvium With Overbank Deposits	6	7
10Bb	River Alluvium Without Overbank Deposits	7	6
Southeast Coastal Plain			
11A	Solution Limestone and Shallow Surficial Aquifers	12	3
11B	Coastal Deposits	4	1

Table C-5. Hydrogeologic Environments for CCW Disposal Sites

Hydrogeologic Environment		Number of CCW Sites
1	Metamorphic and Igneous	13
2	Bedded Sedimentary Rock	44
3	Till Over Sedimentary Rock	17
4	Sand and Gravel	17
5	Alluvial Basins Valleys and Fans	3
6	River Valleys and Floodplains With Overbank Deposit	76
7	River Valleys and Floodplains Without Overbank Deposits	20
8	Outwash	4
9	Till and Till Over Outwash	0
10	Unconsolidated and Semiconsolidated Shallow Aquifers	20
11	Coastal Beaches	1
12	Solution Limestone	20

C.5 Climate Data

The CCW risk assessment selected EPACMTP meteorological (or climate) stations for each CCW disposal site to collect the climatic data necessary for fate and transport modeling. For each station, the following data were compiled:

- Mean annual windspeed
- Mean annual air temperature
- Mean annual precipitation.

With respect to precipitation, EPACMTP uses the climate station, along with soil texture, to select the HELP-modeled infiltration rates to use in the landfill source model and recharge rates to use in EPACMTP (see **Section 3.2.2**). The surface water model uses mean annual windspeed and average air temperature to estimate volatilization losses from the surface waterbodies modeled in the analysis.

To assign the EPACMTP/HELP climate centers to each CCW site, a GIS was used to determine the three meteorological stations closest to the plant. These assignments were passed to a meteorologist, who reviewed the closest stations against plots of the CCW sites and the climate centers on a downloadable map (http://www.nationalatlas.gov) of annual average precipitation rates for the period from 1961 to 1990 across the contiguous United States. (**Figure C-2**). The meteorologist compared the 5-year average precipitation range for each EPACMTP climate center to precipitation ranges for each plant from the map. In most cases, the precipitation rate for the nearest climate center fell within the site's expected precipitation range, and the nearest climate center was assigned in those cases. In some cases, the precipitation rates from the nearest climate center did not fall within the site's expected range. When this occurred, the second or third closest climate center was examined and matched based on:

- A 5-year precipitation average within or close to the site's predicted precipitation range

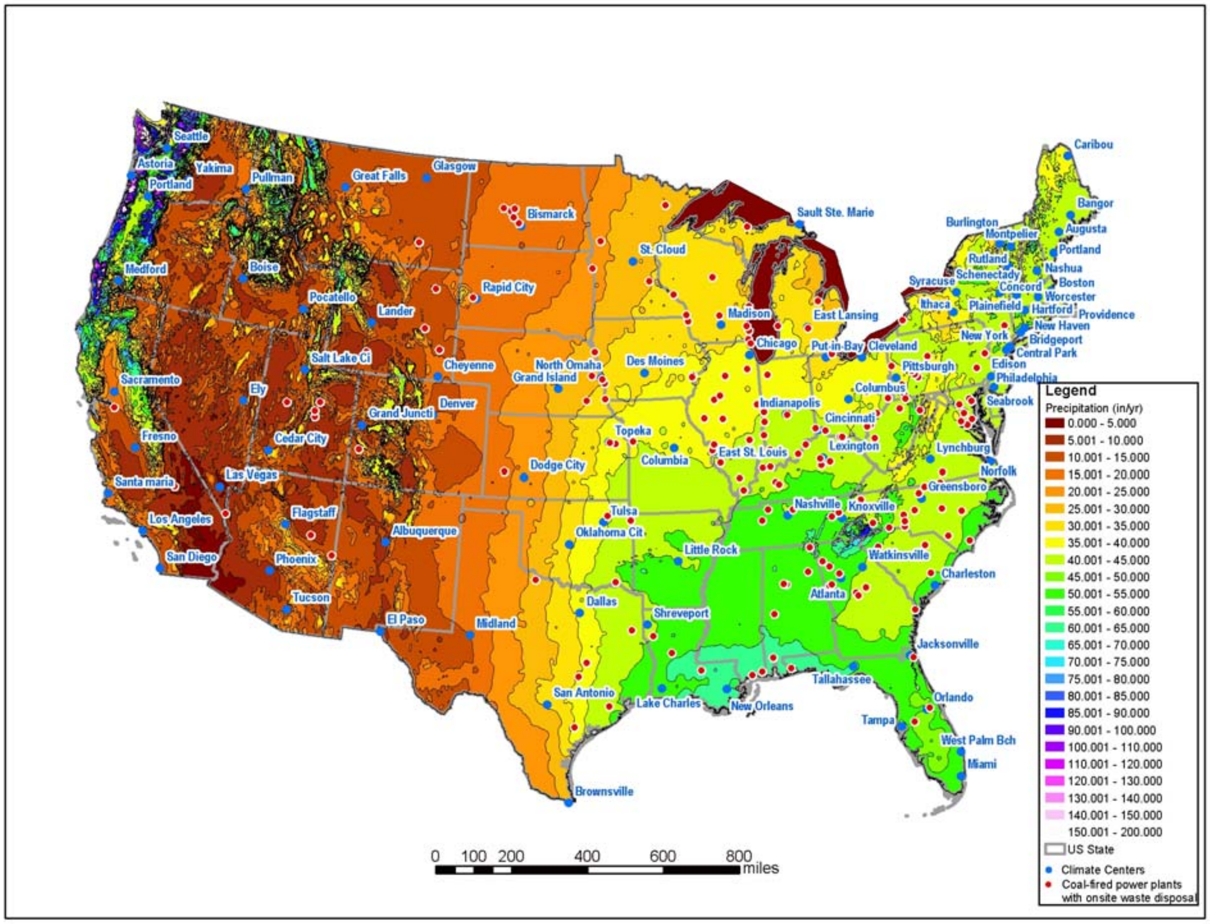

Figure C-2. EPACMTP climate centers, precipitation ranges, and CCW disposal sites.

- Confirmation of a site's average annual rainfall on http://www.weather.com and van der Leeden et al. (1990)
- Geographic similarities between plant and climate center locations
- Best professional judgment.

In a few cases, the three closest climate centers did not reflect the average precipitation rates for a plant's location. In these cases, other nearby stations were examined and the plant was assigned to the closest climate center with similar geography and average precipitation rates. Each assignment was independently checked for accuracy. **Attachment C-3** lists the climate center assigned to each CCW disposal site, along with notes for plants not assigned to the nearest center. **Table C-6** lists all the climate centers used in the CCW risk assessment along with the number of CCW sites assigned to each station.

Table C-6. EPACMTP Climate Centers Assigned to CCW Disposal Sites

Climate Center		State	Number of CCW Sites
4	Grand Junction	CO	2
6	Glasgow	MT	1
7	Bismarck	ND	5
10	Cheyenne	WY	2
11	Lander	WY	1
13	Sacramento	CA	1
16	Ely	NV	1
17	Rapid City	SD	2
18	Cedar City	UT	1
19	Albuquerque	NM	1
20	Las Vegas	NV	3
21	Phoenix	AZ	1
26	Salt Lake City	UT	1
29	Dodge City	KS	1
31	St. Cloud	MN	3
32	East Lansing	MI	3
33	North Omaha	NE	7
34	Tulsa	OK	2
37	Oklahoma City	OK	1
39	Pittsburgh	PA	12
42	Chicago	IL	8
48	Sault Ste. Marie	MI	1
49	Put-in-Bay	OH	3
50	Madison	WI	9
51	Columbus	OH	2
53	Des Moines	IA	2
54	East St. Louis	IL	8
55	Columbia	MO	1
56	Topeka	KS	3
58	San Antonio	TX	4
66	Ithaca	NY	1
69	Lynchburg	VA	2
71	Philadelphia	PA	2
72	Seabrook	NJ	5
73	Indianapolis	IN	12
74	Cincinnati	OH	11
75	Bridgeport	CT	1
76	Orlando	FL	2
77	Greensboro	NC	11

(continued)

EPACMTP Climate Centers Assigned to CCW Disposal Sites. (continued)

Climate Center		State	Number of CCW Sites
78	Jacksonville	FL	1
79	Watkinsville	GA	4
80	Norfolk	VA	2
81	Shreveport	LA	4
85	Knoxville	TN	4
87	Lexington	KY	3
89	Nashville	TN	4
90	Little Rock	AR	1
91	Tallahassee	FL	4
93	Charleston	SC	4
95	Atlanta	GA	9
96	Lake Charles	LA	2

C.6 Surface Water Data

The surface water model used in the CCW risk assessment requires information on surface waterbody type (river or lake), flow conditions, dimensions, and water quality. In addition, the groundwater model requires the distance between the waterbody and the WMU being modeled. Surface waterbody data were collected on a site-based, regional, or national basis depending on the variable and data availability. Collection methods are described below by data source. **Attachment C-4** provides a summary of waterbody assignments, waterbody types, and flow conditions.

C.6.1 Waterbody Type, Stream Flow Conditions, and Dimensions

Waterbody type and flow parameters were obtained by matching the CCW plants to stream segments in the Reach File Version 1.0 (RF1) database (U.S. EPA, 1990). Stream flow estimates for all RF1 flowing reaches were estimated in the early 1980s. Statistics developed for each flowing reach were mean annual flow, low flow (approximately 7Q10),[5] and mean monthly flow. RF1 also contains velocities corresponding to mean annual and low flow, estimated from a compendium of time-of-travel studies. For streams and rivers, the CCW risk assessment used the low flow statistic and the corresponding flow velocity, along with a waterbody type also included in the RF1 database. All RF1 data are indexed by USGS cataloging unit and stream segment (CUSEG).

To assign the CCW plants to the nearest downgradient reach (i.e., the nearest waterbody in the direction of groundwater flow), a GIS was used to identify the closest RF1 stream segment to each CCW plant location. Because of several uncertainties in the nearest reach approach (i.e.,

[5] The 7Q10 is the minimum 7-day average flow expected to occur within a 10-year return period (i.e., at least once in 10 years).

inaccurate WMU location, unknown direction of groundwater flow, and limited lake coverages), the CCW plants also were matched to standard industrial classification (SIC) code 4911 facilities in EPA's Permit Compliance System (PCS) database (http://www.epa.gov/enviro/html/pcs/index.html), to obtain the PCS information (e.g., name, CUSEG) on the receiving waterbody for the plants' National Pollutant Discharge Elimination System (NPDES) discharge point(s). When the two sources matched, the reach was selected for modeling. When they differed, the PCS data were used, because it was judged more likely that the NPDES receiving waterbody would also be receiving loads from the WMU through the groundwater-to-surface-water pathway. CCW plants that could not be matched to the PCS database were simply assigned the nearest RF1 waterbody.

The next step in the assignment process was to review the waterbody names (especially those from PCS) to identify lakes and reservoirs. Finally, visual review, using aerial photos and topographic maps from the Terraserver Web site (http://www.terraserver.com), was used to check all low-flow streams and RF1 reaches whose identity was not clear. **Attachment C-4** provides the RF1 stream assignments, flows, and waterbody types for the CCW disposal sites.

With respect to waterbody type, the RF1 data include several types of waterbodies, including streams and rivers, and types with zero flows such as lakes, Great Lakes, wide rivers, and coastline features. Each of these waterbody types needed to be designated as a river or a lake for the simple waterbody model used in the full-scale CCW risk assessment. Because only the streams and rivers have flow data in RF1 (i.e., are flowing reaches), all other types were assigned to the lake modeling category. Modeling these features as a simple model lake is an uncertainty in the CCW risk assessment **Table C-7** lists the RF1 waterbody types for the waterbodies assigned to the CCW disposal sites, along with the number of CCW plants assigned to each type and the crosswalk to the river (R) or lake (L) waterbody type used in this risk assessment.

Table C-7. RF1 Reach Types Assigned to CCW Disposal Sites

RF1 Code	RF1Name	Description	Reach Model Type[a]	Number of CCW Plants
Flowing Reaches				
M	Artificial Open Water Reach	An artificial reach within any open water, other than a lake or reservoir, to provide connection between input and output reaches of the open water.	R	1
R	Regular Reach	A reach that has upstream and downstream reaches connected to it and that is not classified as another type of reach.	R	106
S	Start Reach	A headwater reach that has no reaches above it and either one or two transport reaches connected to its downstream end.	R	16
T	Terminal Reach	A reach downstream of which there is no other reach (for example, a reach that terminates into an ocean, a land-locked lake, or the ground). This type of reach has either one or two reaches connected to its upstream end.	R	2

(continued)

RF1 Reach Types Assigned to CCW Disposal Sites. (continued)

RF1 Code	RF1Name	Description	Reach Model Type[a]	Number of CCW Plants
Reaches with Zero RF1 Flow				
C	Coastal/Continental Shoreline Segment	A reach that represents a segment of a shoreline of a gulf, sea, or ocean.	L	3
G	Great Lakes Shoreline Segment	A reach that represents a segment of a shoreline of the Great Lakes.	L	12
L	Lake Shoreline Segment	A segment that follows the shoreline of a lake other than one of the Great Lakes.	L	36
W	Wide-River Shoreline Segment	A reach that represents a segment of the left or right bank of a stream.	L	5

[a] R = river; L = lake.

Stream dimensions were calculated from the flow data as follows. First, the length of the modeled stream segment was set to be the width of the groundwater plume as it enters the waterbody. Stream width was then determined from flow (Q) using a liner regression equation derived from empirical data by Kocher and Sartor (1997):

$$Width = 5.1867Q^{0.4559} \tag{C-1}$$

Water column depth (dwc) was derived from width, velocity (V), and flow using the continuity equation:

$$dwc = \frac{Q}{v \times Width} \tag{C-2}$$

C.6.2. Lake Flow Conditions and Dimensions

Areas and depths for many of the lakes assigned to the CCW plant sites were not readily available from RF1, Reach File Version 3 (RF3), the National Hydrography Dataset (NHD), or other sources. In addition, many plants were located on very large waterbodies (e.g., the Great Lakes, wide rivers, or coastlines), where applying the simple steady-state, single-compartment model used in this analysis to the entire lake would not be appropriate. For these reasons, a model lake approach was used to represent all lakes and other nonflowing waterbodies assigned to the CCW disposal site.

The model lake chosen was Shipman City Lake in Illinois, a well-characterized 13-acre lake that EPA has chosen as the index reservoir for modeling drinking water exposures to pesticides (Jones et al., 1998). The parameter values shown in **Table C-8** for Shipman City Lake were used to model all lakes in this initial analysis. Given that many of the lakes assigned to CCW plants were much larger than 13 acres, this produced high-end risk results. However, given that many of the plants were located on very large waterbodies, this necessary simplification is an uncertainty in defining the environmental settings for the CCW risk assessment.

Table C-8. Model Lake Used in CCW Risk Assessment

Parameter	Value
Area [a]	13 acres
Water column depth (dwc)[a]	9 feet
Hydraulic residence time (HRT)	Random, triangular distribution: Minimum = 1 month Mean = 6 months Maximum = 24 months
Annual flow mixing volume	= (Area × dwc) / HRT

[a] Source: Shipman City Lake, IL (Jones et al., 1998).

C.6.3 Water Quality Data

Surface water temperature, total suspended solids (TSS), and pH data were collected by USGS hydrologic region from the STORET database. EPA's STORET system is the largest single source of water quality data in the country. The Legacy STORET database contains over 275 million analyses performed on more than 45 million samples collected from 800,000 stations across the United States for the period 1960 through 1998. STORET can be accessed from the Web at http://www.epa.gov/STORET.

STORET water quality data are notoriously "noisy" because they are influenced by hydrology, point sources, nonpoint sources, stream/lake morphology, and varying data quality. The following issues in using STORET data must be considered before using the data:

- Not all of the data have undergone rigorous QA/QC.
- STORET site locations can be biased, especially to known "problem" waters.
- The sample times are often at critical periods, such as summer low flows.

Statistical analysis techniques were employed taking into account the above issues (including coordination with gage statistical analysis and Reach Files, the use of median values to avoid bias in central tendency estimates, and specification of a minimum number of measurements to estimate median values). As a result of these techniques, which can be thought of as extracting the underlying "signal" of water quality from the inherent "noise" of water quality data, the above issues were manageable.

Surface water temperature data were collected as median values for each hydrologic region. These data are shown in **Table C-9** along with the number of the modeled CCW plants in each region.

Table C-9. Regional Surface Water Temperatures: CCW Disposal Sites

Hydrologic Region	Surface Water Temperature (°C)	Number of CCW Plants
2	16	12
3	21	37
4	14	14
5	17	43
6	18	6
7	15	20
8	20	2
9	10	1
10	13	20
11	17	8
12	21	6
14	9	5
15	17	4
16	9	1
18	15	2

Data source: Legacy STORET database.

Total suspended solids data were collected separately for streams/rivers and lakes because lakes tend to have lower TSS levels. Annual median values were used to develop statistics. For rivers, the minimum, maximum, and geometric mean values were used to define log triangular distributions for each hydrologic region (**Table C-10**); these distributions were then sampled during the preparation of the source data files. (The geometric means were weighted by the annual number of measurements.) For lakes, data were limited and national statistics were developed, with the geometric mean of the median values being weighted by the number of measurements per year and the number of annual values in each region.

Table C-10. Surface Water Total Suspended Solids (TSS) Distributions

Hydrologic Region	Number of CCW Plants	No. of Measure-ments	No. of Annual Medians	Annual Median TSS (log triangular distribution)			Geometric Mean
				Minimum	Maximum	Weighted Geometric Mean	
1	0	9,007	33	3.2	40	8.0	6.0
2	12	47,202	38	10	316	32	40
3	37	43,395	36	6.3	79	25	25
4	14	29,577	37	6.3	794	25	25
5	43	39,900	38	4.0	100	25	25
6	6	4,137	28	5.0	316	16	20

(continued)

Surface Water Total Suspended Solids (TSS) Distributions. (continued)

Hydrologic Region	Number of CCW Plants	No. of Measure-ments	No. of Annual Medians	Annual Median TSS (log triangular distribution)			Geometric Mean
				Minimum	Maximum	Weighted Geometric Mean	
7	20	34,494	37	32	1,585	63	100
8	2	46,231	38	50	316	158	126
9	1	3,254	35	13	3,162	32	63
10	20	62,791	38	10	398	126	126
11	8	48,969	38	25	794	200	126
12	6	7,280	35	40	1,995	79	126
13	0	13,974	37	32	79,433	200	398
14	5	26,699	38	16	5,012	158	251
15	4	9,162	37	20	19,953	200	398
16	1	19,965	33	4	2,512	16	25
17	0	173,136	37	2	316	6.0	10
18	2	42,022	37	13	398	63	50
Lakes (national)	56	4,360	99	1	398	25	25

Data source: Legacy STORET database.

For **surface water pH**, the minimum, maximum, and weighted average annual median values were used to specify triangular distributions for each hydrologic region. **Table C-11** provides these regional statistics, which were applied to both rivers and lakes.

To prepare the water quality data for the source datafile, the 181 CCW disposal sites were assigned to a hydrogeologic region using a GIS. For each region, 10,000-record TSS and pH data sets were created by sampling the distributions shown in Tables C-10 and C-11. During source data file preparation, TSS data were pulled from the appropriate regional data set sequentially for each iteration at a site.

Table C-11. Regional Surface Water pH Distributions

Hydrologic Region	Number of CCW Plants	No. of Measurements	No. of Annual Median Values	Annual Median pH (triangular distribution)			Average Median pH
				Minimum	Maximum	Weighted Average	
1	0	232,025	38	5.9	7.7	6.5	6.8
2	12	447,166	39	7.2	7.6	7.4	7.4
3	37	1,595,237	39	6.3	7.2	7.0	7.0
4	14	335,261	39	7.6	8.2	8.1	8.0
5	43	684,235	41	3.5	7.5	7.2	7.1
6	6	382,915	39	6.3	7.7	7.2	7.4

(continued)

Regional Surface Water pH Distributions. (continued)

Hydrologic Region	Number of CCW Plants	No. of Measurements	No. of Annual Median Values	Annual Median pH (triangular distribution)			Average Median pH
				Minimum	Maximum	Weighted Average	
7	20	234,589	39	7.6	8.1	7.9	7.8
8	2	171,643	39	6.9	7.8	7.1	7.2
9	1	23,038	38	7.5	8.4	7.9	7.9
10	20	269,570	39	7.6	8.2	8.0	8.0
11	8	311,768	39	7.4	8.1	7.8	7.8
12	6	178,990	39	7.0	7.9	7.8	7.6
13	0	35,355	39	7.0	8.1	8.0	7.9
14	5	77,041	39	7.9	8.3	8.1	8.1
15	4	75,145	38	7.7	8.3	8.0	8.0
16	1	68,581	38	7.5	8.3	8.0	8.0
17	0	293,909	39	6.9	8.0	7.5	7.4
18	2	182,049	38	7.4	8.6	7.8	7.8

Data source: Legacy STORET database.

C.6.4 Distance to Surface Water

Because the CCW plant locations were not accurate in terms of locating the WMUs, a national empirical distribution of distances between the WMU and the nearest downgradient surface waterbodies (discussed in **Section C.2.1**) was developed using manual measurements on online maps and aerial photographs for a random selection of 30 CCW landfills and 29 CCW surface impoundments. Scaled USGS maps and aerial photographs were obtained from the Terraserver Web site (http://www.terraserver.com) by entering each plant's longitude and latitude. Labels on the maps, features on the photographs, and best professional judgment were used to identify the power plant and the surface impoundment or landfill in question, along with the nearest downgradient waterbody.

The nearest waterbody matching one of the following descriptions was used in the analysis:

- Lakes or rivers beyond the facility boundary
- Streams originating in or passing through the facility boundary and then coursing downstream beyond the property boundary
- Streams with an order of 3 or greater (i.e., fishable waterbodies).

Stream order was determined by tracing the convergence of tributaries with order 1 assigned to the furthest upstream segment indicated on the map (both ephemeral and perennial streams were assigned as order 1). Topography on the map was used to determine if the waterbody was downgradient of the plant. Many CCW WMUs in the sample were located on a large waterbody.

Once the waterbody was identified, the scale provided on the maps and photos was used to measure the horizontal distance between the CCW impoundment or landfill and the waterbody. All assignments and measurements were independently checked for accuracy.

The two distributions (landfills and surface impoundments) were statistically compared using (1) a Wilcoxon Rank Sum Test (to determine whether one distribution is shifted to the right or left of the other distribution) and (2) a Quantile Test (to test for differences, that is, differing numbers of observations) between the two distributions for the values above a given percentile. The results of the Wilcoxon test showed a p value of 0.64, indicating no significant difference in the shape of the distributions. The Quantile Test evaluated every decile from 0.1 to 0.9, with adjustments to the lower percentiles to be estimated for large numbers of ties in the ranks for the lower end of the data. The nonsignificant p values ranged from 0.33 (for 90th percentile) to 0.17 (for the 40th percentile). One significant p value indicating differences between the two distributions occurred at the 17th percentile (p value = 0.066), but the remainder of the tests showed no significant differences. Based on these results, the distributions were judged to be similar and combined to produce the single distribution of 59 values used to produce a single empirical distribution (previously shown in Table C-2) that was applied nationally to both landfills and surface impoundments at the CCW sites.

C.5 References

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Attachment C-1: Soil Data

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
A B Brown	43.9	SCL	6.0	1.2
A B Brown	51.1	SLT	6.5	1.6
A B Brown	5.0	SNL	6.9	1.4
A/C Power- Ace Operations	8.9	SCL	8.9	0.21
A/C Power- Ace Operations	32.0	SLT	8.4	0.46
A/C Power- Ace Operations	59.1	SNL	8.0	0.46
Allen	48.9	SCL	7.1	0.98
Allen	19.2	SLT	6.2	1.1
Allen	32.0	SNL	7.1	1.1
Alma	18.9	SCL	6.6	1.7
Alma	59.4	SLT	6.5	3.4
Alma	21.7	SNL	5.6	0.69
Antelope Valley	8.4	SCL	7.6	3.2
Antelope Valley	68.5	SLT	7.6	1.7
Antelope Valley	23.1	SNL	7.8	2.4
Arkwright	50.7	SCL	5.4	0.5
Arkwright	24.7	SLT	5.6	0.88
Arkwright	24.5	SNL	5.4	0.64
Asheville	6.3	SCL	5.4	0.43
Asheville	77.8	SLT	5.2	0.99
Asheville	15.8	SNL	5.4	1
Baldwin	39.5	SCL	6.2	1.3
Baldwin	58.6	SLT	6.0	1.6
Baldwin	1.9	SNL	6.5	1.4
Barry	35.8	SCL	4.8	3.6
Barry	23.5	SLT	4.8	7
Barry	40.7	SNL	4.8	4.4
Bay Front	11.7	SCL	7.3	4
Bay Front	21.1	SLT	7.1	3.8
Bay Front	67.2	SNL	7.1	1.4
Bay Shore	90.8	SCL	7.1	4.1
Bay Shore	4.3	SLT	7.2	2.6
Bay Shore	4.9	SNL	7.7	9.3
Belews Creek	69.2	SCL	5.2	0.34
Belews Creek	14.0	SLT	5.4	1

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Belews Creek	16.8	SNL	5.2	0.4
Ben French	25.3	SCL	8.0	0.87
Ben French	59.7	SLT	7.7	1.8
Ben French	15.0	SNL	7.1	1.7
Big Cajun 2	66.4	SCL	7.1	1.1
Big Cajun 2	28.4	SLT	6.3	1.2
Big Cajun 2	5.2	SNL	6.0	1.3
Big Sandy	54.8	SCL	5.4	1.6
Big Sandy	41.5	SLT	5.3	1.9
Big Sandy	3.7	SNL	5.1	2.6
Big Stone	7.3	SCL	7.5	5.7
Big Stone	45.0	SLT	7.7	3.1
Big Stone	47.7	SNL	7.5	1.1
Black Dog Steam Plant	8.2	SCL	6.9	4.2
Black Dog Steam Plant	41.4	SLT	6.8	2.5
Black Dog Steam Plant	50.4	SNL	6.9	1.8
Blue Valley	63.8	SCL	6.3	1.5
Blue Valley	31.6	SLT	6.6	2.8
Blue Valley	4.6	SNL	6.5	1.1
Bowen	18.1	SCL	5.0	1.2
Bowen	81.9	SLT	5.0	0.74
Brandon Shores	18.2	SCL	4.5	0.47
Brandon Shores	16.8	SLT	4.6	3.4
Brandon Shores	64.9	SNL	4.8	0.88
Buck	79.1	SCL	5.4	0.39
Buck	18.9	SLT	5.6	1
Buck	2.0	SNL	5.3	0.6
Bull Run	76.7	SCL	5.2	0.92
Bull Run	18.2	SLT	5.6	1.7
Bull Run	5.1	SNL	5.0	0.67
C D McIntosh Jr	6.5	SCL	8.1	2.3
C D McIntosh Jr	93.5	SNL	5.5	1.8
C P Crane	34.1	SCL	4.8	0.52
C P Crane	34.3	SLT	4.7	1
C P Crane	31.6	SNL	4.9	1.1
Cape Fear	67.6	SCL	5.1	0.97
Cape Fear	24.7	SLT	5.4	1.5
Cape Fear	7.7	SNL	5.2	0.66
Carbon	0.4	SCL	6.3	7.4

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Carbon	95.8	SLT	7.8	3.4
Carbon	3.8	SNL	8.2	1.4
Cardinal	69.1	SCL	5.8	1
Cardinal	30.4	SLT	5.7	1.7
Cardinal	0.5	SNL	6.4	2
Cayuga	32.3	SCL	6.6	1.9
Cayuga	48.7	SLT	7.1	1.4
Cayuga	19.0	SNL	6.8	1.1
Chalk Point	6.9	SCL	4.6	0.58
Chalk Point	16.4	SLT	4.8	8.8
Chalk Point	76.7	SNL	4.6	1.1
Cholla	27.3	SCL	8.4	1.9
Cholla	61.0	SLT	8.1	0.62
Cholla	11.6	SNL	8.3	0.75
Cliffside	66.4	SCL	5.2	0.31
Cliffside	13.6	SLT	5.5	0.77
Cliffside	20.0	SNL	5.2	0.27
Clover	71.0	SCL	5.3	0.71
Clover	23.3	SLT	5.3	1.3
Clover	5.7	SNL	5.1	0.65
Coal Creek	6.1	SCL	6.8	3
Coal Creek	82.7	SLT	7.6	1.7
Coal Creek	11.2	SNL	8.2	2.8
Coleto Creek	12.1	SCL	7.0	1.1
Coleto Creek	86.0	SLT	7.4	0.78
Coleto Creek	1.8	SNL	6.2	0.75
Colstrip	9.0	SCL	8.0	0.79
Colstrip	63.0	SLT	8.2	0.73
Colstrip	27.9	SNL	8.3	0.54
Conemaugh	11.8	SCL	5.0	2.7
Conemaugh	81.4	SLT	4.8	1.3
Conemaugh	6.8	SNL	4.5	1.8
Conesville	44.0	SCL	5.4	2.2
Conesville	45.5	SLT	5.6	1.9
Conesville	10.5	SNL	5.0	2.2
Council Bluffs	43.3	SCL	7.5	1.5
Council Bluffs	47.2	SLT	7.6	1.2
Council Bluffs	9.6	SNL	7.7	0.74
Crawford	48.4	SCL	6.8	1.9

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Crawford	23.6	SLT	6.7	1.4
Crawford	28.0	SNL	6.7	0.82
Crist	18.8	SCL	5.4	4.5
Crist	32.3	SLT	5.3	1.1
Crist	48.8	SNL	5.4	3.3
Cross	3.0	SCL	5.0	1.3
Cross	46.0	SLT	4.6	0.58
Cross	51.0	SNL	4.9	1.2
Cumberland	61.1	SCL	5.3	1.6
Cumberland	34.2	SLT	5.7	0.98
Cumberland	4.8	SNL	5.2	1.3
Dale	91.7	SCL	6.4	1.9
Dale	8.2	SLT	6.4	2
Dale	0.1	SNL	6.7	1.3
Dallman	66.2	SCL	6.4	1.8
Dallman	33.3	SLT	6.7	1.2
Dallman	0.5	SNL	7.0	1.1
Dan E Karn	0.01	SCL	7.0	3
Dan E Karn	53.6	SLT	7.9	4.2
Dan E Karn	46.3	SNL	7.8	5.4
Dan River	73.3	SCL	5.0	0.39
Dan River	12.0	SLT	5.3	1.4
Dan River	14.7	SNL	5.1	0.6
Danskammer	89.8	SLT	5.8	2.9
Danskammer	10.2	SNL	6.9	2.8
Dave Johnston	2.2	SCL	8.9	0.96
Dave Johnston	36.6	SLT	8.2	1.2
Dave Johnston	61.2	SNL	8.2	1.1
Dickerson	6.1	SCL	5.1	0.52
Dickerson	93.9	SLT	5.2	0.68
Dolet Hills	65.7	SCL	4.8	0.97
Dolet Hills	21.6	SLT	5.0	0.77
Dolet Hills	12.7	SNL	5.1	1.1
Duck Creek	65.5	SCL	6.4	0.82
Duck Creek	33.6	SLT	6.5	0.6
Duck Creek	0.9	SNL	7.0	0.98
Dunkirk	8.8	SCL	7.3	5.4
Dunkirk	79.6	SLT	6.9	4.6
Dunkirk	11.6	SNL	6.5	2.7

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
E D Edwards	49.5	SCL	6.4	1.1
E D Edwards	29.8	SLT	6.3	1.2
E D Edwards	20.6	SNL	6.8	1.1
E W Brown	92.9	SCL	6.4	3.7
E W Brown	7.1	SLT	6.6	3.8
Eckert Station	4.8	SCL	7.2	4.5
Eckert Station	82.0	SLT	6.9	1.2
Eckert Station	13.2	SNL	6.7	0.5
Edgewater	58.5	SCL	7.3	3.3
Edgewater	3.7	SLT	7.3	1.2
Edgewater	37.8	SNL	6.8	2.2
Elmer W Stout	29.9	SCL	6.7	1.9
Elmer W Stout	56.7	SLT	7.0	1.2
Elmer W Stout	13.3	SNL	6.8	0.8
F B Culley	45.3	SCL	5.9	0.93
F B Culley	48.9	SLT	6.5	2
F B Culley	5.8	SNL	6.9	1.1
Fayette Power Prj	51.9	SCL	7.7	3.8
Fayette Power Prj	35.7	SLT	7.6	1.2
Fayette Power Prj	12.5	SNL	7.1	1
Flint Creek	62.2	SCL	4.9	0.87
Flint Creek	37.8	SLT	5.3	0.69
Fort Martin	45.9	SCL	5.6	1.2
Fort Martin	54.1	SLT	5.2	1.9
Fort Martin	0.04	SNL	4.6	2.5
Frank E Ratts	30.9	SCL	5.8	1.5
Frank E Ratts	58.0	SLT	6.3	1.1
Frank E Ratts	11.1	SNL	7.0	0.73
G G Allen	85.9	SCL	5.3	0.36
G G Allen	11.9	SLT	5.6	1.1
G G Allen	2.2	SNL	5.2	0.28
Gadsden	45.2	SCL	4.8	0.68
Gadsden	46.4	SLT	5.3	1.3
Gadsden	8.5	SNL	5.1	0.97
Gallatin	56.1	SCL	5.6	0.94
Gallatin	43.9	SLT	5.4	0.94
Gen J M Gavin	35.9	SCL	6.0	1.4
Gen J M Gavin	46.1	SLT	5.6	2.1
Gen J M Gavin	18.0	SNL	5.1	1.3

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Genoa	14.3	SCL	6.1	2.3
Genoa	64.6	SLT	6.6	1.8
Genoa	21.0	SNL	6.1	0.97
Gibson	55.3	SCL	6.6	1.5
Gibson	43.2	SLT	6.4	1.1
Gibson	1.5	SNL	7.3	0.67
Gorgas	17.0	SCL	4.6	0.42
Gorgas	53.0	SLT	5.1	0.77
Gorgas	30.0	SNL	5.2	0.73
Green River	48.4	SCL	5.9	1
Green River	51.6	SLT	6.0	1.4
Greene County	19.5	SCL	5.1	1.8
Greene County	72.6	SLT	5.2	1.4
Greene County	7.9	SNL	4.9	1.6
H B Robinson	0.1	SCL	5.2	0.75
H B Robinson	32.6	SLT	4.8	1
H B Robinson	67.3	SNL	5.3	0.6
Hammond	54.7	SCL	5.1	0.74
Hammond	33.8	SLT	5.3	1.3
Hammond	11.5	SNL	5.0	0.75
Harllee Branch	54.7	SCL	5.3	0.49
Harllee Branch	15.3	SLT	5.6	0.97
Harllee Branch	30.0	SNL	5.3	0.47
Harrison	48.8	SCL	5.6	1
Harrison	51.2	SLT	5.0	2.1
Hatfield's Ferry	39.3	SCL	5.7	1.8
Hatfield's Ferry	60.4	SLT	5.3	1.6
Hatfield's Ferry	0.3	SNL	4.6	2.5
Hennepin	44.6	SCL	6.4	1.5
Hennepin	38.2	SLT	6.7	1.1
Hennepin	17.2	SNL	7.0	1.3
Heskett	39.9	SCL	8.0	2.1
Heskett	44.1	SLT	7.6	2.4
Heskett	16.0	SNL	7.7	1.9
Holcomb	4.4	SLT	7.9	0.67
Holcomb	95.6	SNL	7.3	0.75
Homer City	11.0	SCL	4.9	2.9
Homer City	84.5	SLT	4.8	1.6
Homer City	4.5	SNL	4.5	2.1

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Hoot Lake	3.1	SCL	7.5	5.4
Hoot Lake	38.9	SLT	7.7	2.6
Hoot Lake	58.1	SNL	7.5	1.3
Hugo	55.1	SCL	6.6	1.4
Hugo	35.8	SLT	6.7	1.6
Hugo	9.2	SNL	5.3	0.7
Hunter	90.8	SCL	8.3	0.73
Hunter	3.5	SLT	8.2	2
Hunter	5.7	SNL	8.5	0.75
Huntington	4.5	SCL	8.6	1.5
Huntington	79.5	SLT	8.0	2.4
Huntington	15.9	SNL	8.6	1.3
Intermountain	46.9	SCL	8.6	0.7
Intermountain	8.3	SLT	8.9	0.51
Intermountain	44.8	SNL	8.8	0.44
J H Campbell	5.0	SLT	7.1	1.8
J H Campbell	95.0	SNL	5.9	1.2
J M Stuart	73.5	SCL	6.5	1.6
J M Stuart	24.8	SLT	6.8	2.4
J M Stuart	1.7	SNL	5.5	2
J R Whiting	80.6	SCL	7.1	4.2
J R Whiting	17.1	SLT	7.1	2.1
J R Whiting	2.3	SNL	6.8	2.8
Jack McDonough	58.9	SCL	5.2	0.46
Jack McDonough	7.8	SLT	5.6	1.1
Jack McDonough	33.3	SNL	5.3	0.37
Jack Watson	20.5	SCL	6.7	11
Jack Watson	46.8	SLT	4.8	3
Jack Watson	32.8	SNL	4.9	3.8
James H Miller Jr	17.0	SCL	4.6	0.42
James H Miller Jr	53.0	SLT	5.1	0.77
James H Miller Jr	30.0	SNL	5.2	0.73
Jim Bridger	1.4	SCL	8.7	0.75
Jim Bridger	37.9	SLT	8.6	0.52
Jim Bridger	60.6	SNL	8.2	0.64
John E Amos	35.8	SCL	6.3	1.6
John E Amos	64.2	SLT	5.1	2.2
John Sevier	43.2	SCL	6.2	1.6
John Sevier	56.7	SLT	5.8	1.2

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
John Sevier	0.2	SNL	5.0	0.67
Johnsonville	39.2	SCL	5.1	1.7
Johnsonville	57.3	SLT	5.2	1.3
Johnsonville	3.5	SNL	4.7	1.5
Joliet 29	52.8	SCL	7.1	2.7
Joliet 29	43.5	SLT	7.0	2.1
Joliet 29	3.7	SNL	7.1	1.8
Keystone	7.7	SCL	4.9	2.8
Keystone	90.1	SLT	4.9	1.4
Keystone	2.2	SNL	4.5	2.2
Killen Station	74.3	SCL	6.0	1.9
Killen Station	24.0	SLT	6.3	2.2
Killen Station	1.8	SNL	6.2	1.7
Kingston	66.7	SCL	5.0	1.2
Kingston	21.0	SLT	5.5	1.7
Kingston	12.3	SNL	5.0	0.67
Kraft	57.1	SCL	7.2	11
Kraft	22.8	SLT	5.0	1.3
Kraft	20.1	SNL	5.0	1.4
L V Sutton	18.0	SCL	6.1	3.9
L V Sutton	32.4	SLT	5.0	3.7
L V Sutton	49.6	SNL	5.0	1.6
Lansing	9.0	SCL	5.8	2.6
Lansing	67.7	SLT	6.8	2.1
Lansing	23.3	SNL	6.2	1.4
Laramie R Station	41.1	SLT	8.1	0.87
Laramie R Station	58.9	SNL	7.9	1.2
Lawrence EC	51.5	SCL	6.6	1.9
Lawrence EC	47.7	SLT	6.8	2.9
Lawrence EC	0.8	SNL	7.5	0.75
Lee	16.4	SCL	5.0	1.3
Lee	51.1	SLT	5.0	1.3
Lee	32.5	SNL	5.1	0.96
Leland Olds	13.5	SCL	7.8	2.6
Leland Olds	52.9	SLT	7.6	1.9
Leland Olds	33.6	SNL	7.5	2
Lon Wright	25.7	SCL	7.5	1.5
Lon Wright	8.4	SLT	7.0	2.1
Lon Wright	65.9	SNL	7.8	1.4

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Louisa	35.5	SCL	6.7	1.8
Louisa	16.6	SLT	6.3	1.5
Louisa	47.9	SNL	6.6	0.96
Marion	10.9	SCL	5.6	0.96
Marion	88.8	SLT	5.2	0.95
Marion	0.3	SNL	6.6	1
Marshall	72.1	SCL	5.2	0.33
Marshall	12.9	SLT	5.5	0.87
Marshall	15.0	SNL	5.2	0.27
Martin Lake	34.3	SCL	4.9	1
Martin Lake	25.1	SLT	5.1	0.8
Martin Lake	40.6	SNL	5.1	0.73
Mayo	71.9	SCL	5.6	0.61
Mayo	27.9	SLT	5.6	1
Mayo	0.2	SNL	5.2	0.76
Meramec	87.9	SCL	6.4	1.3
Meramec	12.1	SLT	6.5	1.3
Merom	30.2	SCL	5.5	0.84
Merom	59.2	SLT	5.8	0.96
Merom	10.6	SNL	6.4	0.77
Miami Fort	69.6	SCL	6.5	1.7
Miami Fort	27.3	SLT	6.8	2
Miami Fort	3.1	SNL	6.7	1.2
Milton R Young	4.6	SCL	7.6	3.1
Milton R Young	92.9	SLT	7.7	1.5
Milton R Young	2.5	SNL	7.5	1.8
Mitchell - PA	19.1	SCL	5.9	2.1
Mitchell - PA	80.9	SLT	5.5	1.4
Mitchell - WV	39.9	SCL	6.0	1.7
Mitchell - WV	59.9	SLT	5.2	2
Mitchell - WV	0.2	SNL	6.0	1.3
Mohave	29.0	SLT	8.1	0.26
Mohave	71.0	SNL	8.1	0.31
Monroe	38.5	SCL	7.0	3
Monroe	49.5	SLT	7.2	3.1
Monroe	12.0	SNL	6.8	3.5
Morgantown	21.7	SCL	4.6	1.2
Morgantown	39.3	SLT	4.7	3.2
Morgantown	39.0	SNL	4.9	1.3

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Mountaineer (1301)	56.1	SCL	6.0	1.6
Mountaineer (1301)	34.2	SLT	5.9	2.2
Mountaineer (1301)	9.8	SNL	4.9	2.5
Mt Storm	4.1	SCL	5.0	2.9
Mt Storm	65.3	SLT	4.7	1.4
Mt Storm	30.6	SNL	4.4	1
Muscatine Plant #1	46.8	SCL	6.6	1.8
Muscatine Plant #1	27.4	SLT	6.4	1.4
Muscatine Plant #1	25.8	SNL	6.6	0.84
Muskogee	30.9	SCL	6.5	1.7
Muskogee	53.1	SLT	6.8	1.1
Muskogee	16.0	SNL	6.7	1
Neal North	36.7	SCL	7.9	1.1
Neal North	46.5	SLT	7.9	0.67
Neal North	16.9	SNL	7.7	0.73
Neal South	34.0	SCL	7.8	1.1
Neal South	50.7	SLT	7.8	0.69
Neal South	15.3	SNL	7.7	0.73
Nebraska City	55.5	SCL	7.4	1.4
Nebraska City	35.5	SLT	7.3	1.7
Nebraska City	9.0	SNL	7.7	0.74
New Castle	5.1	SCL	7.7	0.73
New Castle	81.6	SLT	5.9	2.8
New Castle	13.2	SNL	6.1	1.5
Newton	37.9	SCL	5.5	0.54
Newton	61.3	SLT	5.5	0.53
Newton	0.7	SNL	6.5	0.85
North Omaha	29.0	SCL	7.4	1.5
North Omaha	60.1	SLT	7.7	0.82
North Omaha	11.0	SNL	7.7	0.74
Northeastern	76.9	SCL	6.7	2.1
Northeastern	21.3	SLT	6.3	2.2
Northeastern	1.8	SNL	5.6	2
Nucla	61.2	SLT	7.9	0.98
Nucla	38.8	SNL	8.1	0.55
Oklaunion	92.2	SCL	8.0	1.7
Oklaunion	7.0	SLT	7.9	0.94
Oklaunion	0.7	SNL	7.3	1.5
Paradise	14.8	SCL	5.6	1.4

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Paradise	85.2	SLT	5.9	1.2
Petersburg	29.7	SCL	5.9	1.5
Petersburg	62.9	SLT	6.3	1.2
Petersburg	7.5	SNL	7.2	0.59
Pleasant Prairie	97.2	SCL	7.1	1.7
Pleasant Prairie	2.8	SNL	7.3	1.5
Port Washington	86.3	SCL	7.3	3.3
Port Washington	7.7	SLT	7.5	0.68
Port Washington	6.1	SNL	7.3	3
Portland	8.7	SCL	5.8	0.58
Portland	90.8	SLT	5.5	1.1
Portland	0.5	SNL	6.0	1.8
Possum Point	6.3	SCL	4.6	0.58
Possum Point	43.0	SLT	4.9	3
Possum Point	50.7	SNL	4.9	0.8
Potomac River	13.3	SCL	4.5	0.56
Potomac River	35.5	SLT	4.9	2.8
Potomac River	51.2	SNL	5.0	1.1
Presque Isle	18.7	SLT	5.2	2.5
Presque Isle	81.3	SNL	5.3	3.1
R Gallagher	40.4	SCL	5.6	1.5
R Gallagher	59.0	SLT	5.9	2.1
R Gallagher	0.5	SNL	6.9	1.4
R M Schahfer	2.1	SCL	7.1	3.8
R M Schahfer	6.5	SLT	6.9	2.9
R M Schahfer	91.4	SNL	6.6	1.5
Reid Gardner	13.3	SCL	8.4	0.29
Reid Gardner	21.6	SLT	8.3	0.58
Reid Gardner	65.1	SNL	8.4	0.34
Richard Gorsuch	69.9	SCL	6.1	1.7
Richard Gorsuch	27.0	SLT	5.9	2.4
Richard Gorsuch	3.0	SNL	5.1	2.6
Riverbend	77.4	SCL	5.3	0.37
Riverbend	20.1	SLT	5.7	1.1
Riverbend	2.5	SNL	5.2	0.45
Rodemacher	42.9	SCL	6.5	0.96
Rodemacher	51.4	SLT	6.5	0.92
Rodemacher	5.7	SNL	5.3	0.85
Roxboro	40.3	SCL	5.5	0.47

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Roxboro	55.7	SLT	6.0	0.79
Roxboro	4.0	SNL	5.5	1.4
Sandow	0.8	SCL	6.9	0.5
Sandow	37.4	SLT	6.3	0.66
Sandow	61.8	SNL	6.3	0.64
Scherer	58.5	SCL	5.3	0.39
Scherer	12.8	SLT	5.5	0.97
Scherer	28.7	SNL	5.3	0.42
Shawnee	9.5	SCL	5.8	1
Shawnee	84.2	SLT	5.6	1.4
Shawnee	6.3	SNL	6.5	1.1
Shawville	5.2	SCL	5.0	3
Shawville	82.6	SLT	4.9	1.1
Shawville	12.2	SNL	4.4	1.2
Sheldon	62.7	SCL	6.8	2.3
Sheldon	33.2	SLT	7.0	1.6
Sheldon	4.1	SNL	6.9	2
South Oak Creek	95.5	SCL	7.1	1.9
South Oak Creek	4.5	SNL	7.3	1.6
Springerville	10.0	SLT	8.1	0.79
Springerville	90.0	SNL	7.9	0.79
St Johns River Power	27.1	SCL	6.9	49
St Johns River Power	0.4	SLT	5.0	1.3
St Johns River Power	72.5	SNL	5.2	1.1
Stanton Energy Ctr	0.8	SCL	7.0	10
Stanton Energy Ctr	2.4	SLT	7.7	1
Stanton Energy Ctr	96.8	SNL	5.3	4.8
Stockton Cogen Company	89.9	SCL	7.6	1.8
Stockton Cogen Company	6.6	SLT	7.5	1.5
Stockton Cogen Company	3.5	SNL	6.8	0.51
Syl Laskin	8.5	SCL	6.5	3.2
Syl Laskin	4.6	SLT	6.3	6.3
Syl Laskin	86.9	SNL	5.8	3.1
Tecumseh EC	55.2	SCL	6.6	2
Tecumseh EC	41.9	SLT	6.9	2.6
Tecumseh EC	2.9	SNL	7.6	0.62
Texas-New Mexico	4.4	SCL	7.0	0.61
Texas-New Mexico	43.5	SLT	6.3	0.67
Texas-New Mexico	52.1	SNL	6.0	0.77

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Titus	31.8	SCL	6.0	0.76
Titus	63.6	SLT	5.6	1.4
Titus	4.6	SNL	5.0	0.98
Trimble County	57.3	SCL	6.3	2
Trimble County	41.9	SLT	6.5	1.9
Trimble County	0.8	SNL	5.9	1.7
Tyrone	92.1	SCL	6.3	3.7
Tyrone	7.9	SLT	6.6	3.9
Valley	98.5	SCL	6.9	1.2
Valley	0.2	SLT	7.5	0.45
Valley	1.3	SNL	7.4	1.3
Vermilion	82.5	SCL	6.9	1.3
Vermilion	16.6	SLT	7.0	1.2
Vermilion	0.8	SNL	7.2	1.1
Victor J Daniel Jr	46.2	SCL	4.6	2.2
Victor J Daniel Jr	27.7	SLT	4.7	2.3
Victor J Daniel Jr	26.1	SNL	4.7	16
W A Parish	95.8	SCL	7.4	1.4
W A Parish	4.2	SLT	7.9	0.74
W H Weatherspoon	7.4	SCL	5.5	1.9
W H Weatherspoon	50.4	SLT	4.7	2.2
W H Weatherspoon	42.2	SNL	4.8	1.3
W S Lee	68.0	SCL	5.3	0.48
W S Lee	9.0	SLT	5.7	1
W S Lee	23.0	SNL	5.3	0.41
Wabash River	22.0	SCL	6.4	1.6
Wabash River	48.5	SLT	6.9	1.2
Wabash River	29.5	SNL	6.7	1.2
Walter C Beckjord	71.6	SCL	6.3	1.4
Walter C Beckjord	26.5	SLT	6.7	2
Walter C Beckjord	1.9	SNL	6.6	1.1
Wansley	46.3	SCL	5.2	0.52
Wansley	18.1	SLT	5.6	1.2
Wansley	35.5	SNL	5.4	0.5
Warrick	45.8	SCL	6.0	0.95
Warrick	48.6	SLT	6.5	1.9
Warrick	5.6	SNL	7.0	1.1
Waukegan	43.9	SCL	6.6	1
Waukegan	18.1	SLT	6.6	1.4

(continued)

Soil Data (continued)

Plant	Percent Composition	Megatexture Code	Average pH	Average % Organic Material
Waukegan	38.0	SNL	6.7	0.8
Weston	33.5	SLT	5.6	1.7
Weston	66.5	SNL	6.0	1.4
Widows Creek	64.5	SCL	5.3	0.88
Widows Creek	20.0	SLT	5.2	1.4
Widows Creek	15.5	SNL	5.4	1.2
Will County	40.0	SCL	6.8	1.8
Will County	52.7	SLT	7.0	0.96
Will County	7.2	SNL	7.1	0.98
Wyodak	1.3	SCL	8.1	0.38
Wyodak	40.2	SLT	7.9	1.1
Wyodak	58.5	SNL	7.9	0.93
Yates	47.8	SCL	5.2	0.48
Yates	17.7	SLT	5.6	1.2
Yates	34.5	SNL	5.3	0.48

Attachment C-2: Hydrogeologic Environment

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Big Cajun 2	10Ba	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting (100% alluvium); soils have significant fines (SCL+SLT = 95%)
A B Brown	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting; soils have significant fines (SCL+SLT = 95%)
A/C Power-Ace Operations	2C	Alluvial Fans	5	Alluvial Basins Valleys and Fans	100	Based on surficial geology; consistent with alluvial fan setting
Allen	10Ba	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on aquifer coverages, surficial geology; Heath (1985) and soils indicate overbank deposits
Alma	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Percentage based on SNL/SCL soils; setting based on productive aquifers and surficial geology
Alma	7Eb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	50	Percentage based on SNL/SCL soils; setting based on productive aquifers and surficial geology
Antelope Valley	7G	Thin Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Based on principal aquifer and surficial geology coverages
Arkwright	8D	Regolith	1	Metamorphic and Igneous	100	Most common Piedmont setting (residuum)
Asheville	8B	Alluvial Mountain Valleys	5	Alluvial Basins Valleys and Fans	100	Appropriate for alluvial blue ridge valley (colluvium)
Baldwin	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage based on surficial geology (74% Floodplain and alluvium gravel terraces)
Baldwin	7G	Thin Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	30	Percentage based on surficial geology (74% Floodplain and alluvium gravel terraces)

(continued)

Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Barry	10Ba	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting, significant fine grained soils = overbank deposits
Bay Front	7Bb	Outwash Over Bedded Sedimentary Rock	2	Bedded Sedimentary Rock	70	Percentage based on productive aquifers
Bay Front	7D	Buried Valley	4	Sand and Gravel	30	Percentage based on productive aquifers
Bay Shore	7Ac	Glacial Till Over Solution Limestone	12	Solution Limestone	100	Closest setting considering carbonate aquifers, high SCL soils, and lake deposits surficial geology
Belews Creek	6H	Triassic Basins	2	Bedded Sedimentary Rock	50	Sources somewhat dissimilar; fraction based on surficial geology; Triassic basin
Belews Creek	8D	Regolith	1	Metamorphic and Igneous	50	Sources somewhat dissimilar; fraction based on surficial geology
Ben French	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	60	Percentage, thin soils based on surficial geology
Ben French	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	40	Percentage based on surficial geology; significant fine soils (25% SCL)
Big Sandy	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	50	Percentage based on surficial geology; thin soils inferred from colluvium
Big Sandy	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Percentage based on surficial geology; soils have significant fines (SCL+SLT = 95%)
Big Stone	7Ba	Outwash	8	Outwash	100	Based on surficial geology
Black Dog Steam Plant	7Bb	Outwash Over Bedded Sedimentary Rock	2	Bedded Sedimentary Rock	100	Based on surficial geology, aquifer coverages
Blue Valley	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	80	Percentage based on Heath (1985), productive aquifers

(continued)

Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Blue Valley	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	20	Percentage based on Heath (1985), productive aquifers
Bowen	6Db	Alternating Sandstone, Limestone and Shale - Deep Regolith	2	Bedded Sedimentary Rock	100	Based on aquifers, surficial residuum (massive red clay); metamorphic surficial geology not consistent with Valley and Ridge
Brandon Shores	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Assigned based on location and aquifer and surficial geology coverages; Heath region incorrect (it's Atlantic Coastal Plain, not Piedmont)
Buck	8E	River Alluvium	6	River Valleys and Floodplains with Overbank Deposit	100	Based on productive aquifer & Heath region coverages
Bull Run	6Db	Alternating Sandstone, Limestone and Shale - Deep Regolith	2	Bedded Sedimentary Rock	60	Percentage based on surficial geology
Bull Run	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	40	Percentage based on surficial geology; high SCL (77%) = overbank deposits
C D McIntosh Jr	11A	Solution Limestone and Shallow Surficial Aquifers	12	Solution Limestone	100	Based on both aquifer coverages
C P Crane	10Aa	Regional Aquifers	4	Sand and Gravel	50	Appears to be on border between Piedmont and Coastal Plain
C P Crane	8D	Regolith	1	Metamorphic and Igneous	50	Appears to be on border between Piedmont and Coastal Plain
Cape Fear	6H	Triassic Basins	2	Bedded Sedimentary Rock	20	Percentage based on productive aquifer & Heath region coverages; Triassic basin
Cape Fear	8E	River Alluvium	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on productive aquifer & Heath region coverages
Carbon	4B	Consolidated Sedimentary Rock	2	Bedded Sedimentary Rock	100	Setting based on aquifer and surficial geology coverages

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Cardinal	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	30	Percentage based on surficial geology; soils with low (<1%) SNL
Cardinal	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage based on surficial geology; soils with low (<1%) SNL
Cayuga	7D	Buried Valley	4	Sand and Gravel	100	Glaciofluvial aquifer overlaid by alluvial deposits
Chalk Point	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Predominant setting
Cholla	4B	Consolidated Sedimentary Rock	2	Bedded Sedimentary Rock	20	Percentage based on surficial geology (83% Floodplain and alluvium gravel terraces)
Cholla	4C	River Alluvium	7	River Valleys and Floodplains without Overbank Deposits	80	Percentage based on surficial geology (83% Floodplain and alluvium gravel terraces)
Cliffside	8D	Regolith	1	Metamorphic and Igneous	100	Based on surficial geology
Clover	6H	Triassic Basins	2	Bedded Sedimentary Rock	20	Percentage based on surficial geology; Triassic Basin from Heath (1985) and principal aquifer coverage
Clover	8E	River Alluvium	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on surficial geology
Coal Creek	7G	Thin Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Based on principal aquifer and surficial geology coverages
Coleto Creek	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Setting based on aquifer and surficial geology coverages
Colstrip	6da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Based on all coverages

(continued)

Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Conemaugh	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Setting based on aquifer coverages & Heath (1985); thin regolith inferred from colluvium
Conesville	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	40	Percentage based on surficial geology; soils with low (10%) SNL
Conesville	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	60	Percentage based on surficial geology; soils with low (10%) SNL
Council Bluffs	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on productive aquifers
Crawford	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Assigned based on predominant surficial geology (98% Floodplain and alluvium gravel terraces), productive aquifer coverage
Crist	10Bb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	100	Assigned based on predominant surficial geology (96% Floodplain and alluvium gravel terraces), coarse-grained soil (49% SNL)
Cross	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Setting based on aquifers, surficial geology, soils, Heath (1985)
Cumberland	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on surface geology; high (61%) SCL = overbank deposits
Dale	6E	Solution Limestone	12	Solution Limestone	20	Percentage based on surficial geology; setting from principal aquifers (carbonate)
Dale	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on surficial geology; soils have significant fines (SNL = 0.1%)
Dallman	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Based on soils, surficial geology, principal aquifer
Dan E Karn	7F	Glacial Lake Deposits	4	Sand and Gravel	100	Based on surficial geology, soils

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Dan River	6H	Triassic Basins	2	Bedded Sedimentary Rock	100	Based on surfucial geology, principal aquifers; Triassic basin
Danskammer	7D	Buried Valley	4	Sand and Gravel	100	Based on predominant Heath region, productive aquifers; little coarse-grained soils
Dave Johnston	4C	River Alluvium	7	River Valleys and Floodplains without Overbank Deposits	100	Based on aquifer and surficial geology coverages, Heath (1985)
Dickerson	8D	Regolith	1	Metamorphic and Igneous	100	Predominant setting
Dolet Hills	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Predominant shallow unconsolidated aquifer system
Duck Creek	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Assigned based on predominant surficial geology (100% Floodplain and alluvium gravel terraces), Heath Alluvial Valley Region
Dunkirk	7H	Beaches, Beach Ridges and Sand Dunes	11	Coastal Beaches	100	Based on location, surficial geology
E D Edwards	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	20	Percentage based on surficial geology (83% Floodplain and alluvium gravel terraces)
E D Edwards	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on surficial geology (83% Floodplain and alluvium gravel terraces)
E W Brown	6E	Solution Limestone	12	Solution Limestone	20	Percentage based on surficial geology (76% alluvium, 23% clay); soils have significant fine-grained (0% SNL)
E W Brown	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on surficial geology (76% alluvium, 23% clay); soils have significant fine-grained (0% SNL)
Eckert Station	7Bb	Outwash Over Bedded Sedimentary Rock	2	Bedded Sedimentary Rock	30	Percentage based on productive aquifer coverage, Heath regions

(continued)

Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Eckert Station	7Eb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	70	Percentage based on productive aquifer coverage, Heath regions
Edgewater	7Bc	Outwash Over Solution Limestone	12	Solution Limestone	100	Setting based on aquifer and surficial geology coverages
Elmer W Stout	7D	Buried Valley	4	Sand and Gravel	100	Glaciofluvial aquifer overlaid by alluvial deposits
F B Culley	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting; soils have significant fines (SCL+SLT = 94%)
Fayette Power Prj	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Setting based on aquifer and surficial geology coverages
Flint Creek	6Db	Alternating Sandstone, Limestone and Shale - Deep Regolith	2	Bedded Sedimentary Rock	100	Ozark plateau; Heath (1985) indicates dolomite, sandy dolomite, sandstone, with no indication of solutioning. Surficial geology (cherty red clay) noted as thick regolith in Aller et al. (1987)
Fort Martin	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on surficial geology; low SNL (< 1%) = overbank deposits
Frank E Ratts	7D	Buried Valley	4	Sand and Gravel	100	Glaciofluvial aquifer in alluvial valley region (99%)
G G Allen	8D	Regolith	1	Metamorphic and Igneous	100	Based on surficial geology
Gadsden	6Db	Alternating Sandstone, Limestone and Shale - Deep Regolith	2	Bedded Sedimentary Rock	30	Percentage assigned based on productive aquifer coverage
Gadsden	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage assigned based on productive aquifer coverage; soils have significant fines (SCL+SLT > 25%)
Gallatin	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on surface geology; high (56%) SCL = overbank deposits

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Gen J M Gavin	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on productive aquifers, surficial geology
Genoa	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Percentage based on SNL/SCL soils; setting based on surficial geology and productive aquifers
Genoa	6Fb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	50	Percentage based on SNL/SCL soils; setting based on surficial geology and productive aquifers
Gibson	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting; soils have significant fines (SCL+SLT = 99%)
Gorgas	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	30	Percentage based on surficial geology; alluvial setting with coarser soils (= no overbank deposits)
Gorgas	6Fb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	70	Percentage based on surficial geology; alluvial setting with coarser soils (= no overbank deposits)
Green River	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting (>85% alluvium); soils have significant fines (SNL = 0%)
Greene County	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	30	Percentage based on surficial geology; soils have significant fines (SCL+SLT > 90%)
Greene County	10Ba	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage based on surficial geology; soils have significant fines (SCL+SLT > 90%)
H B Robinson	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Setting based on aquifers, surficial geology, soils, Heath (1985); Heath region coverage incorrect (Coastal Plain, not Piedmont)

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Hammond	6Db	Alternating Sandstone, Limestone and Shale - Deep Regolith	2	Bedded Sedimentary Rock	100	Based on aquifers, surficial residuum (massive red clay)
Harllee Branch	8E	River Alluvium	6	River Valleys and Floodplains with Overbank Deposit	100	Assigned based on predominant surficial geology (99% floodplain and alluvium gravel terraces)
Harrison	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	20	Percentage based on surficial geology; thin soils inferred from surficial geology
Harrison	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on surficial geology; 0%SNL = overbank deposits
Hatfield's Ferry	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	40	Percentage based on surficial geology; thin regolith inferred from colluvium
Hatfield's Ferry	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	60	Percentage based on surficial geology; soils < 1% SNL
Hennepin	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	30	Percentage to capture uncertainty in soils, surficial geology, principal aquifer
Hennepin	7Bb	Outwash Over Bedded Sedimentary Rock	2	Bedded Sedimentary Rock	30	Percentage to capture uncertainty in soils, surficial geology, principal aquifer
Hennepin	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	40	Percentage to capture uncertainty in soils, surficial geology, principal aquifer
Heskett	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvium surficial geology(96%); mixed soils
Holcomb	5Gb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	100	Alluvial valley with very coarse soils
Homer City	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Setting based on aquifer coverages & Heath (1985); thin regolith inferred from colluvium

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Hoot Lake	9E	Outwash	8	Outwash	100	Based on productive aquifer, soils, surficial geology
Hugo	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	40	Percentage based on surficial geology; soil/regolith thickness inferred from Heath (1985)
Hugo	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	60	Percentage based on surficial geology; fine soils with about 10% SNL
Hunter	4B	Consolidated Sedimentary Rock	2	Bedded Sedimentary Rock	100	Setting based on aquifer and surficial geology coverages
Huntington	4B	Consolidated Sedimentary Rock	2	Bedded Sedimentary Rock	100	Setting based on aquifer and surficial geology coverages
Intermountain	2E	Playa Lakes	5	Alluvial Basins Valleys and Fans	100	Setting based on surficial geology coverage, Heath (1985)
J H Campbell	7F	Glacial Lake Deposits	4	Sand and Gravel	100	Based on surficial geology, soils
J M Stuart	6E	Solution Limestone	12	Solution Limestone	50	Percentage based on surficial geology; low (< 2%) SNL
J M Stuart	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Percentage based on surficial geology; low (< 2%) SNL
J R Whiting	7F	Glacial Lake Deposits	4	Sand and Gravel	100	Based on surficial geology
Jack McDonough	8C	Mountain Flanks	2	Bedded Sedimentary Rock	100	Assigned based on predominant surficial geology (94% stony colluvium on metamorphic rocks; less silt and clay than in colluvium over limestone)
Jack Watson	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Based on all coverages
James H Miller Jr	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	20	Percentage based on surficial geology; soils have significant fines (SCL+SLT > 25%)

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
James H Miller Jr	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on surficial geology; soils have significant fines (SCL+SLT > 25%)
Jim Bridger	4B	Consolidated Sedimentary Rock	2	Bedded Sedimentary Rock	100	Based on aquifer and surficial geology coverages, Heath (1985)
John E Amos	6da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	40	Percentage based on surficial geology; thin soils inferred from surficial geology
John E Amos	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	60	Percentage based on surficial geology; 0%SNL = overbank deposits
John Sevier	6E	Solution Limestone	12	Solution Limestone	50	Percentage based on surface geology; setting based on surface geology and aquifer type, with possibility of solution limestone from Heath (1985)
John Sevier	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Percentage, setting based on surface geology; low (<1%) SNL = overbank deposits
Johnsonville	6E	Solution Limestone	12	Solution Limestone	30	Percentage based on surface geology; setting based on aquifer coverages, Heath (1985); placed in Nonglaciated Central region based on aquifer coverages and Heath (1985)
Johnsonville	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage, setting based on surface geology; low (3%) SNL = overbank deposits; placed in Nonglaciated Central region based on aquifer coverages and Heath (1985)
Joliet 29	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Based on aquifers, soils; soils don't suggest outwash like surficial geology does
Keystone	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Setting based on aquifer coverages & Heath (1985); thin regolith inferred from colluvium
Killen Station	6E	Solution Limestone	12	Solution Limestone	30	Percentage based on surficial geology; low (< 2%) SNL

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Killen Station	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage based on surficial geology; low (< 2%) SNL
Kingston	6E	Solution Limestone	12	Solution Limestone	20	Percentage based on surface geology; setting based on surface geology and aquifer type, with possibility of solution limestone from Heath (1985)
Kingston	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage, setting based on surface geology; high (67 %) SCL = overbank deposits
Kraft	11A	Solution Limestone and Shallow Surficial Aquifers	12	Solution Limestone	100	Only possible assignment; predominant alluvium (84%) not well represented
L V Sutton	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	20	Percentage based on surficial geology; sandy soils
L V Sutton	10Bb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	80	Percentage based on surficial geology; sandy soils
Lansing	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	40	Percentage based on surficial geology, productive aquifers; loess = thin soils
Lansing	6Fb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	60	Percentage based on surficial geology, productive aquifers; coarse-grained soils
Laramie R Station	6Fb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	100	Based on aquifer and surficial geology coverages, Heath (1985)
Lawrence EC	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Alluvial valley with low coarse soils (<1% SNL)
Lee	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	30	Percentage based on surficial geology; sandy soils
Lee	10Bb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	70	Percentage based on surficial geology; sandy soils

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Leland Olds	7Eb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	50	Percentage based on surficial geology; assumed coarse soils
Leland Olds	7G	Thin Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	50	Percentage based on surficial geology; assumed coarse soils
Lon Wright	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	30	Alluvial based on predominant Heath, productive aquifer; percentage based on soil textures
Lon Wright	7Eb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	70	Alluvial based on predominant Heath, productive aquifer; percentage based on soil textures
Louisa	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Alluvial Valley; significant coarse-grained deposits
Louisa	7Eb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	50	Alluvial Valley; significant coarse-grained deposits
Marion	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Assigned to Glaciated Central region based on surficial geology (pre-Wisconsin drift)
Marshall	8D	Regolith	1	Metamorphic and Igneous	100	Based on surficial geology
Martin Lake	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Setting based on aquifer and surficial geology coverages
Mayo	8D	Regolith	1	Metamorphic and Igneous	100	Based on surficial geology
Meramec	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Based on surficial, predominant Heath
Merom	7D	Buried Valley	4	Sand and Gravel	100	Glaciofluvial aquifer overlaid by alluvial deposits
Miami Fort	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Assigned based on productive aquifers, surficial geology and soil (3% SNL)

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Milton R Young	7G	Thin Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Based on principal aquifer and surficial geology coverages
Mitchell	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	60	Percentage based on surficial geology; thin regolith inferred from colluvium
Mitchell	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	40	Percentage based on surficial geology; soils 0 % SNL
Mitchell	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on surficial geology; low SNL (< 1%) = overbank deposits
Mohave	2Ha	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on predominant surficial geology, Heath (1985)
Monroe	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Based on Heath region, productive aquifers, soils
Morgantown	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Assigned based on location and aquifer and surficial geology coverages; Heath region incorrect (it's Atlantic Coastal Plain, not Piedmont)
Mountaineer (1301)	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Setting based on surficial geology; low SNL (10%) = overbank deposits
Mt Storm	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Setting based on surficial geology, aquifer coverages; thin soils inferred from surficial geology
Muscatine Plant #1	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Alluvial Valley; significant coarse-grained deposits
Muscatine Plant #1	7Eb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	50	Alluvial Valley; significant coarse-grained deposits
Muskogee	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Surficial geology indicates alluvium/colluvium; Heath (1985) indicates fine soils over sands and gravels

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Neal North	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Alluvial Valley setting
Neal South	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Alluvial Valley setting
Nebraska City	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Alluvial based on predominant Heath, productive aquifer, soil textures
New Castle	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	20	Percentage and setting based on Heath region & surficial geology; thin regolith inferred from colluvium
New Castle	7D	Buried Valley	4	Sand and Gravel	80	Percentage and setting based on Heath region & book
Newton	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Based on soils, surficial geology, aquifer coverages
North Omaha	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Alluvial based on predominant Heath, productive aquifer; soil texture (28% SCL, 10% SNL) = overbank deposits
Northeastern	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	40	Percentage based on surficial geology, which indicates thin residual soils
Northeastern	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	60	Percentage based on surficial geology; soils < 2% SNL
Nucla	4B	Consolidated Sedimentary Rock	2	Bedded Sedimentary Rock	100	Based on surficial geology, aquifer coverages
Oklaunion	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Setting based on surficial geology; thin soil inferred
Paradise	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting (93% alluvium); soils have significant fines (SNL = 0%)
Petersburg	7D	Buried Valley	4	Sand and Gravel	100	Glaciofluvial aquifer in alluvial valley region (similar to 1043)

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Pleasant Prairie	7Ac	Glacial Till Over Solution Limestone	12	Solution Limestone	100	Setting based on aquifer and soil coverages (high SCL soils)
Port Washington	7Ac	Glacial Till Over Solution Limestone	12	Solution Limestone	100	Setting based on aquifer and soil coverages (high SCL soils)
Portland	7Ac	Glacial Till Over Solution Limestone	12	Solution Limestone	100	Setting based on aquifer and surficial geology coverage
Possum Point	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Based on productive aquifer coverage; Heath region incorrect
Potomac River	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	50	Percentage based on surficial geology coverage; Heath region incorrect
Potomac River	10Bb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	50	Percentage based on surficial geology coverage; sandy soils (51% SNL) = no overbank deposits; Heath region incorrect
Presque Isle	9F	Moraine	4	Sand and Gravel	100	Based on surficial geology, Heath region, soils
R Gallagher	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting; soils have significant fines (SCL+SLT = 99%)
R M Schahfer	7D	Buried Valley	4	Sand and Gravel	100	Glaciofluvial aquifer in alluvial valley region
Reid Gardner	2C	Alluvial Fans	5	Alluvial Basins Valleys and Fans	100	Based on surficial geology; consistent with productive aquifers
Richard Gorsuch	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Assigned based on productive aquifers, surficial geology and soil (3% SNL)
Riverbend	8D	Regolith	1	Metamorphic and Igneous	100	Based on surficial geology
Rodemacher	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	50	Setting percentage determined from Heath, productive aquifer, and surficial geology coverages

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Rodemacher	10Ba	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Setting percentage determined from Heath, productive aquifer, and surficial geology coverages
Roxboro	8D	Regolith	1	Metamorphic and Igneous	100	Based on surficial geology, productive aquifers
Sandow	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Setting based on aquifer and surficial geology coverages; Heath region coverage is incorrect (based on Heath [1985] and aquifer coverages)
Scherer	8D	Regolith	1	Metamorphic and Igneous	100	Most common Piedmont setting (residuum)
Shawnee	10Bb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	100	Predominant alluvial setting (100% alluvium); soils have low fines (SCL = 9%)
Shawville	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Setting based on aquifer coverages & Heath (1985); thin regolith inferred from colluvium
Sheldon	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	30	Percentage based on productive aquifer coverage; buried valley indicated by Heath (1985)
Sheldon	7D	Buried Valley	4	Sand and Gravel	70	Percentage based on productive aquifer coverage; buried valley indicated by Heath (1985)
South Oak Creek	7Ac	Glacial Till Over Solution Limestone	12	Solution Limestone	100	Setting based on aquifer and soil coverages (high SCL soils)
Springerville	4B	Consolidated Sedimentary Rock	2	Bedded Sedimentary Rock	100	Assigned based on productive aquifers (consolidated sandstone)
St Johns River Power	11B	Coastal Deposits	4	Sand and Gravel	100	Based on sea island surficial geology
Stanton Energy Ctr	11A	Solution Limestone and Shallow Surficial Aquifers	12	Solution Limestone	100	Based on both aquifer coverages

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Stockton Cogen Company	2C	Alluvial Fans	5	Alluvial Basins Valleys and Fans	50	Percentage based on surficial geology; Central Valley soils show significant fines
Stockton Cogen Company	2Ha	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	50	Percentage based on surficial geology; Central Valley soils show significant fines
Syl Laskin	9E	Outwash	8	Outwash	60	Percentage based on surficial geology
Syl Laskin	9Ga	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	40	Percentage based on surficial geology
Tecumseh EC	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Alluvial valley with low coarse soils (<3% SNL)
Texas-New Mexico	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	100	Based on productive aquifers, Heath (1985) (Heath region coverage is incorrect)
Titus	6Db	Alternating Sandstone, Limestone and Shale - Deep Regolith	2	Bedded Sedimentary Rock	100	Setting based on aquifer and surficial geology coverage; deep regolith inferred from red, massive clay
Trimble County	6E	Solution Limestone	12	Solution Limestone	40	Heath incorrect; Percentage based on surficial geology (56% alluvium, 44% clay); soils have significant fine-grained (1% SNL)
Trimble County	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	60	Heath incorrect; Percentage based on surficial geology (56% alluvium, 44% clay); soils have significant fine-grained (1% SNL)
Tyrone	6E	Solution Limestone	12	Solution Limestone	100	Based on principal aquifer coverage
Valley	7Ac	Glacial Till Over Solution Limestone	12	Solution Limestone	100	Setting based on aquifer and soil coverages (high SCL soils)
Vermilion	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	100	Based on aquifers, soils; soils don't suggest outwash like surficial geology does
Victor J Daniel Jr	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	60	Percentage based on surficial geology

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Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Victor J Daniel Jr	10Ba	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	40	Percentage based on surficial geology, soils
W A Parish	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	30	Percentage based on surficial geology and productive aquifer coverages
W A Parish	10Ba	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage based on surficial geology and productive aquifer coverages; high SCL (96%) = overbank deposits
W H Weatherspoon	10Ab	Unconsolidated and Semi-Consolidated Shallow Surficial Aquifer	10	Unconsolidated and Semiconsolidated Shallow Aquifers	30	Percentage based on surficial geology; sandy soils
W H Weatherspoon	10Bb	River Alluvium Without Overbank Deposits	7	River Valleys and Floodplains without Overbank Deposits	70	Percentage based on surficial geology; sandy soils
W S Lee	8D	Regolith	1	Metamorphic and Igneous	100	Setting based on aquifers, surficial geology, soils, Heath (1985)
Wabash River	7D	Buried Valley	4	Sand and Gravel	100	Glaciofluvial aquifer in Alluvial Valley region
Walter C Beckjord	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	60	Percentage based on surficial geology; placed in glaciated central based on Heath (1985); soils 2% SNL
Walter C Beckjord	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	40	Percentage based on surficial geology; placed in glaciated central based on Heath (1985); soils 2% SNL
Wansley	8C	Mountain Flanks	2	Bedded Sedimentary Rock	30	Percentage based on surficial geology
Wansley	8E	River Alluvium	6	River Valleys and Floodplains with Overbank Deposit	70	Percentage based on surficial geology
Warrick	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	100	Predominant alluvial setting; soils have significant fines (SCL+SLT = 94%)
Waukegan	7Bc	Outwash Over Solution Limestone	12	Solution Limestone	100	Based on soils, surficial geology, aquifer coverages

(continued)

Hydrogeologic Environment (continued)

Plant	Hydrogeologic Setting		Hydrogeologic Environment		Percentage	Comment
	Code	Description	Code	Description		
Weston	9E	Outwash	8	Outwash	100	Setting based on productive aquifer, surficial geology coverages
Widows Creek	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	20	Percentage based on surficial geology; thin soils inferred from colluvium
Widows Creek	6Fa	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	80	Percentage based on surficial geology; soils have significant fines (SCL+SLT > 25%)
Will County	7Aa	Glacial Till Over Bedded Sedimentary Rock	3	Till Over Sedimentary Rock	40	Percentage based on surficial geology (65% Floodplain and alluvium gravel terraces)
Will County	7Ea	River Alluvium With Overbank Deposits	6	River Valleys and Floodplains with Overbank Deposit	60	Percentage based on surficial geology (65% Floodplain and alluvium gravel terraces)
Wyodak	6Da	Alternating Sandstone, Limestone and Shale - Thin Soil	2	Bedded Sedimentary Rock	100	Based on aquifer and surficial geology coverages, Heath (1985)
Yates	8D	Regolith	1	Metamorphic and Igneous	40	Percentage assigned based on surficial geology (59% alluvium/colluvium, 42% residuum)
Yates	8E	River Alluvium	6	River Valleys and Floodplains with Overbank Deposit	60	Percentage assigned based on surficial geology (59% alluvium/colluvium, 42% residuum)

SCL = silty clay loam; SNL = sandy loam; SLT = silt loam.

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Heath, R.C. 1985. *National Water Summary 1984*. *State Summaries of Groundwater Resources*. Water-Supply Paper 2275. U.S. Geological Survey, Washington, DC.

Attachment C-3: Climate Center Assignments

Plant	Climate Center	Explanation If Not Closest Climate Center
A B Brown	Indianapolis, IN	Closest Met Station (Nashville) receives much more precipitation (12.26" out of range) than the site location. Used second closest because only slightly below (1.3) expected precipitation range for plant.
A/C Power- Ace Operations	Las Vegas, NV	
Allen	Little Rock, AR	
Alma	Madison, WI	Closest Met Station (St. Cloud) receives less rain than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Antelope Valley	Bismarck, ND	
Arkwright	Watkinsville, GA	Closest Met Station (Atlanta) receives 6.96" more precipitation than plant location. Used second closest Met Station because 5-year averages are only slightly above (0.2) expected precipitation range for the plant.
Asheville	Knoxville, TN	
Baldwin	East St. Louis, IL	
Barry	Tallahassee, FL	Closest Met Station (New Orleans) receives much more precipitation (5.06" out of range) than the site location. Used second closest because only slightly above (3.4) expected precipitation range for plant.
Bay Front	Madison, WI	
Bay Shore	Put-in-Bay, OH	
Belews Creek	Greensboro, NC	
Ben French	Rapid City, SD	
Big Cajun 2	Lake Charles, LA	Closest Met Station (New Orleans) receives much more precipitation (5.06" out of range) than the site location. Used second closest because only slightly below (2.77) expected precipitation range for plant.
Big Sandy	Cincinnati, OH	Closest Met Station (Lexington) receives much more precipitation (8.35" out of range) than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Big Stone	St. Cloud, MN	

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
Black Dog Steam Plant	Madison, WI	Closest Met Station (St Cloud) is dryer (<27.5") than the 28-33" that the site receives. Madison fits in precipitation range (32.5") and is second closest.
Blue Valley	Topeka, KS	
Bowen	Atlanta, GA	
Brandon Shores	Seabrook, NJ	
Buck	Greensboro, NC	
Bull Run	Knoxville, TN	
C D McIntosh Jr	Orlando, FL	Closest Met Station (Tampa) receives less precipitation (5.31" out of range) than site location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
C P Crane	Seabrook, NJ	
Cape Fear	Greensboro, NC	
Carbon	Salt Lake City, UT	
Cardinal	Pittsburgh, PA	
Cayuga	Indianapolis, IN	
Chalk Point	Seabrook, NJ	
Cholla	Phoenix, AZ	Closest Met Station (Flagstaff) receives much more precipitation (13.92" out of range) than plant location. Used second closest Met Station because 5-year averages were close (.31 higher) than the expected precipitation range for the plant.
Cliffside	Greensboro, NC	
Clover	Lynchburg, VA	
Coal Creek	Bismarck, ND	
Coleto Creek	San Antonio, TX	
Colstrip	Glasgow, MT	
Conemaugh	Pittsburgh, PA	
Conesville	Columbus, OH	
Council Bluffs	North Omaha, NE	
Crawford	East St. Louis, IL	
Crist	Tallahassee, FL	

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
Cross	Charleston, SC	
Cumberland	Nashville, TN	
Dale	Lexington, KY	
Dallman	East St. Louis, IL	
Dan E Karn	East Lansing, MI	
Dan River	Greensboro, NC	
Danskammer	Bridgeport, CT	
Dave Johnston	Cheyenne, WY	
Dickerson	Seabrook, NJ	
Dolet Hills	Shreveport, LA	
Duck Creek	East St. Louis, IL	
Dunkirk	Ithaca, NY	
E D Edwards	Chicago, IL	
E W Brown	Lexington, KY	
Eckert Station	East Lansing, MI	
Edgewater	Madison, WI	
Elmer W Stout	Indianapolis, IN	
F B Culley	Indianapolis, IN	Closest Met Station (Nashville) receives much more precipitation (12.26" out of range) than plant location. Used second closest Met Station because 5-year & 30-year averages fell within expected precipitation range for the plant.
Fayette Power Prj	San Antonio, TX	
Flint Creek	Columbia, MO	Used http://www.weather.com and Envirofacts to determine that avg. precipitation for site was ~47". The closest Met Station (Tulsa) receives much less (~17") precipitation per year. Used second closest station.
Fort Martin	Pittsburgh, PA	
Frank E Ratts	Indianapolis, IN	
G G Allen	Greensboro, NC	
Gadsden	Atlanta, GA	

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
Gallatin	Nashville, TN	
Gen J M Gavin	Cincinnati, OH	Closest Met Station (Columbus) receives less rain than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant. Also average precipitation for the second closest Met Station was nearest to http://www.weather.com
Genoa	Madison, WI	
Gibson	Indianapolis, IN	
Gorgas	Atlanta, GA	
Green River	Indianapolis, IN	Closest Met Station (Nashville) receives much more precipitation (12.26" out of range) than plant location. Used third closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Greene County	Atlanta, GA	
H B Robinson	Charleston, SC	
Hammond	Atlanta, GA	
Harllee Branch	Watkinsville, GA	
Harrison	Pittsburgh, PA	
Hatfield's Ferry	Pittsburgh, PA	
Hennepin	Chicago, IL	
Heskett	Bismarck, ND	
Holcomb	Dodge City, KS	
Homer City	Pittsburgh, PA	
Hoot Lake	St. Cloud, MN	
Hugo	Shreveport, LA	Closest Met Station (Dallas) receives less precipitation (6.45" out of range) than plant location. Used second closest because only slightly above (2.07) expected precipitation range for plant.
Hunter	Grand Junction, CO	Closest Met Station (Salt Lake City) receives 8.6" more precipitation than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Huntington	Cedar City, UT	Two closest Met Stations are out of range. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Intermountain	Ely, NV	Closest Met Station (Salt Lake City) receives 6.1" more precipitation than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
J H Campbell	East Lansing, MI	

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
J M Stuart	Cincinnati, OH	
J R Whiting	Put-in-Bay, OH	
Jack McDonough	Atlanta, GA	
Jack Watson	Tallahassee, FL	Closest Met Station (New Orleans) receives much more precipitation (5.06" out of range) than the site location. http://www.weather.com predicted average precipitation at plant location to be 65.2. Used third closest because its average was closest.
James H Miller Jr	Atlanta, GA	
Jim Bridger	Lander, WY	
John E Amos	Cincinnati, OH	The two closest Met Stations are out of the site's precipitation range. Used third closest Met Station because 5-year averages fell within expected precipitation range for the plant. Also average precipitation for the second closest Met Station was nearest to http://www.weather.com average.
John Sevier	Knoxville, TN	
Johnsonville	Nashville, TN	
Joliet 29	Chicago, IL	
Keystone	Pittsburgh, PA	
Killen Station	Cincinnati, OH	
Kingston	Knoxville, TN	
Kraft	Charleston, SC	
L V Sutton	Charleston, SC	
Lansing	Madison, WI	
Laramie R Station	Cheyenne, WY	
Lawrence EC	Topeka, KS	
Lee	Greensboro, NC	
Leland Olds	Bismarck, ND	
Lon Wright	North Omaha, NE	
Louisa	Des Moines, IA	
Marion	East St. Louis, IL	
Marshall	Greensboro, NC	

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
Martin Lake	Shreveport, LA	
Mayo	Lynchburg, VA	
Meramec	East St. Louis, IL	
Merom	Indianapolis, IN	
Miami Fort	Cincinnati, OH	
Milton R Young	Bismarck, ND	
Mitchell - PA	Pittsburgh, PA	
Mitchell - WV	Pittsburgh, PA	
Mohave	Las Vegas, NV	
Monroe	Put-in-Bay, OH	
Morgantown	Norfolk, VA	
Mountaineer (1301)	Cincinnati, OH	Closest Met Station (Columbus) receives more rain than plant location. Although second closest site also falls within range, used third closest Met Station because site geography was similar and the station's 5-year averages fell within expected precipitation range for the plant.
Mt Storm	Pittsburgh, PA	
Muscatine Plant #1	Des Moines, IA	
Muskogee	Tulsa, OK	
Neal North	North Omaha, NE	
Neal South	North Omaha, NE	
Nebraska City	North Omaha, NE	
New Castle	Pittsburgh, PA	
Newton	Indianapolis, IN	Closest Met Station (East St. Louis) receives less rain than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant. Also average precipitation for the second closest Met Station was nearest to http://www.weather.com
North Omaha	North Omaha, NE	
Northeastern	Tulsa, OK	
Nucla	Grand Junction, CO	

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
Oklaunion	Oklahoma City, OK	
Paradise	Cincinnati, OH	Closest Met Station (Nashville) receives much more precipitation (12.26" out of range) than plant location. Used third closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Petersburg	Indianapolis, IN	
Pleasant Prairie	Chicago, IL	
Port Washington	Madison, WI	
Portland	Philadelphia, PA	
Possum Point	Norfolk, VA	
Potomac River	Seabrook, NJ	
Presque Isle	Sault Ste. Marie, MI	
R Gallagher	Cincinnati, OH	Closest Met Station (Lexington) receives much more precipitation (8.35" out of range) than plant location. Used second closest Met Station because 5-year & 30-year averages fell within expected precipitation range for the plant.
R M Schahfer	Chicago, IL	
Reid Gardner	Las Vegas, NV	
Richard Gorsuch	Columbus, OH	
Riverbend	Greensboro, NC	
Rodemacher	Lake Charles, LA	
Roxboro	Greensboro, NC	
Sandow	San Antonio, TX	
Scherer	Watkinsville, GA	Closest Met Station (Atlanta) receives 6.96" more precipitation than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Shawnee	East St. Louis, IL	
Shawville	Pittsburgh, PA	
Sheldon	North Omaha, NE	

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
South Oak Creek	Chicago, IL	
Springerville	Albuquerque, NM	Closest Met Station (Flagstaff) receives much more precipitation (8.92" out of range) than plant location. Used second closest Met Station because 5-year averages were within the expected precipitation range for the plant.
St Johns River Power	Jacksonville, FL	
Stanton Energy Ctr	Orlando, FL	
Stockton Cogen Company	Sacramento, CA	
Syl Laskin	St. Cloud, MN	
Tecumseh EC	Topeka, KS	
Texas-New Mexico	San Antonio, TX	Closest Met Station (Dallas) received less precipitation than site location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant. Also average precipitation for the second closest Met Station was nearest to http://www.weather.com
Titus	Philadelphia, PA	
Trimble County	Cincinnati, OH	
Tyrone	Lexington, KY	
Valley	Madison, WI	
Vermilion	Chicago, IL	Closest Met Station (Indianapolis) receives more precipitation than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.
Victor J Daniel Jr	Tallahassee, FL	Closest Met Station (New Orleans) receives much more precipitation (5.06" out of range) than the site location. Used second closest because only slightly above (3.4) expected precipitation range for plant.
W A Parish	Shreveport, LA	2 Closest Met Stations (Lake Charles & San Antonio) are more than 4" out of range. Used third closest because only slightly above (1.65") expected precipitation range for plant.
W H Weatherspoon	Greensboro, NC	
W S Lee	Watkinsville, GA	
Wabash River	Indianapolis, IN	
Walter C Beckjord	Cincinnati, OH	
Wansley	Atlanta, GA	
Warrick	Indianapolis, IN	Closest Met Station (Nashville) receives 12.2" more precipitation than plant location. Used second closest Met Station because 5-year averages fell within expected precipitation range for the plant.

(continued)

Climate Center Assignments (continued)

Plant	Climate Center	Explanation If Not Closest Climate Center
Waukegan	Chicago, IL	
Weston	Madison, WI	
Widows Creek	Nashville, TN	
Will County	East St. Louis, IL	
Wyodak	Rapid City, SD	
Yates	Atlanta, GA	

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Attachment C-4: Waterbody Assignments and Flow

Plant	CUSEG	Nearest Reach	Reach Type	QLOW	QMEAN
A B Brown	05140202014	OHIO R	Regular Reach	9167.38965	150031.6875
A/C Power- Ace Operations	18090205005	SEARLES L	Lake Shoreline		
Allen	08010211007	HORN LAKE CUTOFF	Lake Shoreline		
Alma	07040003009	MISSISSIPPI R	Regular Reach	5683.02002	25397.4707
Antelope Valley	10130201005	ANTELOPE CR	Start Reach	0	96.87
Arkwright	03070103007	OCMULGEE R	Regular Reach	428.79999	2708.53003
Asheville	06010105026	FRENCH BROAD R	Regular Reach	412.04999	1722.34998
Baldwin	07140204004	KASKASKIA R	Regular Reach	351.72	3832.12012
Barry	03160204014	MOBILE R	Regular Reach	7561.14014	63275.23828
Bay Front	07070005036	L SUPERIOR	Great Lakes Shoreline		
Bay Shore	04100010003	L ERIE, U.S. SHORE	Great Lakes Shoreline	0	0
Belews Creek	03010103098	BELEWS L	Lake Shoreline		
Ben French	10120110010	CASTLE CR	Start Reach	2.96	18.62
Big Cajun 2	08070100005	MISSISSIPPI R	Regular Reach	100937.8125	466865.5625
Big Sandy	05070204008	BIG SANDY R	Regular Reach	152.02	5746.95996
Big Stone	07020001033	BIG STONE LAKE	Lake Shoreline		
Black Dog Steam Plant	07020012001	BLACK DOG LAKE	Lake Shoreline		
Blue Valley	10300101034	LITTLE BLUE R	Regular Reach	23.2	141.75
Bowen	03150104008	ETOWAH R	Regular Reach	413.13	2294.86011
Brandon Shores	02060003037	CURTIS BAY	Coastal Shoreline	0	0
Buck	03040103040	YADKIN R	Regular Reach	912.72998	4722.54004
Bull Run	06010207015	CLINCH R	Regular Reach	102.46	4732.3501
C D McIntosh Jr	03100205014	NO LAKE PARKER	Lake Shoreline		

(continued)

Waterbody Assignments and Flow (continued)

Plant	CUSEG	Nearest Reach	Reach Type	QLOW	QMEAN
C P Crane	02060003025	CURTIS BAY	Coastal Shoreline	0	0
Cape Fear	03030002001	HAW R	Regular Reach	58.98	1584.83997
Carbon	14060007018	PRICE R	Regular Reach	1.92	77
Cardinal	05030106033	OHIO R	Regular Reach	3391.62012	37533.17188
Cayuga	05120108001	WABASH R	Regular Reach	965.09003	10100.21973
Chalk Point	02060006009	PATUXENT R	Wide-River Shoreline	0	0
Cholla	15020008017	CHOLLA COOLING POND	Lake Shoreline		
Cliffside	03050105031	BROAD R	Regular Reach	332.17001	1510.08997
Clover	03010102027	ROANOKE R	Regular Reach	408.64001	2702.59009
Coal Creek	10130101018	UNKNOWN LAKE	Lake Shoreline		
Coleto Creek	12100303014	MARCELINAS CR	Start Reach	1.11	3.79
Colstrip	10100001108	ARMELLS CR, E FK	Start Reach	0	18.64
Conemaugh	05010007002	CONEMAUGH R	Regular Reach	194.53999	1553.52002
Conesville	05040004071	MUSKINGUM R	Regular Reach	447.98001	4707.08008
Council Bluffs	10230006004	MISSOURI R	Regular Reach	4402.58984	31444.83008
Crawford	07130011018	ILLINOIS R	Regular Reach	3444.66992	20788.71094
Crist	03140305001	ESCAMBIA R	Terminal Reach	845.46002	6772.5498
Cross	03050201022	DIVERS CANAL TO LAKE MOU	Lake Shoreline		
Cumberland	05130205017	CUMBERLAND R	Regular Reach	536.47998	25322.66016
Dale	05100205047	KENTUCKY R	Regular Reach	35.32	5213.06982
Dallman	07130007003	LAKE SPRINGFIELD	Lake Shoreline		
Dan E Karn	04080103005	L HURON U.S. SH SAGINAW BAY	Great Lakes Shoreline	0	0
Dan River	03010103014	DAN R	Regular Reach	358.12	1954.15002
Danskammer	02020008022	HUDSON R	Wide-River Shoreline	0	0
Dave Johnston	10180007005	N PLATTE R	Regular Reach	65.24	502.87
Dickerson	02070008013	POTOMAC R	Regular Reach	895.57001	10528.36035
Dolet Hills	11140206019	BAYOU PIERRE LAKE	Lake Shoreline		

(continued)

Waterbody Assignments and Flow (continued)

Plant	CUSEG	Nearest Reach	Reach Type	QLOW	QMEAN
Duck Creek	07130003010	L CHAUTAUQUA	Lake Shoreline		
Dunkirk	04120101003	L ERIE, U.S. SHORE	Great Lakes Shoreline	0	0
E D Edwards	07130003018	ILLINOIS R	Regular Reach	2998.32007	13899.62988
E W Brown	05100205015	HERRINGTON LAKE	Lake Shoreline		
Eckert Station	04050004003	GRAND R	Regular Reach	73.47	484.28
Edgewater	04030101002	L MICHIGAN	Great Lakes Shoreline	0	0
Elmer W Stout	05120201005	WHITE R	Regular Reach	70.17	1429.92004
F B Culley	05140201001	OHIO R	Regular Reach	8728.7002	131543.0625
Fayette Power Prj	12090301003	CEDAR CREEK RESERVOIR	Lake Shoreline		
Flint Creek	11110103031	SWEPCO RSRVR,LT FLINT CK	Lake Shoreline		
Fort Martin	05020003001	MONONGAHELA R	Regular Reach	293.66	4497.75
Frank E Ratts	05120202003	WHITE R	Regular Reach	343.59	11525.13965
G G Allen	03050101009	CATAWBA R	Regular Reach	462.92001	2958.09009
Gadsden	03150106041	COOSA R	Regular Reach	1096.10999	9468
Gallatin	05130201006	OLD HICKORY L	Lake Shoreline		
Gen J M Gavin	05030202005	OHIO R	Regular Reach	4258.12012	55143.35938
Genoa	07060001017	MISSISSIPPI R	Regular Reach	6434.18018	29379.25
Gibson	05120113013	WABASH R	Regular Reach	2247.6001	26799.73047
Gorgas	03160109002	BLACK WARRIOR R, MULBERRY F	Lake Shoreline		
Green River	05110003001	GREEN R	Regular Reach	320.06	9752
Greene County	03160113011	BLACK WARRIOR R	Regular Reach	304.73001	9820.04004
H B Robinson	03040201042	L ROBERTSON	Lake Shoreline		
Hammond	03150105025	COOSA R	Regular Reach	1196.82996	6569.95996
Harllee Branch	03070101006	L SINCLAIR	Lake Shoreline		
Harrison	05020002008	WEST FORK R	Regular Reach	33.03	1038.32996
Hatfield's Ferry	05020005026	MONONGAHELA R	Regular Reach	479.79999	8278.94043
Hennepin	07130001026	ILLINOIS R	Regular Reach	3233.23999	13146.83984
Heskett	10130101001	MISSOURI R	Regular Reach	3461.55005	22744.26953

(continued)

Waterbody Assignments and Flow (continued)

Plant	CUSEG	Nearest Reach	Reach Type	QLOW	QMEAN
Holcomb	11030001001	ARKANSAS R	Regular Reach	0	197.92999
Homer City	05010007015	TWO LICK CR	Regular Reach	4.53	295.22
Hoot Lake	09020103002	OTTER TAIL R	Regular Reach	12.45	271.35999
Hugo	11140105041	KIAMICHI CR, N FK	Start Reach	2.55	53.16
Hunter	14060009034	ROCK CANYON CR	Start Reach	0	0.1
Huntington	14060009020	HUNTINGTON CR	Regular Reach	10.75	91.1
Intermountain		none		0	0
J H Campbell	04050002001	L MICHIGAN	Great Lakes Shoreline	0	0
J M Stuart	05090201024	OHIO R	Regular Reach	6767.47021	92214.6875
J R Whiting	04100001002	L ERIE, U.S. SHORE	Great Lakes Shoreline	0	0
Jack McDonough	03130002044	CHATTAHOOCHEE R	Regular Reach	726.45001	2952.18994
Jack Watson	03170009034	BILOXI BAY	Coastal Shoreline	0	0
James H Miller Jr	03160111005	BLACK WARRIOR R, LOCUST FK	Lake Shoreline		
Jim Bridger	14040105011	UNKNOWN LAKE	Lake Shoreline		
John E Amos	05050008007	KANAWHA R	Regular Reach	1390.22998	14930.83984
John Sevier	06010104011	HOLSTON R	Regular Reach	633	4079.15991
Johnsonville	06040005007	KENTUCKY L	Lake Shoreline		
Joliet 29	07120004004	DES PLAINS R	Regular Reach	1029.93005	3809.69995
Keystone	05010006002	CROOKED CR	Regular Reach	30.72	422.14999
Killen Station	05090201024	OHIO R	Regular Reach	6767.47021	92214.6875
Kingston	06010207001	CLINCH R	Regular Reach	266.35999	7347.89014
Kraft	03060109007	SAVANNAH R	Regular Reach	3570.52002	12365
L V Sutton	03030005011	CAPE FEAR R	Regular Reach	619.95001	8594.57031
Lansing	07060001009	MISSISSIPPI R	Regular Reach	7684.02002	32253.15039
Laramie R Station	10180011002	LARAMIE R	Regular Reach	28.53	90.8
Lawrence EC	10270104021	KANSAS R	Regular Reach	403.81	6720.29004
Lee	03020201007	NEUSE R	Regular Reach	76.18	1657.39001
Leland Olds	10130101020	MISSOURI R	Regular Reach	4270.4502	21650.67969

(continued)

Waterbody Assignments and Flow (continued)

Plant	CUSEG	Nearest Reach	Reach Type	QLOW	QMEAN
Lon Wright	10220003048	RAWHIDE CR	Start Reach	0.94	11.59
Louisa	07080101003	MISSISSIPPI R	Regular Reach	15067.92969	54665.96094
Marion	05140204030	L OF EGYPT	Lake Shoreline		
Marshall	03050101015	L NORMAN	Lake Shoreline		
Martin Lake	12010002050	MARTIN LAKE	Lake Shoreline		
Mayo	03010104045	MAYO CR	Start Reach	5.99	61.03
Meramec	07140101014	MISSISSIPPI R	Regular Reach	33305	177021.1875
Merom	05120111011	TURTLE CR RESERVOIR	Lake Shoreline		
Miami Fort	05090203012	OHIO R	Regular Reach	6516.18994	98615.0625
Milton R Young	10130101024	NELSON LAKE AND MISSOURI RIVER	Lake Shoreline		
Mitchell - PA	05020005002	MONONGAHELA R	Regular Reach	848.58002	9284.13965
Mitchell - WV	05030106013	OHIO R	Regular Reach	3419.20996	38713.19922
Mohave	15030101011	COLORADO R	Regular Reach	1916.72998	12134.36035
Monroe	04100001002	L ERIE, U.S. SHORE	Great Lakes Shoreline	0	0
Morgantown	02070011051	POTOMAC R	Wide-River Shoreline	0	0
Mountaineer (1301)	05030202008	OHIO R	Regular Reach	4242.58984	54823.21094
Mt Storm	02070002027	STONY R RES	Lake Shoreline		
Muscatine Plant #1	07080101005	MISSISSIPPI R	Regular Reach	14573.71973	54469.48047
Muskogee	11110102012	ARKANSAS R	Regular Reach	227.57001	21258.39062
Neal North	10230001021	MISSOURI R	Regular Reach	4217.7998	29486.82031
Neal South	10230001021	MISSOURI R	Regular Reach	4217.7998	29486.82031
Nebraska City	10240001002	MISSOURI R	Regular Reach	5807.77002	36764.01172
New Castle	05030104002	BEAVER R	Regular Reach	268.48001	2425.32007
Newton	05120114006	NEWTON LAKE	Lake Shoreline		
North Omaha	10230006009	MISSOURI R	Regular Reach	4365.6499	31400.93945
Northeastern	11070105012	VERDIGRIS R	Regular Reach	3.85	2168.47998
Nucla	14030003012	SAN MIGUEL R	Regular Reach	8.1	307.64001
Oklaunion	11130302061	BOGGY CR	Start Reach	0.09	14.93

(continued)

Waterbody Assignments and Flow (continued)

Plant	CUSEG	Nearest Reach	Reach Type	QLOW	QMEAN
Paradise	05110003003	GREEN R	Regular Reach	316.59	9663.71973
Petersburg	05120202003	WHITE R	Regular Reach	343.59	11525.13965
Pleasant Prairie	07120004012	L MICHIGAN AND J	Lake Shoreline		
Port Washington	04030101002	L MICHIGAN	Great Lakes Shoreline	0	0
Portland	02040105012	DELAWARE R	Regular Reach	1995.12	9089.00977
Possum Point	02070011074	POTOMAC R	Wide-River Shoreline	0	0
Potomac River	02070010025	POTOMAC R	Artificial Open Water Reach	919.89001	11721.87988
Presque Isle	04020105002	L SUPERIOR, U.S. SHORE	Great Lakes Shoreline	0	0
R Gallagher	05140101001	OHIO R	Regular Reach	7634.39014	119152.1875
R M Schahfer	07120001012	KANAKEE R	Regular Reach	458.92001	1410.56006
Reid Gardner	15010012006	MUDDY R	Regular Reach	0.68	19.22
Richard Gorsuch	05030202039	OHIO R	Regular Reach	4079.81006	48956.14062
Riverbend	03050101012	CATAWBA R	Regular Reach	412.28	2623.09009
Rodemacher	11140207020	RODEMACHER LAKE	Lake Shoreline		
Roxboro	03010104034	HYCO L	Lake Shoreline		
Sandow	12070102012	ALCOA LAKE	Lake Shoreline		
Scherer	03070103012	OCMULGEE R	Start Reach	655.48999	2490.72998
Shawnee	05140206009	OHIO R	Regular Reach	21748.59961	288452.1875
Shawville	02050201002	SUSQUEHANNA R, W BR	Regular Reach	96.9	1947.33997
Sheldon	10240008030	UNKNOWN LAKE	Lake Shoreline		
South Oak Creek	04040002004	L MICHIGAN	Great Lakes Shoreline	0	0
Springerville	15020002025	*A	Start Reach	0	2.49
St Johns River Power	03080103003	ST JOHNS R	Wide-River Shoreline	0	0
Stanton Energy Ctr	03080101036	ECOHLOCKHATCHEE R	Start Reach	5.95	131.42999
Stockton Cogen Company	18040002005	LITTLEJOHNS CR	Start Reach	0.21	50.61
Syl Laskin	04010201034	COLBY L AND PARTRIDGE R	Lake Shoreline		
Tecumseh EC	10270102003	KANSAS R	Regular Reach	388.51999	5923.74023
Texas-New Mexico	12070101008	LITTLE BRAZOS R	Start Reach	0.55	139.05

(continued)

Waterbody Assignments and Flow (continued)

Plant	CUSEG	Nearest Reach	Reach Type	QLOW	QMEAN
Titus	02040203010	SCHUYLKILL R	Regular Reach	91.25	1880.77002
Trimble County	05140101007	OHIO R	Regular Reach	7524.29004	117896.3125
Tyrone	05100205013	KENTUCKY R	Regular Reach	154.36	7097.54004
Valley	04040003001	MILWAUKEE R	Terminal Reach	10.71	540.60999
Vermilion	05120109006	VERMILION R, M FK	Regular Reach	3.45	340.35999
Victor J Daniel Jr	03170006007	PASCAGOULA R	Regular Reach	1256.55005	12878.25
W A Parish	12070104021	SMITHERS L	Lake Shoreline		
W H Weatherspoon	03040203016	LUMBER R	Regular Reach	97.9	865.13
W S Lee	03050109066	SALADA R	Regular Reach	20.68	461.51001
Wabash River	05120111018	WABASH R	Regular Reach	985.53998	10551.67969
Walter C Beckjord	05090201001	OHIO R	Regular Reach	6416.77002	92084.0625
Wansley	03130002032	CHATTAHOOCHEE R	Regular Reach	702.71002	4400.72021
Warrick	05140201022	LITTLE PIGEON CR	Regular Reach	61.57	1149.60999
Waukegan	04040002002	L MICHIGAN	Great Lakes Shoreline	0	0
Weston	07070002023	WISCONSIN R	Regular Reach	1069.30005	3484.32007
Widows Creek	06030001049	TENNESSEE R	Regular Reach	7221.95996	38237.07031
Will County	07110009002	WOOD R	Start Reach	29	87.81
Wyodak	10120201038	DONKEY CR	Start Reach	0	4.4
Yates	03130002061	CHATTAHOOCHEE R	Regular Reach	702.21997	4063.29004

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Appendix D. MINTEQA2 Nonlinear Sorption Isotherms

D.1 Overview of MINTEQA2 Modeling

Chemicals in leachate can be subject to complex geochemical interactions in soil and groundwater, which can strongly affect their rate of transport in the subsurface. EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) treats these interactions as equilibrium sorption processes. The equilibrium assumption means that the sorption process occurs instantaneously, or at least very quickly relative to the time scale of constituent transport. Although sorption—or the attachment of leachate constituents to solid soil or aquifer particles—may result from multiple chemical processes, EPACMTP lumps these processes together into an effective soil-water partition coefficient (K_d). The retardation factor (R) accounts for the effects of equilibrium sorption of dissolved constituents onto the solid phase, removing them from solution and reducing the available mass in the dissolved phase. R, a function of the constituent-specific K_d and the soil or aquifer properties, is calculated as:

$$R = 1 + \frac{\rho_b \times K_d}{\Phi} \qquad \text{(D-1)}$$

where

R = Retardation factor
ρ_b = Soil or aquifer bulk density (g/cm^3)
K_d = Solid-water partition coefficient (g/cm^3)
ϕ = Water content (in unsaturated zone) or porosity (in saturated zone).

An isotherm is an expression of the equilibrium relationship between the aqueous concentration and the sorbed concentration of a metal (or other constituent) at a constant temperature. For metals, EPACMTP accounts for more complex geochemical reactions by using effective sorption isotherms generated using EPA's geochemical equilibrium speciation model for dilute aqueous systems, MINTEQA2 (U.S. EPA, 1991).

The MINTEQA2 model was used to generate one set of isotherms for each metal reflecting the range in geochemical environments expected at waste sites across the nation. The variability in geochemical environments at CCW sites across the country was represented by five geochemical master variables (groundwater composition, pH, concentration of iron oxide adsorption sites, leachate ionic strength, and concentration of dissolved and particulate natural organic matter), and the MINTEQA2 modeling was repeated (separately for each metal) for numerous combinations of master variable settings. This procedure resulted in nonlinear K_d versus aqueous metal concentration curves for combinations of master variable settings spanning the range of reasonable values (U.S. EPA 2003a).

For each metal, the resulting set of isotherms was tabulated into a supplementary input data file for use by the EPACMTP model, hereafter referred to as an "empirical nonlinear isotherm." In the fate and transport modeling for a particular metal, EPACMTP was executed, and the national probability distributions for these five master variables formed the basis for the Monte Carlo selection of the appropriate adsorption isotherm.

In modeling metals transport in the unsaturated zone, EPACMTP uses a range of K_d values from the nonlinear sorption isotherms. However, in modeling metals transport in the saturated zone, EPACMTP selects the lowest from all available K_d values corresponding to concentrations less than or equal to the maximum water table concentration. For more details see the *EPACMTP Technical Background Document* (U.S. EPA, 2003b). This simplification in the saturated zone is required for all solution options and is based on the assumption that, after dilution of the leachate plume in groundwater, the concentrations of metals will typically be in a range where the isotherm is approximately linear. However, this assumption may not be valid when the metal concentrations in the leachate are exceedingly high. Although EPACMTP is able to account for the effect of the geochemical environment at a site on the mobility of metals, the model assumes that the geochemical environment at a site is constant and not affected by the presence of the leachate plume. In reality, the presence of a leachate plume may alter the ambient geochemical environment.

D.2 Previous CCW Metals Modeling Effort

In a previous risk assessment for fossil fuel combustion wastes (FFCWs) conducted in 1998 (U.S. EPA, 1998), sorption isotherms generated using MINTEQA2 were used in EPACMTP to account for metal partitioning. However, these isotherms were not calculated specifically for use in FFCW modeling—they had been computed using MINTEQA2 in 1995 for use in modeling support for the Hazardous Waste Identification Rule (HWIR).

The disposal scenario for HWIR was the industrial Resource Conservation and Recovery Act (RCRA) Subtitle D nonhazardous waste landfill. In fact, the MINTEQA2 modeling that produced the isotherms had originally been designed to represent municipal solid waste landfills, and leachate from those landfills had been sampled so that appropriate forms of leachate organic acids at various concentrations could be included in the modeling. For the HWIR analysis, the scenario was changed to industrial Subtitle D, and only the isotherms corresponding to low concentrations of the leachate organic acids were used for HWIR modeling. The same isotherms were used in the 1998 FFCW risk assessment. As in the HWIR modeling, only the isotherms corresponding to the lowest setting of leachate organic carbon were used.

In 1999, EPA received review comments concerning the use of the industrial Subtitle D metal partitioning isotherms in the 1998 risk assessment. The most comprehensive review was prepared by Charles Norris and Christina Hubbard on behalf of the Environmental Defense Fund and other environmental advocacy groups (Norris and Hubbard, 1999). The Norris and Hubbard report criticized the 1998 risk assessment for using MINTEQA2 isotherms designed for a different scenario (nonhazardous industrial landfills). Norris and Hubbard also offered 20 specific criticisms on the input parameters and other factors involved in the MINTEQA2 modeling. EPA responded by evaluating each of these criticisms through review and assessment of MINTEQA2 input values, model sensitivity tests, and consultations with experts. This review is documented in U.S. EPA (2000, 2001a). The evaluation of the Norris and Hubbard comments resulted in suggested revisions in the MINTEQA2 modeling strategy, as described in U.S. EPA (2001b).

Based on a review of available information on CCW leachate composition and an analysis of the potential effects of this composition on metals mobility, EPA (U.S. EPA, 2001b) also determined that if MINTEQA2 is to be used at CCW sites, leachate from CCW facilities should be studied to look for trends in composition, especially with regard to the concentrations of constituents that may

- Contribute to elevated groundwater pH
- Compete with the contaminant metal for sorption sites and thus result in reduced metal sorption (e.g., Ca, Mg, SO_4, other metals)
- Complex with the contaminant metal so that the metal is less likely to be sorbed (e.g., SO_4, CO_3, organic ligands)
- Precipitate with the contaminant metal (e.g., SO_4, CO_3).

D.3 MINTEQA2 Modeling Revisions for CCW Risk Assessment

Many of the suggested revisions from U.S. EPA (2001b) were implemented in the MINTEQA2 modeling for the current CCW risk assessment. Some of the suggested revisions were not implemented, either because they were not applicable (e.g., organic carbon assumptions were not changed, because CCW leachate has negligible organic carbon) or because models or data were not adequate to carry forth the recommendation. These revisions are discussed in greater detail in U.S. EPA (2003c).

In addition to revising the MINTEQA2 model, EPA compiled leachate characteristics into the CCW constituent database (see **Appendix A**) and statistically analyzed these data to identify three chemically distinct CCW leachate types: conventional CCW (including ash and flue gas desulfurization [FGD] sludge), codisposed CCW and coal cleaning wastes, and fluidized bed combustion (FBC) waste. Leachate concentration ranges for major ions (e.g., Ca, SO_4, Mg, Na, Cl, etc.) and pH were developed for each of these waste types and were used to represent CCW leachate during MINTEQA2 modeling.

As needed, sorption reactions were included for those CCW constituents known to undergo significant sorption. Including elevated concentrations of leachate constituents and their corresponding sorption reactions in the MINTEQA2 model allowed for full competition with the contaminant metal for sorption sites. The metal solubilizing effect through complexation between the contaminant metal and dissolved ligands was also included, as was the potential for metal precipitation. Because precipitation of the metal can serve to attenuate the transportable concentration, the equilibrium fraction in all three phases (dissolved, sorbed, and precipitated) were stored and made available for use by EPACMTP. The precipitated fraction was used to develop a solubility limit that was used during EPACMTP modeling (U.S. EPA, 2003c).

D.4 MINTEQA2 Modeling for CCW Risk Assessment

The expected natural variability in K_d for a particular metal was represented during the MINTEQA2 modeling effort by varying the input parameters that most impact K_d: groundwater type (carbonate or noncarbonate), pH, concentration of aquifer sorbents, composition and concentration level of CCW leachate, and concentration of the contaminant metal. The natural pH range for the two groundwater types was sampled from a range of 7 to 8 for carbonate aquifers and 4 to 10 for noncarbonate aquifers (U.S. EPA, 2003c).

In addition, CCW leachate ranges from acidic (pH < 2) to highly alkaline (pH > 12), and it can impact unsaturated zone and groundwater pH. To account for this possibility, the CCW leachate/ groundwater system was equilibrated at a series of pH values that spanned the range of expected variability in mixed CCW leachate-groundwater systems (U.S. EPA, 2003c).

To account for the variability in the sorption capacity of soil and aquifer materials, the soil and groundwater systems were equilibrated with various concentrations of two commonly occurring natural sorbents: ferric (iron) oxyhydroxide (FeOx) and particulate organic matter (POM). CCW leachate can include elevated concentrations of inorganic constituents such as calcium, sulfate, sodium, potassium, and chloride, which may reduce sorption of metals due to competition for sorption sites or complexation with metals in solution. To account for this effect, these leachate components were added to the MINTEQA2 model inputs at concentrations representative of the three CCW waste types (conventional CCWs, codisposed CCW and coal cleaning wastes, and FBC wastes). This new MINTEQA2 master variable is termed leachate "richness" or ionic strength (U.S. EPA, 2003c).

The results of each MINTEQA2 model run were compiled as the equilibrium distribution of the contaminant metal among dissolved, sorbed, and precipitated fractions for each metal concentration, and were saved in a separate file indexed with the settings of all variables used to define the system. These files were produced for all possible values for the variables defining the system, and were compiled into a database of indexed K_d values for use in the EPACMTP fate and transport model (U.S. EPA, 2003c).

D.5 EPACMTP Modeling Revisions to Accommodate MINTEQA2 Updates

EPA updated EPACMTP to support the new system variable (leachate ionic strength) for isotherm selection, to address issues regarding the impacts of leachate pH on ambient soil and aquifer pH, and to address issues regarding solubility limits for metals in solution. A brief description of these model changes are discussed below, with more detail provided in U.S. EPA (2003d).

Ionic Strength. A new system or "master" variable was added to include ionic strength as a key for choosing the representative isotherm from the database for both the unsaturated and saturated zones.

Leachate Effects on Geochemical Environment. These effects were addressed in EPACMTP under the following constraints: (1) no significant impairment of the computational efficiency for probabilistic applications; (2) data requirements limited to readily available data;

and (3) a scientifically defensible approach, given significant uncertainties with respect to the true impacts of leachate pH on the subsurface. Two modifications to the EPACMTP were considered: (1) determine the governing pH in the soil column (either the pH of the leachate or the native soils); and (2) determine the pH of the saturated zone as a result of the infiltrating leachate.

The approach selected for determining the governing pH of the soil column (unsaturated zone) beneath the waste management unit (WMU) compares the operational life of the WMU (the duration of leaching) to an estimate of the first arrival time of the contaminant front at the water table (a surrogate for the residence time of the contaminant in the soil column). If the operational life of the WMU is *relatively* long compared to the time required for the contaminant to migrate to the water table, there is a high likelihood that the leachate permeates the soil column and that the pH environment is governed by the leachate. Conversely, a relatively short operational life and retarded contaminant migration would favor ambient soil pH conditions. An analysis of the relationship between operational life and travel time indicated that a ratio of approximately 5 (operational life over travel time) would, in many cases, result in a balanced selection of cases where leachate pH governs versus cases where soil pH governs over approximately 10,000 Monte Carlo iterations.

For each iteration of EPACMTP, the operational life was compared to a travel-time estimate based on a K_d averaged from isotherms selected based on the leachate pH and soil pH. If the ratio was greater than 5, the pH of the leachate was assumed to govern, and the pH of the leachate was used to select the isotherm for transport in the unsaturated zone. If the ratio was less than 5, the soil pH was used to select the isotherm.

In the saturated zone, the impacts of leachate pH were handled using a simple homogeneous mixing calculation. The volume of leachate released from the WMU was mixed with the volume of the aquifer that was likely to be impacted by a plume. The resulting mixed pH was used to select the isotherm for transport in the saturated zone with one limitation: in carbonate environments, the mixed pH in the aquifer was not allowed to drop below a pH of 6. Such acid conditions would likely result in significant dissolution of the soil matrix.

Metal Solubility Limits. As mentioned above, each sorption isotherm comprises equilibrium concentrations of the three contaminant phases (dissolved, sorbed, and precipitated) over a range of total concentration values. An examination of the change in the dissolved-phase concentrations relative to changes in the total concentration in any isotherm reveals solubility behavior for that contaminant: if the dissolved component does not change with increasing total concentration, a solubility limit has been achieved. If, however, the dissolved component increases along with the total concentration, then there is capacity for more dissolved mass in the groundwater or soil porewater.

EPACMTP uses this information (contained in each isotherm file) to determine if a solubility limit should be imposed in the saturated zone. Once an isotherm has been selected (after pH considerations have been addressed), the equilibrium states corresponding to the three highest total concentrations are examined. If the dissolved concentration changes more than one tenth of one percent over the last three points, then EPACMTP assumes there is no solubility limit. If the change in dissolved concentration is less than one tenth of one percent, EPACMTP assumes a solubility limit has been reached and caps the concentration of the leachate entering the saturated zone at the water table to that limit.

D.6 Sampled K_ds from MINTEQA2 Isotherms by EPACMTP

As described above, a range of K_ds from an isotherm were used by EPACMTP in each unsaturated zone transport simulation. To simplify the presentation of K_d here, an *effective* K_d value was calculated and reported by EPACMTP. An effective K_d was determined by first estimating the value of the retardation factor, described in Equation D-1, as follows:

$$R = \frac{t_{WT} \times q}{d_{soil}}$$

where

t_{wt}	=	time for leachate to reach the water table (yr)
q	=	seepage velocity of leachate through the unsaturated soil column (m/yr)
d_{dsoil}	=	depth to the water table or length of the unsaturated soil column (m)

Substituting this value for R in Equation D-1 and solving for K_d yields an effective K_d that is based on the first arrival of the leachate front at the water table.

Table D-1 presents selected percentiles of K_d sampled from the MINTEQA2 isotherms for every waste management modeling scenario conducted in the CCW risk assessment for the groundwater pathway. Each scenario corresponds to a unique combination of waste type, metal species, waste management unit type, and subsurface domain (unsaturated zone or saturated zone). The values presented for the saturated zone are taken from the set of actual K_d values used in each modeling scenario.

Table D-1. Select Percentiles of K_d Sampled from MINTEQA2 Isotherms by Updated EPACMTP by Waste Type, Metal Species, WMU Type, and Subsurface Domain

Waste Stream	Metal	CASID	WMU	Zone	Percentiles of K_d							
					10%	25%	50%	75%	80%	85%	90%	95%
Ash	Aluminum	7429905	LF	Saturated	8.5E-20	3.0E-16	5.1E-10	5.0E-03	7.1E-02	9.2E-01	1.6E+00	2.8E+00
Ash	Aluminum	7429905	SI	Saturated	8.6E-20	2.5E-10	2.6E-04	9.4E-01	2.2E+00	2.7E+00	2.8E+00	6.2E+00
Ash	Aluminum	7429905	LF	Unsaturated	6.9E-03	1.0E-01	2.0E-01	1.8E+01	5.9E+01	1.0E+02	1.8E+02	3.7E+02
Ash	Aluminum	7429905	SI	Unsaturated	2.0E-11	3.7E-02	1.6E-01	1.1E+00	1.6E+00	2.8E+00	3.0E+00	6.6E+00
Ash	Antimony	7440360	LF	Saturated	4.3E-03	2.5E-02	7.5E-02	2.0E-01	2.1E-01	3.0E-01	3.4E-01	7.1E-01
Ash	Antimony	7440360	SI	Saturated	2.8E-03	1.9E-02	9.6E-02	2.0E-01	2.1E-01	3.3E-01	3.5E-01	5.9E-01
Ash	Antimony	7440360	LF	Unsaturated	9.1E-02	2.9E-01	9.6E-01	7.6E+00	1.0E+01	1.4E+01	2.2E+01	4.9E+01
Ash	Antimony	7440360	SI	Unsaturated	0.0E+00	1.1E-01	3.4E-01	6.8E-01	7.9E-01	9.5E-01	1.3E+00	1.6E+00
Ash	Arsenic3	22569728	LF	Saturated	5.2E-02	1.5E-01	4.1E-01	6.6E-01	8.0E-01	9.2E-01	1.0E+00	1.1E+00
Ash	Arsenic3	22569728	SI	Saturated	4.1E-02	1.4E-01	4.1E-01	6.8E-01	8.1E-01	9.2E-01	1.0E+00	1.1E+00
Ash	Arsenic3	22569728	LF	Unsaturated	1.5E-01	5.0E-01	1.2E+00	2.2E+00	2.7E+00	3.7E+00	5.8E+00	1.2E+01
Ash	Arsenic3	22569728	SI	Unsaturated	5.7E-05	3.1E-01	7.4E-01	1.3E+00	1.5E+00	1.6E+00	1.8E+00	2.1E+00
Ash	Arsenic5	15584040	LF	Saturated	1.1E+00	7.0E+00	3.4E+01	9.8E+01	1.2E+02	1.6E+02	2.1E+02	6.3E+02
Ash	Arsenic5	15584040	SI	Saturated	1.2E+00	6.7E+00	2.9E+01	8.9E+01	1.1E+02	1.5E+02	2.9E+02	5.9E+02
Ash	Arsenic5	15584040	LF	Unsaturated	0.0E+00	4.2E+00	3.6E+01	1.0E+02	1.3E+02	1.6E+02	2.1E+02	4.2E+02
Ash	Arsenic5	15584040	SI	Unsaturated	2.9E-01	3.2E+00	2.1E+01	7.6E+01	9.5E+01	1.3E+02	2.0E+02	4.7E+02
Ash	Barium	7440393	LF	Saturated	2.4E-01	4.2E-01	5.6E-01	9.2E-01	1.1E+00	1.2E+00	1.6E+00	2.3E+00
Ash	Barium	7440393	SI	Saturated	2.5E-01	4.4E-01	5.7E-01	9.3E-01	1.1E+00	1.2E+00	1.6E+00	2.4E+00
Ash	Barium	7440393	LF	Unsaturated	0.0E+00	7.1E+00	2.0E+02	6.6E+02	7.9E+02	1.0E+03	1.4E+03	2.2E+03
Ash	Barium	7440393	SI	Unsaturated	0.0E+00	8.7E-01	1.8E+00	5.9E+00	8.0E+00	1.2E+01	1.9E+01	5.3E+01
Ash	Boron	7440428	LF	Saturated	3.8E-11	4.3E-10	1.7E-07	2.8E-06	3.6E-06	5.4E-06	7.1E-06	1.0E-05
Ash	Boron	7440428	SI	Saturated	2.6E-10	3.2E-08	1.7E-06	6.5E-06	7.7E-06	8.9E-06	1.1E-05	1.3E-05
Ash	Boron	7440428	LF	Unsaturated	2.6E-03	1.3E-01	4.4E-01	1.8E+00	2.2E+00	2.8E+00	3.9E+00	6.2E+00
Ash	Boron	7440428	SI	Unsaturated	0.0E+00	2.5E-02	1.1E-01	2.2E-01	2.5E-01	3.4E-01	6.6E-01	1.6E+00
Ash	Cadmium	7440439	LF	Saturated	1.6E-01	4.0E-01	7.7E-01	1.8E+00	2.1E+00	3.4E+00	5.1E+00	7.0E+00
Ash	Cadmium	7440439	SI	Saturated	1.6E-01	4.0E-01	7.1E-01	1.7E+00	2.0E+00	3.4E+00	5.1E+00	7.3E+00
Ash	Cadmium	7440439	LF	Unsaturated	2.2E-01	9.8E-01	2.0E+00	4.3E+00	5.2E+00	7.1E+00	9.4E+00	1.3E+01
Ash	Cadmium	7440439	SI	Unsaturated	-4.1E-02	3.1E-01	7.8E-01	2.0E+00	2.7E+00	4.0E+00	6.3E+00	1.0E+01

(continued)

Select Percentiles of K_d Sampled from MINTEQA2 Isotherms by Updated EPACMTP by Waste Type, Metal Species, WMU Type, and Subsurface Domain (continued)

Waste Stream	Metal	CASID	WMU	Zone	Percentiles of K_d							
					10%	25%	50%	75%	80%	85%	90%	95%
Ash	Cobalt	7440484	LF	Saturated	5.2E-01	1.0E+00	4.0E+00	1.6E+01	1.8E+01	3.5E+01	6.1E+01	1.1E+02
Ash	Cobalt	7440484	SI	Saturated	6.5E-01	9.6E-01	2.7E+00	1.1E+01	1.6E+01	2.9E+01	6.7E+01	1.2E+02
Ash	Cobalt	7440484	LF	Unsaturated	2.4E-01	2.6E+00	8.7E+00	2.8E+01	3.5E+01	4.6E+01	7.1E+01	1.1E+02
Ash	Cobalt	7440484	SI	Unsaturated	-2.9E-02	1.3E+00	3.3E+00	1.0E+01	1.3E+01	1.9E+01	3.9E+01	8.7E+01
Ash	Lead	7439921	LF	Saturated	9.0E+00	1.6E+01	2.5E+01	3.9E+01	4.3E+01	5.0E+01	9.7E+01	1.7E+02
Ash	Lead	7439921	SI	Saturated	8.3E+00	1.6E+01	2.2E+01	3.5E+01	4.0E+01	4.5E+01	6.3E+01	1.8E+02
Ash	Lead	7439921	LF	Unsaturated	0.0E+00	2.0E+01	3.3E+01	5.2E+01	5.9E+01	7.0E+01	9.6E+01	1.6E+02
Ash	Lead	7439921	SI	Unsaturated	-1.1E-01	1.3E+00	1.9E+01	3.3E+01	3.6E+01	4.1E+01	4.9E+01	1.3E+02
Ash	Mercury	7439976	LF	Saturated	2.0E-05	1.0E-04	4.4E-04	2.1E-03	2.4E-03	4.6E-03	5.6E-03	9.5E-03
Ash	Mercury	7439976	LF	Unsaturated	8.9E-02	2.0E+00	5.4E+00	1.1E+01	1.3E+01	1.7E+01	2.3E+01	3.7E+01
Ash	Molybdenum	7439987	LF	Saturated	7.8E-07	3.0E-05	1.8E-03	6.0E-02	1.2E-01	2.3E-01	3.7E-01	5.9E-01
Ash	Molybdenum	7439987	SI	Saturated	3.2E-07	3.0E-05	4.3E-03	6.0E-02	1.1E-01	2.1E-01	2.4E-01	4.0E-01
Ash	Molybdenum	7439987	LF	Unsaturated	2.3E-02	1.6E-01	3.4E-01	9.1E-01	1.1E+00	1.5E+00	2.0E+00	3.1E+00
Ash	Molybdenum	7439987	SI	Unsaturated	6.0E-11	5.0E-02	1.6E-01	4.0E-01	5.3E-01	7.0E-01	1.3E+00	1.6E+00
Ash	Nitrate/Nitrite	14797558	LF	Saturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash	Nitrate/Nitrite	14797558	SI	Saturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash	Nitrate/Nitrite	14797558	LF	Unsaturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash	Nitrate/Nitrite	14797558	SI	Unsaturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash	Selenium4	10026036	LF	Saturated	3.3E-01	7.3E+00	1.5E+02	1.2E+03	2.0E+03	2.9E+03	3.6E+03	5.8E+03
Ash	Selenium4	10026036	SI	Saturated	4.5E-02	2.9E+00	2.4E+02	1.3E+03	2.0E+03	3.0E+03	3.6E+03	5.8E+03
Ash	Selenium4	10026036	LF	Unsaturated	1.8E-01	5.4E+00	1.3E+02	8.6E+02	1.5E+03	2.3E+03	3.2E+03	5.2E+03
Ash	Selenium4	10026036	SI	Unsaturated	0.0E+00	2.0E+00	1.6E+02	9.4E+02	1.7E+03	2.5E+03	3.4E+03	5.6E+03
Ash	Selenium6	7782492	LF	Saturated	5.1E-13	6.3E-11	3.0E-07	2.7E-04	6.7E-04	1.8E-03	2.7E-03	4.9E-03
Ash	Selenium6	7782492	SI	Saturated	7.4E-09	6.8E-07	8.4E-05	9.5E-04	1.4E-03	2.2E-03	3.2E-03	4.5E-03
Ash	Selenium6	7782492	LF	Unsaturated	3.3E-03	1.1E-01	2.0E-01	9.1E-01	1.3E+00	1.7E+00	2.5E+00	4.0E+00
Ash	Selenium6	7782492	SI	Unsaturated	0.0E+00	2.2E-02	1.1E-01	2.1E-01	2.3E-01	2.8E-01	5.0E-01	1.6E+00
Ash	Thallium	7440280	LF	Saturated	1.1E-02	1.7E-02	2.7E-02	4.3E-02	5.2E-02	6.3E-02	8.1E-02	1.1E-01
Ash	Thallium	7440280	SI	Saturated	1.2E-02	1.7E-02	2.5E-02	4.4E-02	5.2E-02	6.6E-02	8.5E-02	1.6E-01

(continued)

Select Percentiles of K_d Sampled from MINTEQA2 Isotherms by Updated EPACMTP by Waste Type, Metal Species, WMU Type, and Subsurface Domain (continued)

Waste Stream	Metal	CASID	WMU	Zone	Percentiles of K_d							
					10%	25%	50%	75%	80%	85%	90%	95%
Ash	Thallium	7440280	LF	Unsaturated	5.5E-02	2.0E-01	4.0E-01	1.5E+00	1.8E+00	2.4E+00	3.2E+00	4.8E+00
Ash	Thallium	7440280	SI	Unsaturated	0.0E+00	8.1E-02	1.7E-01	2.9E-01	3.5E-01	4.9E-01	9.3E-01	1.6E+00
Ash & Coal	Aluminum	7429905	LF	Saturated	1.8E-07	1.8E-07	4.0E-07	1.3E-01	1.3E-01	1.3E-01	3.5E-01	2.8E+00
Ash & Coal	Aluminum	7429905	SI	Saturated	1.8E-07	4.0E-07	7.3E-03	1.9E-01	2.0E-01	8.8E-01	5.8E+00	1.4E+01
Ash & Coal	Aluminum	7429905	LF	Unsaturated	0.0E+00	1.2E-01	1.1E+01	4.7E+01	5.9E+01	7.6E+01	9.8E+01	1.5E+02
Ash & Coal	Aluminum	7429905	SI	Unsaturated	1.4E-02	1.1E-01	2.6E-01	9.4E-01	1.5E+00	1.7E+00	2.9E+00	6.3E+00
Ash & Coal	Antimony	7440360	LF	Saturated	1.8E-03	5.4E-03	1.7E-02	7.3E-02	8.0E-02	1.5E-01	3.2E-01	5.5E-01
Ash & Coal	Antimony	7440360	LF	Unsaturated	0.0E+00	1.8E-01	1.4E+00	6.4E+00	8.2E+00	1.1E+01	1.4E+01	2.2E+01
Ash & Coal	Arsenic3	22569728	LF	Saturated	5.5E-03	1.7E-02	6.4E-02	1.9E-01	2.7E-01	4.6E-01	7.4E-01	9.9E-01
Ash & Coal	Arsenic3	22569728	SI	Saturated	4.6E-03	1.6E-02	5.1E-02	1.4E-01	2.6E-01	4.5E-01	7.1E-01	1.1E+00
Ash & Coal	Arsenic3	22569728	LF	Unsaturated	0.0E+00	1.6E-01	3.8E-01	1.9E+00	2.6E+00	3.6E+00	5.4E+00	9.8E+00
Ash & Coal	Arsenic3	22569728	SI	Unsaturated	3.8E-02	1.1E-01	2.3E-01	6.3E-01	8.8E-01	1.3E+00	1.6E+00	2.1E+00
Ash & Coal	Arsenic5	15584040	LF	Saturated	3.3E-02	7.2E-01	6.3E+00	3.3E+01	4.6E+01	5.4E+01	9.5E+01	3.2E+02
Ash & Coal	Arsenic5	15584040	SI	Saturated	3.3E-02	3.5E-01	2.3E+00	1.4E+01	2.1E+01	2.9E+01	4.8E+01	1.5E+02
Ash & Coal	Arsenic5	15584040	LF	Unsaturated	0.0E+00	4.8E-01	6.4E+00	3.4E+01	4.6E+01	6.3E+01	9.8E+01	2.2E+02
Ash & Coal	Arsenic5	15584040	SI	Unsaturated	1.9E-01	9.6E-01	3.5E+00	1.6E+01	2.2E+01	3.2E+01	5.1E+01	1.3E+02
Ash & Coal	Barium	7440393	LF	Saturated	3.7E-02	4.5E-02	2.3E-01	1.3E+00	1.3E+00	1.5E+00	1.9E+00	2.2E+00
Ash & Coal	Barium	7440393	SI	Saturated	1.3E-02	4.5E-02	1.8E-01	1.3E+00	1.3E+00	1.5E+00	2.1E+00	2.2E+00
Ash & Coal	Barium	7440393	LF	Unsaturated	0.0E+00	4.6E-01	1.5E+01	5.0E+01	6.2E+01	7.4E+01	1.0E+02	1.6E+02
Ash & Coal	Barium	7440393	SI	Unsaturated	5.2E-02	5.0E-01	2.4E+00	9.6E+00	1.4E+01	2.1E+01	3.7E+01	5.4E+01
Ash & Coal	Boron	7440428	LF	Saturated	7.1E-08	2.1E-07	8.1E-07	2.4E-06	3.5E-06	5.9E-06	9.5E-06	1.3E-05
Ash & Coal	Boron	7440428	SI	Saturated	6.0E-08	2.1E-07	6.3E-07	1.8E-06	3.6E-06	6.4E-06	1.0E-05	1.5E-05
Ash & Coal	Boron	7440428	LF	Unsaturated	0.0E+00	5.2E-02	1.5E-01	2.2E-01	2.5E-01	3.2E-01	4.4E-01	6.9E-01
Ash & Coal	Boron	7440428	SI	Unsaturated	7.9E-07	3.1E-02	1.1E-01	2.0E-01	2.3E-01	2.8E-01	5.6E-01	1.6E+00
Ash & Coal	Cadmium	7440439	LF	Saturated	1.7E-03	4.6E-02	1.5E-01	7.7E-01	1.0E+00	2.1E+00	2.9E+00	4.7E+00
Ash & Coal	Cadmium	7440439	SI	Saturated	1.7E-03	4.6E-02	8.5E-02	6.1E-01	1.0E+00	2.1E+00	3.2E+00	4.5E+00
Ash & Coal	Cadmium	7440439	LF	Unsaturated	0.0E+00	2.6E-01	7.9E-01	2.2E+00	2.7E+00	3.9E+00	5.9E+00	9.0E+00
Ash & Coal	Cadmium	7440439	SI	Unsaturated	6.4E-02	1.7E-01	4.0E-01	1.6E+00	2.2E+00	3.3E+00	4.4E+00	7.1E+00

(continued)

Select Percentiles of K_d Sampled from MINTEQA2 Isotherms by Updated EPACMTP by Waste Type, Metal Species, WMU Type, and Subsurface Domain (continued)

Waste Stream	Metal	CASID	WMU	Zone	Percentiles of K_d							
					10%	25%	50%	75%	80%	85%	90%	95%
Ash & Coal	Cobalt	7440484	LF	Saturated	7.6E-03	6.6E-02	5.8E-01	2.8E+00	3.2E+00	5.4E+00	8.5E+00	2.9E+01
Ash & Coal	Cobalt	7440484	SI	Saturated	7.6E-03	6.5E-02	2.1E-01	2.4E+00	2.9E+00	4.1E+00	6.1E+00	1.1E+01
Ash & Coal	Cobalt	7440484	LF	Unsaturated	0.0E+00	7.9E+00	3.1E+01	9.3E+01	1.1E+02	1.5E+02	2.9E+02	5.7E+02
Ash & Coal	Cobalt	7440484	SI	Unsaturated	2.3E-01	4.5E-01	1.7E+00	4.9E+00	5.9E+00	7.3E+00	1.1E+01	2.1E+01
Ash & Coal	Lead	7439921	LF	Saturated	1.1E-01	2.3E+00	6.6E+00	2.1E+01	2.9E+01	3.8E+01	4.1E+01	6.3E+01
Ash & Coal	Lead	7439921	SI	Saturated	1.1E-01	2.3E+00	3.7E+00	2.2E+01	2.9E+01	3.9E+01	4.4E+01	6.3E+01
Ash & Coal	Lead	7439921	LF	Unsaturated	0.0E+00	4.4E+00	1.4E+01	4.1E+01	4.9E+01	5.6E+01	7.1E+01	1.2E+02
Ash & Coal	Lead	7439921	SI	Unsaturated	-6.3E-03	9.5E-01	4.5E+00	2.0E+01	3.0E+01	3.9E+01	4.6E+01	6.4E+01
Ash & Coal	Mercury	7439976	LF	Saturated	9.0E-04	2.1E-03	1.3E-02	7.9E-02	3.3E-01	6.8E-01	2.9E+00	4.3E+00
Ash & Coal	Mercury	7439976	SI	Saturated	1.7E-03	3.3E-03	6.2E-02	8.8E-01	1.5E+00	2.8E+00	2.9E+00	4.3E+00
Ash & Coal	Mercury	7439976	LF	Unsaturated	0.0E+00	1.6E+00	6.3E+00	1.5E+01	1.8E+01	2.2E+01	3.0E+01	4.4E+01
Ash & Coal	Mercury	7439976	SI	Unsaturated	4.8E-02	1.5E-01	3.6E-01	1.6E+00	1.6E+00	2.1E+00	3.0E+00	4.4E+00
Ash & Coal	Molybdenum	7439987	LF	Saturated	3.4E-06	6.7E-05	2.5E-03	4.6E-02	7.5E-02	1.6E-01	2.7E-01	7.1E-01
Ash & Coal	Molybdenum	7439987	SI	Saturated	3.4E-06	3.1E-04	1.1E-02	7.5E-02	7.5E-02	1.6E-01	3.1E-01	9.4E-01
Ash & Coal	Molybdenum	7439987	LF	Unsaturated	0.0E+00	7.3E-02	2.1E-01	7.7E-01	1.0E+00	1.4E+00	2.0E+00	2.9E+00
Ash & Coal	Molybdenum	7439987	SI	Unsaturated	4.7E-03	8.3E-02	2.0E-01	5.0E-01	7.6E-01	1.3E+00	1.6E+00	2.2E+00
Ash & Coal	Nitrate/Nitrite	14797558	LF	Saturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash & Coal	Nitrate/Nitrite	14797558	SI	Saturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash & Coal	Nitrate/Nitrite	14797558	LF	Unsaturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash & Coal	Nitrate/Nitrite	14797558	SI	Unsaturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Ash & Coal	Selenium4	10026036	LF	Saturated	3.7E-01	6.1E+00	5.3E+01	5.3E+02	8.5E+02	1.1E+03	1.9E+03	6.5E+03
Ash & Coal	Selenium4	10026036	SI	Saturated	3.7E-01	1.6E+01	1.2E+02	7.7E+02	9.1E+02	1.4E+03	3.3E+03	7.3E+03
Ash & Coal	Selenium4	10026036	LF	Unsaturated	0.0E+00	2.9E+00	4.4E+01	3.2E+02	5.5E+02	8.7E+02	1.5E+03	5.1E+03
Ash & Coal	Selenium4	10026036	SI	Unsaturated	4.7E-01	1.0E+01	1.0E+02	6.1E+02	8.6E+02	1.1E+03	2.9E+03	7.0E+03
Ash & Coal	Selenium6	7782492	LF	Saturated	2.9E-08	7.7E-08	1.8E-05	6.4E-04	1.1E-03	1.4E-03	3.2E-03	8.8E-03
Ash & Coal	Selenium6	7782492	SI	Saturated	4.7E-08	3.2E-06	1.1E-04	9.6E-04	1.1E-03	1.6E-03	5.1E-03	1.0E-02
Ash & Coal	Selenium6	7782492	LF	Unsaturated	0.0E+00	5.9E-02	1.6E-01	7.0E-01	1.0E+00	1.5E+00	2.3E+00	3.7E+00
Ash & Coal	Selenium6	7782492	SI	Unsaturated	1.7E-03	5.2E-02	1.3E-01	2.6E-01	3.4E-01	5.6E-01	1.2E+00	1.6E+00

(continued)

Select Percentiles of K_d Sampled from MINTEQA2 Isotherms by Updated EPACMTP by Waste Type, Metal Species, WMU Type, and Subsurface Domain (continued)

Waste Stream	Metal	CASID	WMU	Zone	Percentiles of K_d							
					10%	25%	50%	75%	80%	85%	90%	95%
Ash & Coal	Thallium	7440280	LF	Saturated	2.9E-04	1.9E-03	9.8E-03	2.0E-02	2.4E-02	3.7E-02	5.0E-02	7.7E-02
Ash & Coal	Thallium	7440280	LF	Unsaturated	0.0E+00	1.2E-01	3.9E-01	1.3E+00	1.7E+00	2.1E+00	2.7E+00	3.9E+00
FBC	Aluminum	7429905	LF	Saturated	4.1E-25	4.6E-25	1.4E-17	5.2E-08	1.7E-07	1.7E-07	5.3E-07	7.1E-03
FBC	Aluminum	7429905	LF	Unsaturated	0.0E+00	1.5E-01	2.5E-01	4.6E+02	8.6E+02	1.9E+03	3.9E+03	8.7E+03
FBC	Antimony	7440360	LF	Saturated	3.0E-04	1.2E-02	2.0E-02	6.9E-02	8.7E-02	1.1E-01	1.4E-01	2.3E-01
FBC	Antimony	7440360	LF	Unsaturated	0.0E+00	2.1E-01	4.1E-01	2.2E+00	3.0E+00	4.3E+00	7.2E+00	1.8E+01
FBC	Arsenic3	22569728	LF	Saturated	4.5E-02	1.0E-01	3.9E-01	5.0E-01	6.1E-01	6.4E-01	6.6E-01	6.7E-01
FBC	Arsenic3	22569728	LF	Unsaturated	0.0E+00	4.6E-01	1.1E+00	2.1E+00	7.0E+00	1.6E+01	3.4E+01	1.5E+02
FBC	Arsenic5	15584040	LF	Saturated	3.3E+00	1.0E+01	3.4E+01	7.3E+01	9.3E+01	9.4E+01	1.6E+02	2.4E+02
FBC	Arsenic5	15584040	LF	Unsaturated	0.0E+00	1.1E+01	3.8E+01	8.2E+01	9.9E+01	1.1E+02	1.7E+02	2.5E+02
FBC	Barium	7440393	LF	Saturated	1.6E-01	2.1E-01	4.6E-01	1.4E+00	5.7E+00	7.8E+00	9.3E+00	1.1E+01
FBC	Barium	7440393	LF	Unsaturated	0.0E+00	7.7E+00	7.1E+01	2.7E+02	3.7E+02	4.7E+02	6.3E+02	1.0E+03
FBC	Boron	7440428	LF	Saturated	5.5E-07	1.3E-06	4.9E-06	6.3E-06	7.8E-06	8.1E-06	8.2E-06	8.7E-06
FBC	Boron	7440428	LF	Unsaturated	0.0E+00	1.6E-01	2.6E-01	2.0E+00	2.5E+00	3.2E+00	4.6E+00	8.2E+00
FBC	Cadmium	7440439	LF	Saturated	2.0E-01	2.5E-01	5.9E-01	2.7E+00	3.3E+00	3.4E+00	4.0E+00	5.3E+00
FBC	Cadmium	7440439	LF	Unsaturated	0.0E+00	9.5E-01	2.4E+00	6.3E+00	7.3E+00	8.5E+00	1.0E+01	2.1E+01
FBC	Cobalt	7440484	LF	Saturated	4.7E-01	1.1E+00	5.8E+00	4.4E+01	4.6E+01	7.0E+01	7.3E+01	9.5E+01
FBC	Cobalt	7440484	LF	Unsaturated	0.0E+00	2.2E+00	8.9E+00	4.1E+01	5.5E+01	7.3E+01	9.0E+01	1.1E+02
FBC	Lead	7439921	LF	Saturated	6.8E+00	9.9E+00	2.1E+01	6.9E+01	1.1E+02	1.2E+02	1.7E+02	1.8E+02
FBC	Lead	7439921	LF	Unsaturated	0.0E+00	1.3E+01	2.5E+01	8.3E+01	1.0E+02	1.3E+02	1.5E+02	2.0E+02
FBC	Mercury	7439976	LF	Saturated	1.6E-05	4.2E-05	2.2E-04	1.6E-03	3.1E-03	4.4E-03	5.8E-03	7.0E-03
FBC	Mercury	7439976	LF	Unsaturated	0.0E+00	1.1E+00	6.7E+00	1.9E+01	2.8E+01	4.5E+01	7.8E+01	2.1E+02
FBC	Molybdenum	7439987	LF	Saturated	7.5E-07	8.0E-06	1.3E-04	3.1E-03	7.8E-03	1.3E-02	2.7E-02	4.5E-02
FBC	Molybdenum	7439987	LF	Unsaturated	0.0E+00	1.5E-01	2.3E-01	6.7E-01	9.6E-01	1.3E+00	1.9E+00	3.7E+00
FBC	Nitrate/Nitrite	14797558	LF	Saturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
FBC	Nitrate/Nitrite	14797558	LF	Unsaturated	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
FBC	Selenium4	10026036	LF	Saturated	6.4E-02	1.2E+00	1.8E+01	1.2E+02	2.8E+02	4.8E+02	8.8E+02	1.4E+03
FBC	Selenium4	10026036	LF	Unsaturated	0.0E+00	2.1E+00	1.9E+01	1.5E+02	2.9E+02	4.8E+02	7.9E+02	1.3E+03

(continued)

Select Percentiles of K_d Sampled from MINTEQA2 Isotherms by Updated EPACMTP by Waste Type, Metal Species, WMU Type, and Subsurface Domain (continued)

Waste Stream	Metal	CASID	WMU	Zone	Percentiles of K_d							
					10%	25%	50%	75%	80%	85%	90%	95%
FBC	Selenium6	7782492	LF	Saturated	1.7E-08	1.8E-07	2.9E-06	5.9E-05	1.4E-04	2.3E-04	3.8E-04	6.9E-04
FBC	Selenium6	7782492	LF	Unsaturated	0.0E+00	1.4E-01	2.3E-01	1.6E+00	2.3E+00	3.5E+00	7.6E+00	2.1E+01
FBC	Thallium	7440280	LF	Saturated	9.5E-03	1.5E-02	2.3E-02	5.1E-02	5.3E-02	6.2E-02	1.1E-01	2.3E-01
FBC	Thallium	7440280	LF	Unsaturated	0.0E+00	2.3E-01	6.2E-01	1.9E+00	2.2E+00	2.7E+00	3.3E+00	5.0E+00

D.7 References

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Appendix E. Surface Water, Fish Concentration, and Contaminant Intake Equations

This appendix presents the equations used to model surface water and fish concentrations and intake of drinking water and fish. These equations are presented in the following attachments:

- **Attachment E-1** provides the equations comprising the surface water equilibrium partitioning model, including equations that estimate steady state concentrations in the water column (dissolved and total) and sediments.
- **Attachment E-2** provides the equations that use bioconcentration factors (BCFs) to calculate fish tissue concentrations from total.
- **Attachment E-3** provides the equations used to calculate daily contaminant intake rates from drinking water and fish consumption.

E.1 Aluminum Surface Water Precipitation

Because the fate and transport of aluminum is controlled more by solubility than by sorption in surface water, the surface water model includes algorithms to estimate aluminum concentrations in the water column and sediments by accounting for precipitation and fallout of aluminum in the water column. These calculations proceed in a stepwise fashion, as follows.

Step 1. Initially, assume all influent aluminum is dissolved in the water column.

Fraction in water column (fwater) = 1
Fraction in sediment layer (fbenth) = 0
Fraction dissolved (fd) = 1

Total water column concentration (Cwctot) = dissolved water column concentration (Cwd).

Step 2. Compare the dissolved water column concentration (Cwd) to the maximum soluble concentration (Csol) calculated in MINTEQA2 for the waterbody pH (see **Section 3.5.4**, Table 3-6 for aluminum solubilities and **Section C.6.3**, Table C-11 for waterbody pH).

Step 3. If the dissolved water concentration (Cwd) is greater than the solubility limit (Csol), reset the dissolved water concentration to the solubility limit, and precipitate and settle out the excess aluminum to the benthic sediment layer.

```
If Cwctot > Csol, then
        Fwater  =  Csol / Cwctot
        Fbenth  =  (Cwctot - Csol) / Cwctot
          Cwbs  =  (Cwctot - Csol) * dwc / db
         Cwtot  =  Cwctot * dwc / dz
           Cdw  =  Csol
        Cwctot  =  Csol
Else
           Cdw  =  Cwctot
          Cwbs  =  0
         Cwtot  =  Cwctot * rsParam!dwc / rsParam!dz
End If
```

where:

Cdw	=	issolved waterbody concentration
Csol	=	maximum soluble concentration
Cwbs	=	total concentration in bed sediment
Cwtot	=	total waterbody concentration from loading
db	=	depth of the upper benthic layer
dwc	=	depth of the water column
dz	=	depth of the waterbody
fbenth	=	fraction in sediment layer
fd	=	fraction dissolved
fwater	=	fraction in water column.

Table E-1-1. Fraction of Contaminant in Water Column (Unitless)

f_{Water}

$$d_w = d_z - d_b$$

$$f_{Water} = \frac{\left[1+\left(K_{dsw} \times TSS \times 0.000001\right)\right] \times \frac{d_w}{d_z}}{\left[\left[1+\left(K_{dsw} \times TSS \times 0.000001\right)\right] \times \frac{d_w}{d_z}\right] + \left[\left(bsp + K_{dbs} \times bsc\right) \times \frac{d_b}{d_z}\right]}$$

Name	Description	Value
bsc	Bed sediment particle concentration (g/cm^3) or (kg/L)	1
bsp	Bed sediment porosity (cm^3/cm^3)	0.6
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Site Data; See Appendix C
d_z	Depth of the waterbody (m)	Calculated
K_{dbs}	Sediment-water partition coefficient (mL/g)	Chemical Data; See Section 3
K_{dsw}	Suspended sediment-water partition coefficient (mL/g)	Chemical Data; See Section 3
TSS	Total suspended solids (mg/L)	Site Data; See Appendix C
0.000001	Conversion factor (L/mL)(g/mg)	

Table E-1-2. Fraction of Contaminant in Benthic Sediments (Unitless)

f_{Benth}

$$f_{Benth} = \frac{(bsp + K_{dbs} \times bsc) \times \frac{d_b}{d_z}}{\left[(1 + K_{dsw} \times TSS \times 0.000001) \times \frac{d_W}{d_z}\right] + \left[(bsp + K_{dbs} \times bsc) \times \frac{d_b}{d_z}\right]}$$

Name	Description	Value
bsc	Bed sediment particle concentration (g/cm^3) or (kg/L)	1
bsp	Bed sediment porosity (cm^3/cm^3)	0.6
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Site Data; See Appendix C
d_z	Depth of the waterbody (m)	Calculated
K_{dbs}	Sediment-water partition coefficient (mL/g)	Chemical Data; See Section 3
K_{dsw}	Suspended sediment-water partition coefficient (mL/g)	Chemical Data; See Section 3
TSS	Total suspended solids (mg/L)	Site Data; See Appendix C
0.000001	Conversion factor (L/mL)(g/mg)	

Table E-1-3. Dissolved Fraction (Unitless)

f_d

$$f_d = \frac{1}{1 + K_{dsw} \times TSS \times 0.000001}$$

Name	Description	Value
K_{dsw}	Suspended sediment-water partition coefficient (mL/g)	Chemical Data; See Section 3
TSS	Total suspended solids (mg/L)	Site Data; See Appendix C
0.000001	Conversion factor (L/mL)(g/mg)	

Table E-1-4. Liquid-Phase Transfer Coefficient - Lakes (m/day) (Mercury Only)

KL_{lakes}

$$KL_{Lakes} = \sqrt{C_d} \times u_w \times \sqrt{\frac{R_a}{R_w}} \times \frac{k^{0.33}}{L_2} \times \left(\frac{{}_w}{R_w \times D_w}\right)^{-0.67} \times 86400$$

Name	Description	Value
C_d	Drag coefficient (unitless)	0.0011
D_w	Diffusivity in water (cm^2/s)	Chemical Data; See Section 3, Table 3-4
k	von Karman's constant (unitless)	0.4
L_2	Viscous sublayer thickness (unitless)	4
${}_w$	Viscosity of water (g/cm-s)	0.0169
R_a	Density of air (g/cm^3)	0.0012
R_w	Density of water (g/cm^3)	1
u_w	Mean annual wind speed (m/sec)	Site Data; See Appendix C
86400	Conversion factor (sec/day)	

Table E-1-5. Liquid-Phase Transfer Coefficient - Rivers (m/day) (Mercury Only)

KL_{rivers}

$$KL_{Rivers} = \sqrt{\frac{D_w \times U \times 0.0001}{d_z}} \times 86400$$

Name	Description	Value
D_w	Diffusivity in water (cm^2/s)	Chemical Data; See Section 3, Table 3-4
d_z	Depth of the waterbody (m)	Calculated
U	Current velocity of the waterbody (m/s)	Site Data; See Appendix C
86400	Conversion factor (sec/day)	

Table E-1-6. Gas-Phase Transfer Coefficient - Lakes (m/day) (Mercury Only)

K_{gas}

$$K_{gas} = \sqrt{C_d} \times u_w \times \frac{k^{0.33}}{L_2} \times \left(\frac{a}{R_a \times D_a} \right)^{-0.67} \times 86400$$

Name	Description	Value
C_d	Drag coefficient (unitless)	0.0011
D_a	Diffusivity of chemical in air (cm^2/s)	Chemical Data; See Section 3, Table 3-4
k	von Karman's constant (unitless)	0.4
L_2	Viscous sublayer thickness (unitless)	4
$_A$	Viscosity of air (g/cm-s)	0.000181
R_a	Density of air (g/cm^3)	0.0012
u_w	Mean annual wind speed (m/sec)	Site Data; See Appendix C
86400	Conversion factor (sec/day)	

Table E-1-7. Diffusion Transfer Rate (m/day) (Mercury Only)

K_v

$$Tempadjust = \theta_{water}^{(T_w - T_{hlc})}$$

$$K_v = \frac{1}{\frac{1}{K_L} + \frac{1}{K_g \times H'}} \times TempAdjust$$

$$H' = \frac{HLC}{R \times T_w}$$

Name	Description	Value
HLC	Henry's Law constant (atm-m^3/mole	Chemical Data; See Section 3, Table 3-4
H'	Dimensionless Henry's Law constant (unitless)	Calculated
K_g	Gas-Phase Transfer Coefficient (m/d)	Calculated
K_L	Liquid-Phase Transfer Coefficient (m/d)	Calculated
R	Ideal Gas Constant (atm-m^3/K-mole)	0.00008205
θ_{water}	Temperature correction (unitless)	1.026
T_{hlc}	Temperature of HLC (K)	298
T_w	Temperature of the waterbody (K)	Site Data; See Appendix C

Note: Drawn from U.S. EPA, 1998 (EPA-530-D-98-001A and EPA-600/R-98/137).

Table E-1-8. Water Concentration Dissipation Rate Constant (1/day)

K_{wt}

$$K_{wt} = \left(f_{Water} \times f_d \times k_{vol}\right) + \left(f_{benth} \times K_b\right) + \left(f_{Water} \times k_{sw}\right) + \left(f_{benth} \times k_{sed}\right) + k_h$$

$$K_b = \frac{WB}{d_b}$$

$$k_{vol} = \frac{K_v}{d_w}$$

Name	Description	Value
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Site Data; See Appendix C
F_{benth}	Fraction of contaminant in benthic sediments (unitless)	Calculated
f_d	Dissolved fraction (unitless)	Calculated
f_{Water}	Fraction of contaminant in water column (unitless)	Calculated
K_b	Benthic burial rate constant (1/day)	Calculated
k_h	Hydrolysis rate (1/day)	0
k_{sed}	Degradation rate for sediment (1/day)	0
k_{sw}	Degradation rate for water column (1/day)	0
K_v	Diffusion transfer rate (m/day)	Calculated (mercury only)
k_{vol}	Water column volatilization rate constant (1/day)	Calculated (mercury only)
WB	Rate of Burial (m/day)	0

Table E-1-7. Diffusion Transfer Rate (m/day) (Mercury Only)

K_v
$$Tempadjust = \theta_{water}^{(T_w - T_{hlc})}$$ $$K_v = \frac{1}{\frac{1}{K_L} + \frac{1}{K_g \times H'}} \times TempAdjust$$ $$H' = \frac{HLC}{R \times T_w}$$

Name	Description	Value
HLC	Henry's Law constant (atm-m^3/mole	Chemical Data; See Section 3, Table 3-4
H'	Dimensionless Henry's Law constant (unitless)	Calculated
K_g	Gas-Phase Transfer Coefficient (m/d)	Calculated
K_L	Liquid-Phase Transfer Coefficient (m/d)	Calculated
R	Ideal Gas Constant (atm-m^3/K-mole)	0.00008205
θ_{water}	Temperature correction (unitless)	1.026
T_{hlc}	Temperature of HLC (K)	298
T_w	Temperature of the waterbody (K)	Site Data; See Appendix C

Note: Drawn from U.S. EPA, 1998 (EPA-530-D-98-001A and EPA-600/R-98/137).

Table E-1-10. Total Water Column Concentration (g/m^3 or mg/L)

C_{wcTot}

$$d_w = d_z - d_b$$

$$C_{wcTot} = C_{wTot} \times f_{water} \times \frac{d_z}{d_w}$$

Name	Description	Value
Cw_{Tot}	Total Waterbody Concentration from Loading (g/m^3 or mg/L)	Calculated
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Site Data; See Appendix C
d_z	Depth of the waterbody (m)	Calculated
f_{Water}	Fraction of contaminant in water column (unitless)	Calculated

Table E-1-11. Dissolved Waterbody Concentration (mg/L)

C_{dw}

$$d_w = d_z - d_b$$

$$C_{dw} = Cw_{Tot} \times f_{Water} \times f_d \times \frac{d_Z}{d_w}$$

Name	Description	Value
Cw_{Tot}	Total Waterbody Concentration from Loading (g/m^3 or mg/L)	Calculated
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Site Data; See Appendix C
d_z	Depth of the waterbody (m)	Calculated
f_d	Dissolved fraction (unitless)	Calculated
f_{Water}	Fraction of contaminant in water column (unitless)	Calculated

Table E-1-12. Total Concentration in Bed Sediment (g/m^3 or mg/L)

C_{wbs}

$$d_z = d_w + d_b$$

$$C_{bs} = C_{wTot} \times f_{benth} \times \frac{d_z}{d_b}$$

Name	Description	Value
Cw_{Tot}	Total Waterbody Concentration from Loading (g/m^3 or mg/L)	Calculated
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Site Data; See Appendix C
d_z	Depth of the waterbody (m)	Calculated

Table E-2-1. Concentration in Fish at Different Trophic Levels (mg/kg)

C_{fish}

For Mercury:

$$C_{fish} = 0.15 * C_{dw} \times BCF$$

For Non-Volatile Metals:

$$C_{fish} = Cw_{tot} \times BCF$$

Name	Description	Value
BCF	Bioconcentration factor for specified trophic level (L/kg)	Chemical Data; See Section 3
C_{dw}	Dissolved waterbody concentration (mg/L)	Calculated
Cw_{Tot}	Total waterbody concentration from loading (g/m^3 or mg/L)	Calculated
0.15	Fraction of dissolved mercury assumed to be methyl mercury (unitless)	

Table E-2-2. Average Fish Fillet Concentration Ingested by Humans (mg/kg)

C_{fish_fillet}

$$C_{fish\_fillet} = F_{T3} \times C_{fishT3F} + F_{T4} \times C_{fishT4F}$$

Name	Description	Value
$C_{fishT3F}$	Concentration of contaminant in fish at different trophic levels (mg/kg)	Calculated
$C_{fishT4F}$	Concentration of contaminant in fish at different trophic levels (mg/kg)	Calculated
F_{T3}	Fraction of trophic level 3 intake (unitless)	0.36
F_{T4}	Fraction of trophic level 4 intake (unitless)	0.64

Table E-3-1. Contaminant Intake from Drinking Water (mg/kg-d)

Idw

$$I_{dw} = \frac{C_{dw} \times CR_{dw} \times F_{dw}}{BW * 1000}$$

Name	Description	Value
BW	Body weight (kg)	Exposure Data; See Appendix F
C_{dw}	Dissolved waterbody concentration (mg/L)	Calculated
CR_{dw}	Consumption rate of water (mL/day)	Exposure Data; See Appendix F
F_{dw}	Fraction of drinking water ingested that is contaminated (unitless)	1
1000	Conversion factor (mL/L)	

Table E-3-2. Daily Intake of Contaminant from Fish Ingestion (mg/kg BW/day)

I_{fish}

$$I_{fish} = \frac{C_{fish\_fillet} \times CR_{fish} \times F_{fish}}{1000 \times BW}$$

Name	Description	Value
BW	Body weight (kg)	Exposure Data; See Appendix F
C_{fish_fillet}	Average fish fillet concentration ingested by humans (mg/kg)	Calculated
CR_{fish}	Consumption rate of fish (g WW/day)	Exposure Data; See Appendix F
F_{fish}	Fraction of fish intake from contaminated source (unitless)	1
1000	Conversion factor (g/kg)	

Appendix F. Human Exposure Factors

Exposure factors are data that quantify human behavior patterns (e.g., ingestion rates of fish and drinking water) and characteristics (e.g., body weight) that affect a person's exposure to environmental contaminants. These data can be used to construct realistic assumptions concerning an individual's exposure to and subsequent intake of a contaminant in the environment. The exposure factors data also enable EPA to differentiate the exposures of individuals of different ages (e.g., a child vs. an adult). The derivation and values used for the human exposure factors in this risk assessment are described below, and the exposure factors selected for the probabilistic analyses are also presented.

F.1 Exposure Parameters Used in Probabilistic Analysis

F.1.1 Introduction

The general methodology for collecting human exposure data for the probabilistic analysis relied on the *Exposure Factors Handbook*, or EFH (U.S. EPA, 1997a-c), which was used in one of three ways:

1. When EFH percentile data were adequate (most input variables), maximum likelihood estimation was used to fit selected parametric models (gamma, lognormal, Weibull, and generalized gamma) to the EFH data. The chi-square measure of goodness of fit was then used to choose the best distribution. Parameter uncertainty information (e.g., for averages, standard deviations) also was derived using the asymptotic normality of the maximum likelihood estimate or a regression approach.

2. When EFH percentile data were not adequate for statistical model fitting (a few variables), models were selected on the basis of results for other age cohorts or, if no comparable information was available, by assuming lognormal as a default distribution and reasonable coefficients of variation (CVs).

3. When data were not adequate for either 1 or 2 above, variables were fixed at EFH-recommended mean values or according to established EPA policy.

Table F-1 lists all of the parameters used in the probabilistic analysis. Both fixed variables and the values used to define distributed data are provided.

Probabilistic risk analyses involve "sampling" values from probability distribution functions (PDFs) and using the values to estimate risk. In some cases, distributions are infinite, and there is a probability, although very small, that very large or very small values might be selected from the distributions. Because selecting extremely large or extremely small values is unrealistic (e.g., the range of adult body weights is not infinite), maximum and minimum values were imposed on the distributions. The minimum and maximum values are included in Table F-1.

F.1.2 Exposure Parameter Distribution Methodology

This section describes how stochastic or distributed input data for each exposure factor were collected and processed. Exposure parameter distributions were developed for use in the Monte Carlo analysis. For most variables for which distributions were developed, exposure factor data from the EFH were analyzed to fit selected parametric models (i.e., gamma, lognormal, Weibull). Steps in the development of distributions included preparing data, fitting models, assessing fit, and preparing parameters to characterize distributional uncertainty in the model inputs.

For many exposure factors, EFH data include sample sizes and estimates of the following parameters for specific receptor types and age groups: mean, standard deviation, standard error, and percentiles corresponding to a subset of the following probabilities: 0.01, 0.02, 0.05, 0.10, 0.15, 0.25, 0.50, 0.75, 0.85, 0.90, 0.95, 0.98, and 0.99. These percentile data, where available, were used as a basis for fitting distributions. Although in no case were all of these percentiles actually provided for a single factor, seven or more are typically present in the EFH data. Therefore, using the percentiles was a fuller use of the available information than fitting distributions simply based on the method of moments (e.g., selecting models that agree with the data mean and standard deviation). For some factors, certain percentiles were not used in the fitting process because sample sizes were too small to justify their use. Percentiles were used only if at least one data point was in the tail of the distribution. If the EFH data repeated a value across several adjacent percentiles, only one value (the most central or closest to the median) was used in most cases (e.g., if both the 98th and 99th percentiles had the same value, only the 98th percentile value was used).

The EFH does not use standardized age cohorts across exposure factors. Data for different exposure factors are reported for different age categories. Therefore, to obtain the percentiles for fitting the four standardized age cohorts (i.e., ages 1 to 5, 6 to 11, 12 to 19, and more than 20), each EFH cohort-specific value for a given exposure factor was assigned to one of these four cohorts. When multiple EFH cohorts fitted into a single CCW cohort, the EFH percentiles were averaged within each CCW cohort (e.g., data on 1- to 2-year-olds and 3- to 5-year-olds from EFH were averaged for the CCW 1- to 5-year-old cohort). If sample sizes were available, weighted averages were used, with weights proportional to sample sizes. If sample sizes were not available, equal weights were assumed (i.e., the percentiles were simply averaged).

Table F-1. Summary of Exposure Parameters Used in Probabilistic Analysis

Parameter	Units	Variable Type	Constants	Mean (or shape)	Std Dev (or scale)	Minimum	Maximum	Reference
Averaging time for carcinogens	yr	Constant	7.00E+01					U.S. EPA (1989)
Body weight (adult)	kg	Lognormal		7.12E+01	1.33E+01	1.50E+01	3.00E+02	U.S. EPA (1997a); Tables 7-2, 7-4, 7-5
Body weight (child 1)	kg	Lognormal		1.55E+01	2.05E+00	4.00E+00	5.00E+01	U.S. EPA (1997a); Tables 7-3, 7-6, 7-7
Body weight (child 2)	kg	Lognormal		3.07E+01	5.96E+00	6.00E+00	2.00E+02	U.S. EPA (1997a); Tables 7-3, 7-6, 7-7
Body weight (child 3)	kg	Lognormal		5.82E+01	1.02E+01	1.30E+01	3.00E+02	U.S. EPA (1997a); Tables 7-3, 7-6, 7-7
Consumption rate: fish (adult, child)	g/d	Lognormal		6.48E+00	1.99E+01	0.00E+00	1.50E+03	U.S. EPA (1997b); Table 10-64
Exposure duration (adult resident)	yr	Weibull		1.34E+00	1.74E+01	1.00E+00	5.00E+01	U.S. EPA (1999) (ACS)
Exposure duration (child)	yr	Weibull		1.32E+00	7.06E+00	1.00E+00	5.00E+01	U.S. EPA (1999) (ACS)
Exposure frequency (adult resident)	d/yr	Constant	3.50E+02					U.S. EPA Policy
Fraction contaminated: drinking water	Fraction	Constant	1.00E+00					U.S. EPA Policy
Fraction contaminated: fish	Fraction	Constant	1.00E+00					U.S. EPA Policy
Fraction of fish consumed that is trophic level (T3) fish	Fraction	Constant	3.60E-01					U.S. EPA (1997b); Table 10-66
Fraction of fish consumed that is trophic level 4 (T4) fish	Fraction	Constant	6.40E-01					U.S. EPA (1997b); Table 10-66
Ingestion rate: drinking water (adult resident)	mL/d	Gamma		3.88E+00	3.57E+02	1.04E+02	1.10E+04	U.S. EPA (1997a); Table 3-6
Ingestion rate: drinking water (child 1 resident)	mL/d	Gamma		2.95E+00	2.37E+02	2.60E+01	3.84E+03	U.S. EPA (1997a); Table 3-6
Ingestion rate: drinking water (child 2 resident)	mL/d	Gamma		3.35E+00	2.35E+02	3.40E+01	4.20E+03	U.S. EPA (1997a); Table 3-6
Ingestion rate: drinking water (child 3 resident)	mL/d	Gamma		2.82E+00	3.42E+02	3.30E+01	5.40E+03	U.S. EPA (1997a); Table 3-6

Because the EFH data are always positive and are almost always skewed to the right (i.e., have a long right tail), three two-parameter probability models commonly used to characterize such data (gamma, lognormal, and Weibull) were selected. In addition, a three-parameter model (generalized gamma) was used that unifies them[1] and allows for a likelihood ratio test of the fit of the two-parameter models. However, only the two-parameter models were selected for use in the analysis because the three-parameter generalized gamma model did not significantly improve the goodness of fit over the two-parameter models. This simple setup constitutes a considerable improvement over the common practice of using a lognormal model in which adequate EFH data are available to support maximum likelihood estimation.

Lognormal, gamma, Weibull, and generalized gamma distributions were fit to each factor data set using maximum likelihood estimation (Burmaster and Thompson, 1998). When sample sizes were available, the goodness of fit was calculated for each of the four models using the chi-square test (Bickel and Doksum, 1977). When percentile data were available but sample sizes were unknown, a regression F-test for the goodness of fit against the generalized gamma model was used. For each of the two-parameter models, parameter uncertainty information (i.e., mean, standard deviation, scale, and shape) was provided as parameter estimates for a bivariate normal distribution that could be used for simulating parameter values (Burmaster and Thompson, 1998). The information necessary for such simulations includes estimates of the two model parameters, their standard errors, and their correlation. To obtain this parameter uncertainty information, the asymptotic normality of the maximum likelihood estimate (Burmaster and Thompson, 1998) was used when sample sizes were available, and a regression approach was used when sample sizes were not available (Jennrich and Moore, 1975; Jennrich and Ralston, 1979). In either case, uncertainty can be expressed as a bivariate normal distribution for the model parameters.

The parameter values selected are described in more detail in the following subsections. **Section F.1.3** discusses fixed parameters. **Section F.1.4** describes, for each exposure factor, the EFH data used to develop the distributions, along with the final distributional statistics.

F.1.3 Fixed Parameters

Certain parameters were fixed, based on central tendency values from the best available source (usually EFH recommendations), either because no variability was expected or because the available data were not adequate to generate distributions. Fixed (constant) parameters are shown in **Table F-2** along with the value selected for the risk analysis and the data source. These constants included variables for which limited or no percentile data were provided in the EFH: exposure frequency, fractions of T3 and T4 fish consumed, and fraction contaminated for the various media. Most of these values were extracted directly from the EFH. When evaluating carcinogens, total dose was averaged over the lifetime of the individual, assumed to be 70 years.

[1] Gamma, Weibull, and lognormal distributions are all special cases of the generalized gamma distribution.

Table F-2. Summary of Human Exposure Factor Data Used in Modeling: Constants

Description	Value	Units	Source
Fraction contaminated: drinking water	1	Fraction	EPA policy
Fraction contaminated: fish	1	Fraction	EPA policy
Fraction of T3 fish consumed	0.36	Fraction	U.S. EPA (1997b); Table 10-66
Fraction of T4 fish consumed	0.64	Fraction	U.S. EPA (1997b); Table 10-66
Exposure frequency (adult, child)	350	d/yr	EPA policy
Averaging time for carcinogens (adult, child)	70	yr	U.S. EPA (1989)

The fraction contaminated for drinking water was assumed to be 1 (i.e., all drinking water available for consumption at a site is potentially contaminated), with actual concentrations depending on fate and transport model results. Thus, households for which the drinking water pathway was analyzed were assumed to get 100 percent of their drinking water from groundwater. Exposure frequency was set to 350 days per year in accordance with EPA policy, assuming that residents take an average of 2 weeks' vacation time away from their homes each year.

F.1.4 Variable Parameters

F.1.4.1 Fish Consumption

Table F-3 presents fish consumption data and distributions. Fish consumption data were obtained from Table 10-64 of the EFH (U.S. EPA, 1997b). Data (in g/d) were available for adult freshwater anglers in Maine. The Maine fish consumption study was one of four recommended freshwater angler studies in the EFH (U.S. EPA, 1997b). The other recommended fish consumption studies (i.e., Michigan and New York) had large percentages of anglers who fished from Great Lakes, which is not consistent with the modeling scenarios used in this risk analysis. The anglers in the Maine study fished from streams, rivers, and ponds; these data were more consistent with the CCW modeling scenarios. Although the Maine data have a lower mean than the Michigan data, the Maine data compared better with a national U.S. Department of Agriculture (USDA) study. Also, the Maine study included percentile data, which were necessary to develop a distribution.

Percentile data were used to fit parametric models (gamma, lognormal, and Weibull), and measures of goodness of fit were used to select lognormal as the most appropriate model. The fraction of fish intake that is locally caught was assumed to be 1 (in accordance with EPA policy). The fraction of consumed T3 and T4 fish was 0.36 and 0.64, respectively (Table 10-66, U.S. EPA, 1997b).

Table F-3. Fish Consumption Data and Distribution

EFH Data (g/d)									Distribution		
Age Cohort	N	Data Mean	Data SD	P50	P66	P75	P90	P95	Distribution	Pop-Estd Mean	Pop-Estd SD
All ages	1,053	6.4		2	4	5.8	13	26	Lognormal	6.48	19.9

N = Number of samples; P50–P95 = Percentiles; Pop-Estd = Population-estimated; SD = Standard deviation.

F.1.4.2 Drinking Water Intake

Table F-4 presents drinking water intake data and distributions. Drinking water intake data were obtained from Table 3-6 of the EFH (U.S. EPA, 1997a). Data (in mL/d) were presented by age groups. Weighted averages of percentiles, means, and standard deviations were calculated for the three child age groups and adults. Percentile data were used to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model. The fraction of drinking water contaminated was assumed to be 1 (in accordance with EPA policy).

Table F-4. Drinking Water Intake Data and Distributions

EFH Data (mL/d)													Distributions		
Age Cohort	**N**	**Data Mean**	**Data SD**	**P01**	**P05**	**P10**	**P25**	**P50**	**P75**	**P90**	**P95**	**P99**	**Distribution**	**Pop-Estd Mean**	**Pop-Estd SD**
1–5	3,200	697.1	401.5	51.62	187.6	273.5	419.2	616.5	900.8	1,236	1,473	1,917	Gamma	698	406
6–11	2,405	787	417	68	241	318	484	731	1,016	1,338	1,556	1,998	Gamma	787	430
12–19	5,801	963.2	560.6	65.15	241.4	353.8	574.4	868.5	1,247	1,694	2,033	2,693	Gamma	965	574
20+	13,394	1,384	721.6	207.6	457.5	607.3	899.6	1,275	1,741	2,260	2,682	3,737	Gamma	1,383	703

N = Number of samples; P01–P99 = Percentiles; Pop-Estd = Population-estimated; SD = Standard deviation.

F.1.4.3 Body Weight

Table F-5 presents body weight data and distributions. Body weight data were obtained from Tables 7-2 through 7-7 of the EFH (U.S. EPA, 1997a). Data (in kg) were presented by age and gender. Weighted averages of percentiles, means, and standard deviations were calculated for 1- to 5-year-olds, 6- to 11-year-olds, 12- to 19-year olds, and adult age groups; male and female data were weighted and combined for each age group. These percentile data were used as the basis for fitting distributions. These data were analyzed to fit parametric models (gamma, lognormal, and Weibull) using maximum likelihood estimation. Measures of goodness of fit were used to select the most appropriate model.

Table F-5. Body Weight Data and Distributions

EFH Data (kg)													Distributions		
Age Cohort	**N**	**Data Mean**	**Data SD**	**P05**	**P10**	**P15**	**P25**	**P50**	**P75**	**P85**	**P90**	**P95**	**Distribution**	**Pop-Estd Mean**	**Pop-Estd SD**
1–5	3,762	15.52	3.719	12.5	13.1	13.45	14.03	15.26	16.67	17.58	18.32	19.45	Lognormal	15.5	2.05
6–11	1,725	30.84	9.561	22.79	24.05	25.07	26.44	29.58	33.44	36.82	39.66	43.5	Lognormal	30.7	5.96
12–19	2,615	58.45	13.64	43.84	46.52	48.31	50.94	56.77	63.57	68.09	71.98	79.52	Lognormal	58.2	10.2
20+	12,504	71.41	15.45	52.86	55.98	58.21	61.69	69.26	78.49	84.92	89.75	97.64	Lognormal	71.2	13.3

N = Number of samples; P05–P95 = Percentiles; Pop-Estd = Population-estimated; SD = Standard deviation.

F.1.4.4 Exposure Duration

Table F-6 presents exposure duration data and distributions. Exposure duration was assumed to be equivalent to the average residence time for each receptor. Exposure durations for adult and child residents were determined using data on residential occupancy from the EFH Table 15-168 (U.S. EPA, 1997c). The data represent the total time a person is expected to live at a single location, based on age. The table presents male and female data combined. Adult residents aged 21 to 90 were pooled. For child residents, the 3-year-old EFH age group was used for the 1- to 5-year-old CCW cohort. The 6- and 9-year-old EFH age groups were pooled for the 6- to 11-year-old CCW cohort.

Table F-6. Exposure Duration Data and Distributions

EFH Data		Distributions		
Age Cohort	Data Mean (yr)	Distribution	Pop-Estd Shape (yr)[a]	Pop-Estd Scale (yr)
1–5	6.5	Weibull	1.32	7.059
6–11	8.5	Weibull	1.69	9.467
Adult	16.0	Weibull	1.34	17.38

Pop-Estd = Population-estimated.
[a] Distributions used in risk assessment.

In an analysis of residential occupancy data, Myers et al. (U.S. EPA, 2000) found that the data, for most ages, were best fit by a Weibull distribution. The Weibull distribution as implemented in Crystal Ball is characterized by three parameters: location, shape, and scale. Location is the minimum value and, in this case, was presumed to be 0. Shape and scale were determined by fitting a Weibull distribution to the pooled data, as follows. To pool residential occupancy data for the age cohorts, an arithmetic mean of data means was calculated for each age group. Then, assuming a Weibull distribution, the variance within each age group (e.g., 6-year-olds) was calculated in the age cohort. These variances in turn were pooled over the age cohort using equal weights. This is not the usual type of pooled variance, which would exclude the variation in the group means. However, this way, the overall variance reflected the variance of means within the age groups (e.g., within the 6-year-old age group). The standard deviation was estimated as the square root of the variance. The coefficient of variation was calculated as the ratio of the standard deviation divided by the Weibull mean. For each cohort, the population-estimated parameter uncertainty information (e.g., shape and scale) was calculated based on a Weibull distribution, the calculated data mean for the age cohort, and the CV.

F.2 Exposure Parameters Used in Screening Analysis

The 50th percentile values used for the human exposure factors in the screening analysis are presented in **Table F-7**.

Table F-7. 50th Percentile Exposure Data Used in the Screening Analysis

Parameter	Value	Age Cohort				Units	Reference	Table
		1–5 yr	6–11 yr	12–19 yr	20+ yr			
Body weight		15.3	29.6	56.8	69.3	kg	U.S. EPA (1997a)	T7-2, 7-3, 7-4, 7-5, 7-6, 7-7
Consumption rate of fish		2	2	2	2	g WW/d	U.S. EPA (1997b)	T10-64
Exposure duration		5	7.5	8	10	yr	U.S. EPA (1997c)	T15-164, 15-168
Ingestion rate of drinking water		0.6165	0.731	0.8685	1.275	L/d	U.S. EPA (1997a)	T3-6

F.3 References

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Appendix G. Human Health Benchmarks

The CCW screening analysis and risk assessment require human health benchmarks to assess potential risks from chronic oral exposures. EPA uses reference doses (RfDs) to evaluate noncancer risk from oral exposures. Oral cancer slope factors (CSFs) are used to evaluate risk for carcinogens. This appendix provides the human health benchmarks used in the CCW screening and risk assessment. **Section G.1** describes the data sources and general hierarchy used to collect these benchmarks. **Section G.2** provides the benchmarks along with discussions of individual human health benchmarks extracted from a variety of sources.

G.1 Methodology and Data Sources

Several sources of health benchmarks are available. The hierarchy used health benchmarks developed by EPA to the extent that they were available. The analysis used available benchmarks from non-EPA sources for chemicals for which EPA benchmarks were not available, and ranked human health benchmark sources in the following order of preference:

- Integrated Risk Information System (IRIS)
- Superfund Technical Support Center Provisional Benchmarks
- Health Effects Assessment Summary Tables (HEAST)
- EPA health assessment documents
- Various other EPA health benchmark sources
- Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRLs)
- California Environmental Protection Agency (CalEPA) chronic inhalation reference exposure levels (RELs) and cancer potency factors.

G.1.1 Integrated Risk Information System (IRIS)

Benchmarks in IRIS are prepared and maintained by EPA, and RTI used values from IRIS whenever available. IRIS is EPA's electronic database containing information on human health effects (U.S. EPA, 2009). Each chemical file contains descriptive and quantitative information on potential health effects. Health benchmarks for chronic noncarcinogenic health effects include RfDs and inhalation reference concentrations (RfCs). Cancer classification, oral CSFs, and inhalation unit risk factors (URFs) are included for carcinogenic effects. IRIS is the official repository of Agency-wide consensus of human health risk information.

G.1.2 Superfund Provisional Benchmarks

The Superfund Technical Support Center (EPA's National Center for Environmental Assessment [NCEA]) derives provisional RfCs, RfDs, and CSFs for certain chemicals. Some of the provisional values have been externally peer reviewed. These provisional values have not undergone EPA's formal review process for finalizing benchmarks and do not represent Agency-wide consensus information.

G.1.3 Health Effects Assessment Summary Tables

HEAST is a listing of provisional noncarcinogenic and carcinogenic health toxicity values (RfDs, RfCs, URFs, and CSFs) derived by EPA (U.S. EPA, 1997). Although the health toxicity values in HEAST have undergone review and have the concurrence of individual EPA program offices, either they have not been reviewed as extensively as those in IRIS or their data set is not complete enough to be listed in IRIS. HEAST benchmarks have not been updated in several years and do not represent Agency-wide consensus information.

G.1.4 Other EPA Health Benchmarks

EPA has also derived health benchmark values in other risk assessment documents, such as Health Assessment Documents (HADs), Health Effects Assessments (HEAs), Health and Environmental Effects Profiles (HEEPs), Health and Environmental Effects Documents (HEEDs), Drinking Water Criteria Documents, and Ambient Water Quality Criteria Documents. Evaluations of potential carcinogenicity of chemicals in support of reportable quantity adjustments were published by EPA's Carcinogen Assessment Group (CAG) and may include cancer potency factor estimates. Health benchmarks derived by EPA for listing determinations (e.g., solvents) or studies (e.g., Air Characteristic Study) are also available. Health toxicity values identified in these EPA documents are usually dated and are not recognized as Agency-wide consensus information or verified benchmarks.

G.1.5 ATSDR Minimal Risk Levels

The ATSDR MRLs are substance-specific health guidance levels for noncarcinogenic endpoints (ATSDR, 2009). An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. MRLs are based on noncancer health effects only and are not based on a consideration of cancer effects. MRLs are derived for acute, intermediate, and chronic exposure durations for oral and inhalation routes of exposure. Inhalation and oral MRLs are derived in a manner similar to EPA's RfCs and RfDs, respectively (i.e., ATSDR uses the no observed adverse effect level/uncertainty factor [NOAEL/UF] approach); however, MRLs are intended to serve as screening levels and are exposure duration specific. Also, ATSDR uses EPA's (U.S. EPA, 1994) inhalation dosimetry methodology in the derivation of inhalation MRLs.

G.1.6 CalEPA Cancer Potency Factors and Reference Exposure Levels

CalEPA has developed cancer potency factors for chemicals regulated under California's Hot Spots Air Toxics Program (CalEPA, 1999a). The cancer potency factors are analogous to EPA's oral and inhalation CSFs. CalEPA has also developed chronic inhalation RELs, analogous to EPA's RfC, for 120 substances (CalEPA, 1999b, 2000, 2008). CalEPA used EPA's inhalation dosimetry methodology (U.S. EPA, 1994) in the derivation of inhalation RELs. The cancer potency factors and inhalation RELs have undergone internal peer review by various California agencies and have been the subject of public comment.

G.1.7 Surrogate Health Benchmarks

If no human health benchmarks were available from EPA or alternative sources, we sought benchmarks for similar chemicals to use as surrogate data. For example, the health benchmark of a mixture could serve as the surrogate benchmark for its components or a benchmark of a metal salt could serve as the surrogate for an elemental metal.

G.2 Human Health Benchmarks

The chronic human health benchmarks used to calculate the health-based numbers (HBNs) in the CCW screening analysis and risk assessment are summarized in **Table G-1**, which provides the Chemical Abstract Service Registry Number (CASRN), constituent name, RfD (mg/kg-d), oral CSF (mg/kg-d^{-1}), and reference for each benchmark. A key to the references cited and abbreviations used is provided at the end of the table.

For a majority of constituents, human health benchmarks were available from IRIS (U.S. EPA, 2009), Superfund Provisional Benchmarks, or HEAST (U.S. EPA, 1997). Benchmarks also were obtained from ATSDR (2009) or CalEPA (1999a, 1999b, 2000, 2008). This section describes benchmarks obtained from other sources, along with the Superfund Provisional Benchmarks values and special uses of IRIS benchmarks.

Table G-1. Human Health Benchmarks Used in CCW Risk Assessment

Constituent Name	CASRN	RfD (mg/kg-d)	Ref	CSFo (per mg/kg-d)	Ref	MCL (mg/L)	Notes
Aluminum	7429-90-5	1.0E+00	P				
Antimony	7440-36-0	4.0E-04	I				
Arsenic, inorganic	7440-38-2	3.0E-04	I	1.5E+0	I		
Barium	7440-39-3	2.0E-01	I				
Beryllium	7440-41-7	2.0E-03	I				
Boron	7440-42-8	2.0E-01	I				
Cadmium	7440-43-9	5.0E-04	I				RfD for H_2O (food = 1E-3)
Chloride	16887-00-6					250	
Chromium (III), insoluble salts	16065-83-1	1.5E+00	I				
Chromium (VI)	18540-29-9	3.0E-03	I				
Cobalt (and compounds)	7440-48-4	3.0E-04	P				
Copper	7440-50-8	1.0E-02	A			1.3	RfD is the intermediate oral MRL
Cyanide (amenable)	57-12-5	2.0E-02	I				

(continued)

Human Health Benchmarks Used in CCW Risk Assessment (continued)

Constituent Name	CASRN	RfD (mg/kg-d)	Ref	CSFo (per mg/kg-d)	Ref	MCL (mg/L)	Notes
Divalent mercury		3.0E-04	H				RfD is for mercuric chloride; used for food, water, soil
		1.0E-04	I				RfD is for methyl mercury; used for fish only
Fluoride	16984-48-8	1.2E-01	I				RfD is for fluorine; the alternative IRIS value (for skeletal, rather than dental, fluorosis) was used
Iron	7439-89-6	7.0E-01	P				
Lead and compounds (inorganic)	7439-92-1					0.015	
Manganese	7439-96-5	1.4E-01	I				RfD for food; H_2O and soil = 4.7E-2 mkd
Molybdenum	7439-98-7	5.0E-03	I				
Nickel, soluble salts	7440-02-0	2.0E-02	I				
Nitrate	14797-55-8	1.6E+00	I			10	
Nitrite	14797-65-0	1.0E-01	I				
Selenium	7782-49-2	5.0E-03	I				
Silver	7440-22-4	5.0E-03	I				
Strontium	7440-24-6	6.0E-01	I				
Sulfate	14808-79-8					250	
Thallium, elemental	7440-28-0	8.0E-05	I				RfD is for thallium chloride
Vanadium	7440-62-2	7.0E-03	H				
Zinc	7440-66-6	3.0E-01	I				

Key:
CASRN = Chemical Abstract Service registry number.
CSFo = Oral cancer slope factor.
RfD = Reference dose.
MCL = Maximum Contaminant Level.
Sources:
A = ATSDR MRLs (ATSDR, 2009)
H = HEAST (U.S. EPA, 1997)
I = IRIS (U.S. EPA, 2009)
P = PPRTV (U.S. EPA, 2006a, 2006b, 2008)

The provisional RfD of 1 mg/kg-d developed by NCEA for the Superfund Technical Support Center (U.S. EPA, 2006a) was used for aluminum.

The provisional RfD of 0.0003 mg/kg-d developed by NCEA for the Superfund Technical Support Center (U.S. EPA, 2008) was used for cobalt.

The provisional RfD of 0.7 mg/kg-d developed by NCEA for the Superfund Technical Support Center (U.S. EPA, 2006b) was used for iron.

For several constituents, IRIS benchmarks for similar chemicals were used as surrogate data. The rationale for these recommendations is as follows:

- Fluoride was based on fluorine. The IRIS RfD for fluorine is based on soluble fluoride. The primary RfD cited in IRIS (6E-02 mg/kg-d) is for dental fluorosis, a cosmetic effect. In this analysis, an alternative IRIS value (1.2E-01 mg/kg-d) for skeletal fluorosis in adults was used instead.

- Thallium was based on thallium chloride. IRIS contains RfDs for several thallium salts. The lowest value among the thallium salts (8E-05 mg/kg-d) is routinely used to represent thallium in risk assessments.

G.3 References

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U.S. EPA (Environmental Protection Agency). 2008. *Provisional Peer Reviewed Toxicity Values for Cobalt (CASRN 7440-48-4).* 8-25-2008. National Center for Environmental Assessment. Superfund Technical Support Center, Cincinnati, OH.

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Appendix H. Ecological Benchmarks

Both the screening and full-scale CCW assessments included an ecological risk assessment that paralleled the human health risk assessment. The ecological risk assessment addressed two routes of exposure for ecological receptors: direct contact with contaminated media and ingestion of contaminated food items. For each CCW chemical for which ecological effect data were available, hazard quotients (HQs) were calculated using chemical-specific media concentrations assumed to be protective of ecological receptors of concern.

This appendix provides the ecological benchmarks used in both the CCW screening and full-scale risk assessment. **Section H.1** describes the data sources and methods used to develop these benchmarks. Additional details can be found in U.S. EPA (1998). **Section H.2** provides the benchmarks.

H.1 Data Sources and Methodology

To calculate ecological HQs, the concentration-based ecological benchmarks (also known as chemical stressor concentration limits, or CSCLs) were divided by the estimated concentrations of constituents in environmental media contaminated by CCW. The CSCLs are environmental quality criteria intended to represent a protective threshold value for adverse effects to various ecological receptors in aquatic ecosystems (surface water and sediment). An HQ greater than target of 1 indicates that the predicted concentration will be above the CSCL and, therefore, the potential for adverse ecological effects exists. In this regard, the use of CSCLs to calculate an ecological HQ is analogous to the use of the reference concentration (RfC) for human health where the air concentration is compared to the health-based concentration (the RfC), and an HQ greater than the target value of 1 is considered to indicate the potential for adverse health effects. **Table H-1** shows the receptor types assessed for each exposure route in each environmental medium addressed by the CCW risk assessment.

Table H-1. Ecological Receptors Assessed by Medium Impacted by CCW

Receptor Type	Surface Water	Sediment
Direct Contact Exposure		
Aquatic Community	✔	
Sediment Community		✔
Amphibians	✔	
Aquatic Plants and Algae	✔	
Ingestion Exposure		
Mammals	✔	
Birds	✔	

Ecological benchmarks for the CCW risk assessment were taken directly from the 1998 fossil fuel combustion risk analysis, *Non-Groundwater Pathways, Human Health and Ecological*

Risk Analysis for Fossil Fuel Combustion Phase 2 (FFC2) (U.S. EPA, 1998). The receptors and endpoints selected for the 1998 analysis were evaluated and considered appropriate for the goals of this risk assessment. The benchmarks were derived for each chemical and receptor to the extent that supporting data were available.

As in 1998, the lowest (most sensitive) benchmark for each chemical in each medium was selected to calculate HQs in the CCW risk assessment. For example, several receptors (aquatic invertebrates, mammals, and birds) may be exposed to constituents in surface water. The surface water HQ for a given chemical was calculated using whichever benchmark was lowest and would thus give the highest (most protective) HQ.

H.1.1 Direct Contact Exposure

Ecological receptors that live in close contact with contaminated media are considered to be potentially at risk. These receptors are exposed through direct contact with contaminants in surface water and sediment. The receptors selected to assess the direct contact exposure route for each medium are summarized in Table H-1. The benchmarks for receptor communities are not truly *community-level* concentration limits in that they do not consider predator-prey interactions. Rather, they are based on the theory that protection of 95 percent of the species in the community will provide a sufficient level of protection for the community (see, for example, Stephan et al., 1985, for additional detail). The following sections summarize the benchmark derivation methods for each receptor assessed for the direct contact route of exposure.

Aquatic Community Benchmarks

The aquatic community receptor comprises fish and aquatic invertebrates exposed through direct contact with constituents in surface water. For the aquatic community, the final chronic value (FCV), developed either for the Great Lakes Water Quality Initiative (U.S. EPA, 1993) or the National Ambient Water Quality Criteria (NAWQC) (U.S. EPA, 1995a,b), was the preferred source for the benchmark. If an FCV was unavailable and could not be calculated from available data, a secondary chronic value (SCV) was estimated using methods developed for wildlife criteria for the Great Lakes Initiative (e.g., 58 FR 20802; U.S. EPA, 1993). The SCV methodology is based on the original species data set established for the NAWQC; however, it requires fewer data points and includes statistically derived adjustment factors. For benchmark derivation, the minimum data set required at least one data point.

Amphibian Benchmarks

For amphibian populations, data availability severely limited benchmark development. A review of several compendia presenting amphibian ecotoxicity data (e.g., U.S. EPA, 1996; Power et al., 1989), as well as primary literature sources, found a lack of standard methods on endpoints, species, and test durations necessary to derive a chronic benchmark for amphibians. Consequently, an acute benchmark was derived for aqueous exposures in amphibians by taking a geometric mean of LC_{50} (i.e., concentration lethal to 50 percent of test subjects) data identified in studies with exposure durations less than 8 days. Although the use of acute effects levels produced a benchmark that was not consistent with the other (chronic) ecological benchmarks, the sensitivity of these receptors warranted the use of acute effects levels in the absence of chronic concentration limits. Recent studies (Hopkins and Rowe, 2004; Hopkins et al., 2006) have confirmed that amphibians are among the most sensitive taxa to metals found in CCW, and selenium appears to be a significant stressor in CCW disposal scenarios. The endpoints considered in these studies were related to population sustainability and, consequently, are highly relevant to ecological risk assessment. However, these field studies were confounded by the fact that wildlife were exposed to multiple chemical pollutants (including radionuclides) and, as a result, acute effects data on individual metals remain the most appropriate source for quantitative benchmarks to assess the potential for adverse effects in amphibians.

Sediment Community Benchmarks

For the sediment community, benchmarks were selected based on a complete assessment of several sources proposing sediment benchmark values. Primary sources evaluated for developing sediment community benchmarks are shown in **Table H-2**.

Table H-2. Primary Sources Evaluated for Developing Sediment Community Benchmarks

Long, E.R., and L.G. Morgan. 1991. *The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program*. Technical Memorandum NOS OMA 52. National Oceanic and Atmospheric Administration (NOAA), Washington, DC.
Jones, D.S., G.W. Suter, II, and R.N. Hull. 1997. *Toxicological Benchmarks for Screening Contaminants of Potential Concern for Effects on Sediment-Associated Biota: 1997 Revision.* Oak Ridge National Laboratory, Oak Ridge, TN.
U.S. EPA (Environmental Protection Agency). 1997. *Protocol for Screening Level Ecological Risk Assessment at Hazardous Waste Combustion Facilities*. Internal Review Draft, February 28. Office of Solid Waste, Washington, DC.
U.S. EPA (Environmental Protection Agency). 1995. *Technical Support Document for the Hazardous Waste Identification Rule: Risk Assessment for Human and Ecological Receptors*. Office of Solid Waste, Washington, DC.
MacDonald, D.D. 1994. *Approach to the Assessment of Sediment Quality in Florida Coastal Waters. Volume 1*. Florida Department of Environmental Protection, Tallahassee, FL.

Algae and Aquatic Plant Benchmarks

For algae and aquatic plants, adverse effects concentrations were identified in the open literature or from a data compilation presented in *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision* (Suter and Tsao, 1996). For most contaminants, studies were not available for aquatic vascular plants, and lowest effects concentrations were identified for algae. The benchmark for algae and aquatic plants was based on (1) an LOEC for vascular aquatic plants or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). Because of the lack of data for this receptor group and the differences between vascular aquatic plants and algae sensitivity, the lowest value of those identified was usually chosen.

H.1.2 Ingestion Exposure

The ingestion route of exposure addresses the exposure of terrestrial mammals and birds through ingestion of aquatic plants and prey. Thus, the CCW ecological benchmarks for ingestion exposure express media concentrations that, based on certain assumptions about receptor diet and foraging behavior, were expected to be protective of populations of mammals and birds feeding and foraging in contaminated surface water bodies.

The derivation of ingestion benchmarks began with the selection of appropriate ecotoxicological data based on a hierarchy of data sources. The assessment endpoint for the CCW ecological risk assessment was population viability; therefore, ecological benchmarks were developed from measures of reproductive/developmental success or, if unavailable, from other effects that could conceivably impair population dynamics. Population-level benchmarks were preferred over benchmarks for individual organisms; however, very few population-level benchmarks have been developed. Therefore, the CCW risk assessment used benchmarks derived from individual organism studies, and protection was inferred at the population level.

Once an appropriate ingestion exposure study was identified, a benchmark was calculated using a three-step process. The remainder of this section outlines the basic technical approach used to convert avian or mammalian benchmarks (in daily doses) to the media concentration benchmarks (in units of concentration) used to assess ecological risks for surface water and sediment contaminated by CCW waste constituents. The methods reflect exposure through the ingestion of contaminated plants, prey, and media, and include parameters on accumulation (e.g., bioconcentration factors), uptake (e.g., consumption rates), and dietary preferences.

Step 1: Scale Benchmark

The benchmarks derived for test species can be extrapolated to wildlife receptor species within the same taxon using a cross-species scaling equation (Equation H-1) (Sample et al., 1996). This is the default methodology EPA proposed for carcinogenicity assessments and reportable quantity documents for adjusting animal data to an equivalent human dose (57 FR 24152).

$$Benchmark_w = LOAEL_t \times \left(\frac{bw_t}{bw_w}\right)^{1/4} \qquad \text{(H-1)}$$

where

$Benchmark_w$ = scaled ecological benchmark for species *w* (mg/kg/d)
$LOAEL_t$ = lowest observed adverse effects level for test species (mg/kg/d)
bw_t = body weight of the surrogate test species (kg)
bw_w = body weight of the representative wildlife species (kg).

Step 2: Identify Bioconcentration Factors/Bioaccumulation Factors

For metal constituents, whole-body bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) were identified for aquatic organisms that could be used as food sources (e.g., fish). The Oak Ridge National Laboratory has proposed methods and data that are useful in predicting bioaccumulation (Sample et al. 1998a,b). These values were typically identified in the open literature and EPA references.

Step 3: Calculate Benchmarks

The following equation provided the basis for calculating surface water benchmarks using a population-inference benchmark (e.g., endpoint on fecundity).

$$Benchmark = \frac{\left[I_{fish} \times \left(BAF \ \ C_w\right)\right] + \left(I_w \times C_w\right)}{bw} \tag{H-2}$$

where

I_{fish} = intake of contaminated fish (kg/d)
BAF = whole-body bioaccumulation factor (L/kg)
bw = weight of the representative species (kg)
I_w = intake of contaminated water (L/d)
C_w = total concentration in the water (mg/L).

For chemicals that bioaccumulate significantly in fish tissue, the ingestion of contaminated food tends to dominate the exposure (i.e., $[I_{fish} \times C_{fish}] >> [I_w\ C_w]$), and the water term (i.e., $[I_w \times C_w]$) can be dropped from Equation H-2, resulting in Equation H-3:

$$Benchmark = \frac{I_{fish} \times \left(BAF \times C_w\right)}{bw} \tag{H-3}$$

At the benchmark dose (mg/kg/d), the concentration in water is equivalent to the chemical stressor concentration limit for that receptor as a function of body weight, ingestion rate, and the bioaccumulation potential for the chemical of concern. Hence, Equation H-3 can be rewritten to solve for the surface water ($CSCL_{sw}$) as follows:

$$CSCL_{sw} = \frac{benchmark \times bw}{I_w + \left(I_{fish} \times BAF\right)} \tag{H-4}$$

H.2 Ecological Benchmarks

The ecological benchmarks used to calculate ecological HQs in the CCW risk assessment are summarized in **Table H-3**, which provides the constituent name; the criterion and receptor for sediment and aquatic receptors; and the source for each benchmark.

Table H-3. Ecological Benchmarks Used in the CCW Risk Assessment

Constituent	Sediment Criterion (mg/kg)	Sediment Receptor	Aquatic Criterion (mg/L)	Aquatic Receptor	Source
Aluminum	ID	--	0.09	Aquatic Biota	U.S. EPA (1998)
Antimony	2	Sediment biota	0.03	Aquatic Biota	U.S. EPA (1998)
Arsenic total	0.51	Spotted sandpiper	ID	--	U.S. EPA (1998)
Arsenic III	ID	--	0.15	Aquatic Biota	U.S. EPA (1998)
Arsenic IV	ID	--	8.10E-03	Aquatic Biota	U.S. EPA (1998)
Barium	190	Spotted sandpiper	4.00E-03	Aquatic Biota	U.S. EPA (1998)
Beryllium	ID	--	6.60E-04	Aquatic Biota	U.S. EPA (1998)
Boron	ID	--	1.60E-03	Aquatic Biota	U.S. EPA (1998)
Cadmium	0.68	Sediment biota	2.50E-03	Aquatic Biota	U.S. EPA (1998)
Chromium total	16.63	Spotted sandpiper	ID	--	U.S. EPA (1998)
Chromium IV	ID	--	0.09	Aquatic Biota	U.S. EPA (1998)
Chromium VI	ID	--	0.01	Aquatic Biota	U.S. EPA (1998)
Cobalt	ID	--	0.02	Aquatic Biota	U.S. EPA (1998)
Copper	18.7	Sediment biota	9.30E-03	Aquatic Biota	U.S. EPA (1998)
Lead	0.22	Spotted sandpiper	3.00E-04	River Otter	U.S. EPA (1998)
Mercury	0.11	Spotted sandpiper	1.90E-07	Kingfisher	U.S. EPA (1998)
Molybdenum	34	Spotted sandpiper	0.37	Aquatic Biota	U.S. EPA (1998)
Nickel	15.9	Sediment biota	0.05	Aquatic Biota	U.S. EPA (1998)
Selenium total	ID	--	5.00E-03	Aquatic Biota	U.S. EPA (1998)
Selenium IV	ID	--	0.03	Aquatic Biota	U.S. EPA (1998)
Selenium VI	ID	--	9.50E-03	Aquatic Biota	U.S. EPA (1998)
Silver	0.73	Sediment biota	3.60E-04	Aquatic Biota	U.S. EPA (1998)
Thallium	ID	--	0.01	Aquatic Biota	U.S. EPA (1998)
Vanadium	18	Spotted sandpiper	0.02	Aquatic Biota	U.S. EPA (1998)
Zinc	120	Sediment biota	0.12	Aquatic Biota	U.S. EPA (1998)

ID = insufficient data.

H.3 References

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U.S. EPA (Environmental Protection Agency). 1995a. *Great Lakes Water Quality Initiative Criteria Documents for the Protection of Aquatic Life in Ambient Water*. EPA-820-B-95-004. Office of Water, Washington, DC.

U.S. EPA (Environmental Protection Agency). 1995b. *Great Lakes Water Quality Initiative Criteria Documents for the Protection of Wildlife: DDT, Mercury, 2,3,78-TCDD, and PCBs*. EPA-820-B-95-008. Office of Water, Washington, DC.

U.S. EPA (Environmental Protection Agency). 1996. *Water Quality Criteria Documents for the Protection of Aquatic Life in Ambient Water: 1995 Updates.* EPA-820-B-96-001. Office of Water, Washington, DC.

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U.S. EPA (Environmental Protection Agency). 1998. Non-Groundwater Pathways, Human Health and Ecological Risk Analysis for Fossil Fuel Combustion Phase 2 (FFC2). Office of Solid Waste, Washington, DC.

Appendix I. Calculation of Health-Based Numbers (HBNs) for CCW Constituent Screening

Key Features of HBN Calculations

- HBNs calculated for groundwater (mg/L) and surface water (mg/L)
- HBNs based on a target cancer risk of 10^{-5} and a HQ of 1
- Groundwater HBNs based on a residential drinking water scenario
- Surface water HBNs based on a recreational fisher scenario
- Adult and child receptors first exposed at ages 3, 8, 15 and 20
- Exposure factors set at central tendency values
- Source size set at the 95th percentile of CCW landfills.

Management of CCW can result in contaminants moving from a waste management unit (WMU) and contaminating groundwater, and surface water via groundwater transport from a CCW WMU. Under these scenarios, individuals living near WMUs may then come into contact with chemicals via ingestion of contaminated drinking water or ingestion of fish contaminated via chemical uptake and accumulation.

Health-based numbers (HBNs) for groundwater (as drinking water) and surface water were used in this analysis to consider risks and hazards to human receptors from chemicals that are released from CCW management units and move through the subsurface. HBNs represent concentrations in environmental media that will not cause an exceedance of a target cancer risk of 10^{-5} or a hazard quotient (HQ) of 1.

The pathways included in the HBN calculations are summarized in **Table I-1**. The HBN for groundwater was based on domestic use of groundwater as drinking water. Surface water HBNs were based on a recreational fisher scenario in which the receptor was assumed to live at a different off-site location and to be exposed only to fish caught recreationally.

Table I-1. Pathways Included in HBN Calculations

HBN Calculation	Drinking Water Ingestion	Fish Ingestion
Groundwater HBN	✓	
Surface water HBN		✓

I.1 Methodology

All HBNs considered human receptors exposed to contaminated media and/or food items at different ages to take into account changing exposure patterns with age. The specific receptors considered were individuals exposed starting at ages 3, 8, 15, and 20. Depending on the start age, an appropriate exposure duration was selected for each receptor based on residency data. Each receptor was exposed for the period of time determined by the exposure duration, and the model accounted for changes in exposure patterns as a person ages. All exposure parameters selected for this analysis were based on 50th percentile values. Once the cancer risks and HQs were calculated for each receptor, HBNs were calculated based on total cancer risk, noncancer inhalation, and noncancer ingestion. The most protective HBN (i.e., the lowest across all age groups) was selected. In all cases, the HBN calculations used central tendency exposure factors (e.g., body weight, exposure duration, exposure frequency, consumption rates).

The equations used to calculate the HBNs are provided at the end of this appendix; **Table I-2** lists the tables of equations by exposure pathway (**Tables I-4** through **I-8**). Data used in these equations to calculate the CCW HBNs can be found in the other appendices to this report, as well as in **Table I-9**, which provides the age cohort–specific human exposure factors used in the HBN calculations.

Table I-2. Key to Tables of Equations Used to Calculate HBNs

Equation for Fish Concentrations	
I-4	Concentration in Fish at Different Trophic Levels (mg/kg)
Equations for Human Exposure	
I-5	Daily Intake of Contaminant from Consumption of Fish (mg/kg BW/day)
I-6	Daily Intake of Contaminant from Consumption of Drinking Water (mg/kg BW/day)
Equations for Unit Risk Calculations and Health-based Numbers	
I-7	Cancer Risk and Hazard Quotient Due to Ingestion (unitless)
I-8	Health-Based Concentration (mg/L)

Groundwater HBNs were based on standard residential exposure assumptions for drinking water consumption, using equations from (U.S. EPA, 1998a). The surface water HBNs were based on concentrations in fish estimated using an aquatic food chain model; that methodology is described in the rest of this section.

The methodology used for estimating concentrations in fish was based on EPA's *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions* (U.S. EPA, 1998a). An aquatic food chain model was used to estimate the concentration of constituent that may accumulate in fish. It was assumed for this analysis that fish are a food source for a recreational fisher. Trophic level three (T3) and four (T4) fish were considered in this analysis. T3 fish are those that consume invertebrates and plankton. T4 fish are those that consume other fish. Most of the fish that humans eat are T4 fish (e.g., salmon, trout, walleye, bass) and medium to large T3 fish (e.g., carp, smelt, perch, catfish, sucker, bullhead, sauger). For metals other than mercury, the calculation of contaminants in fish was based on the total concentration of contaminants in the waterbody (i.e., dissolved and suspended solids). For mercury, the calculation of contaminants in fish was based on the dissolved concentration of methyl mercury in the waterbody.

Fish tissue concentrations are dependent on a bioconcentration factor (BCF), which is used to estimate the amount of constituent being transferred from the waterbody into the fish tissue. Specifically, BCFs reflect the ratio between the tissue concentration in fish and the appropriate waterbody concentration. BCFs were developed for each constituent to reflect accumulation in each trophic level considered. They were also developed to estimate the concentration in the fish filet versus the total fish. Human receptors consume only the filet portion of the fish, which has a lower lipid content. Because some constituents tend to accumulate in the fatty tissue, the concentration in the filet portion of the fish is sometimes lower than the concentration in the whole fish.

I.2 Health-Based Numbers

Table I-3 provides the HBNs for surface water and groundwater.

Table I-3. Groundwater and Surface Water HBNs

Chemical	Benchmark Type	Groundwater HBN (mg/L)[1]	Surface Water HBN[2] (mg/L)
Aluminum	Noncancer	29.4	NA
Antimony	Noncancer	0.012	NA
Arsenic	Cancer	0.0029	0.23
Arsenic	Noncancer	0.0088	0.71
Barium	Noncancer	5.89	NA
Beryllium	Noncancer	0.059	1.0
Boron	Noncancer	5.87	NA
Cadmium	Noncancer	0.015	0.035
Chromium (III)	Noncancer	44	23,700
Chromium (VI)	Noncancer	0.088	47
Cobalt	Noncancer	0.0088	NA
Copper[3]	Noncancer (GW)/AWQ (SW)	0.29	1.3
Cyanide	Noncancer	0.59	NA
Fluoride	Noncancer	3.52	NA
Lead	MCL	0.015	NA
Manganese	Noncancer	1.4	NA
Mercury	Noncancer	0.0088	3.85E-06
Molybdenum	Noncancer	0.147	12
Nickel	Noncancer	0.59	237
Nitrate	MCL	10	NA
Nitrate	Noncancer	47	NA
Nitrite	Noncancer	2.9	NA
Selenium	Noncancer	0.147	0.038
Silver	Noncancer	0.147	NA
Strontium	Noncancer	17.6	NA
Thallium	Noncancer	0.0024	0.008
Vanadium	Noncancer	0.21	NA
Zinc	Noncancer	8.8	8.13

[1] Based on domestic drinking water ingestion.
[2] Based on fish consumption by a recreational fisher.
[3] Fish bioconcentration factor values for copper are zero. HBN based on National Ambient Water Quality Criteria.
AWQ = National Ambient Water Quality Criteria
MCL = maximum contaminant level or drinking water action level (for lead and copper)
NA = not available

Table I-4. Concentration in Fish at Different Trophic Levels (mg/kg)

Cfish_T

For Mercury:

$$Cfish_T = Cdiss \times BCF_T$$

$$Cdiss = 0.05 \times Cwt$$

For NonvolatileMetals:

$$Cfish_T = Cwt \times BCF_T$$

Name	Description	Value
Cdiss	Concentration in surface water (dissolved) (mg/L)	Calculated
Cwt	Concentration in surface water (total) (mg/L)	Set equal to 1 for HBN calculation
0.05	Fraction of total mercury as dissolved methyl mercury	Derived from U.S. EPA, 1997a
BCF_T3F	Bioconcentration factor for trophic level 3, fish filet (L/kg)	Chemical-specific (see App. J)
BCF_T3W	Bioconcentration factor for trophic level 3, fish whole (L/kg)	Chemical-specific (see App. J)
BCF_T4F	Bioconcentration factor for trophic level 4, fish filet (L/kg)	Chemical-specific (see App. J)
BCF_T4W	Bioconcentration factor for trophic level 4, fish whole (L/kg)	Chemical-specific (see App. J)

Source: U.S. EPA, 1998a.

Table I-5. Daily Intake of Contaminant from Consumption of Fish (mg/kg BW/day)

Ifish

$$Cfish_T = F_{T3} \times C_{fishT3F} + F_{T4} \times C_{fishT4F}$$

$$Ifish = Cfish_T \times CR_{fish} \times \frac{F_{fish}}{1{,}000 \times BW}$$

Name	Description	Value
1000	Conversion factor (g/kg)	
C_fishT3F	Concentration of contaminant in fish at different trophic levels (mg/kg)	Calculated (Table I-4)
C_fishT4F	Concentration of contaminant in fish at different trophic levels (mg/kg)	Calculated (Table I-4)
$Cfish_T$	Concentration of contaminant in fish (mg/kg)	Calculated (Table I-4)
BW	Body weight (kg)	Age-cohort-specific (Table I-9)
CR_fish	Consumption rate of fish (g WW/day)	Age-cohort-specific (Table I-9)
F_fish	Fraction of fish intake from contaminated source (unitless)	1 (protective value)
F_T3	Fraction of trophic level 3 intake (unitless)	0.36 (U.S. EPA, 1997d)
F_T4	Fraction of trophic level 4 intake (unitless)	0.64 (U.S. EPA, 1997d)

Source: U.S. EPA, 1998a.

Table I-6. Daily Intake of Contaminant from Consumption of Drinking Water (mg/kg BW/day)

Idw

$$Idw = C_{dw} \times Cr_{dw} \times \frac{F_{dw}}{BW}$$

Name	Description	Value
1000	Conversion factor (mL/L)	
Cdw	Concentration of contaminant in drinking water (mg/L)	Set equal to 1 for HBN calculation
BW	Body weight (kg)	Age-cohort-specific (Table I-9)
CR_dw	Consumption rate of water (L/day)	Age-cohort-specific (Table I-9)
F_dw	Fraction of drinking water ingested that is contaminated (unitless)	1 (protective value)

Source: U.S. EPA, 1998a.

Table I-7. Cancer Risk and Hazard Quotient Due to Ingestion (unitless)

Risk_Oral

$$HQ_{Oral} = \frac{I}{RfD}$$

$$Risk_{Oral} = \frac{I \times ED \times EF \times CSF_{Oral}}{AT \times 365}$$

Name	Description	Value
365	Conversion factor (days/yr)	
I	Intake rate from fish or drinking water (mg/kg/day)	Calculated (Tables I-5 and I-6)
CSF_{Oral}	Oral cancer slope factor (mg/kg/day)-1	Chemical-specific (see Appendix G)
RfD	Noncancer reference dose (mg/kg/day)	Chemical-specific (see Appendix G)
AT	Averaging time (yr)	70 (U.S. EPA, 1991)
ED	Exposure duration for oral ingestion (yr)	Age-cohort-specific (Table I-9)
EF	Exposure frequency (days/yr)	350 (U.S. EPA, 1991)

Table I-8. Health-Based Concentration (ppm)

CalcHBN

$$HBN_{NC_{Oral}} = \frac{C}{HQ_{Oral}} \times THQ$$

$$HBN_{Risk} = \frac{C}{Risk} \times TR$$

Name	Description	Value
THQ	Target noncancer hazard quotient (unitless)	1
TR	Target cancer risk (unitless)	1.00E-5
HQ_Oral	Noncancer hazard quotient for ingestion (unitless)	Calculated (Table I-7)
Risk	Total cancer risk (unitless)	Calculated (Table I-7)
C	Constituent concentration in media (mg/L or mg/kg)	Value set to unit concentration of 1

Back calculation assuming linearity.

Table I-9. Age Cohort-Specific Human Exposure Factors

Parameter	Cohort_1	Cohort_2	Cohort_3	Cohort_4
Body weight (BW) (kg)	15.3	29.6	56.8	69.3
Start year (SY) (yr)	3	8	15	20
Fish consumption rate (CR_fish) (g WW/day)	2	2	2	2
Exposure duration (ED) (yr)	5	7.5	8	10
Drinking water consumption rate (CR_dw) (L/day)	0.6165	0.731	0.8685	1.275

I.3 References

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Appendix J. Chemical-Specific Inputs Used in CCW Constituent Screening

Chemical-specific inputs used to develop the CCW HBNs include the bioconcentration factors needed to estimate exposure concentrations in fish. Values for these inputs are obtained from the best available literature source. **Table J-1** provides, for each chemical in the CCW screening analysis, the values used in the analysis along with the source of each value.

Table J-1. Fish Bioconcentration Factors

Parameter[a]	Value (L/kg)	Reference	Comment
Aluminum (7429905)			
No Data			
Antimony (7440360)			
BCF_T3F	0	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T3W	0	Barrows et al. (1980)	Species was sunfish.
BCF_T4F	0	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T4W	0	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
Arsenic (7440382)			
BCF_T3F	4	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T3W	4	Barrows et al. (1980)	Species was sunfish.
BCF_T4F	4	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T4W	4	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
Barium (7440393)			
No Data			
Beryllium (7440417)			
BCF_T3F	19	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T3W	19	Barrows et al. (1980)	Species was sunfish.
BCF_T4F	19	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T4W	19	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
Boron (7440428)			
No Data			
Cadmium (7440439)			
BCF_T3F	270	Kumada et al. (1972)	BCF_T3W was used as a surrogate.
BCF_T3W	270	Kumada et al. (1972)	Geomean of 3 data points in Table 2.
BCF_T4F	270	Kumada et al. (1972)	BCF_T4W was used as a surrogate.
BCF_T4W	270	Kumada et al. (1972)	Geomean of 3 data points in Table 2. Species were doce and rainbow trout.

(continued)

Fish Bioconcentration Factors (continued)

Parameter[a]	Value (L/kg)	Reference	Comment
Chromium(III) (16065831)			
BCF_T3F	0.6	Stephan (1993)	BCF_T4F was used as a surrogate.
BCF_T3W	0.6	Stephan (1993)	BCF_T4F was used as a surrogate.
BCF_T4F	0.6	Stephan (1993)	Geomean (as cited in Stephan, 1993) based on Buhler et al. (1977) and Calamari et al. (1982). Used chromium as a surrogate.
BCF_T4W	0.6	Stephan (1993)	BCF_T4F was used as a surrogate.
Chromium(VI) (18540299)			
BCF_T3F	0.6	Stephan (1993)	BCF_T4F was used as a surrogate.
BCF_T3W	0.6	Stephan (1993)	BCF_T4F was used as a surrogate.
BCF_T4F	0.6	Stephan (1993)	Geomean (as cited in Stephan, 1993) based on Buhler et al. (1977) and Calamari et al. (1982). Used chromium as a surrogate.
BCF_T4W	0.6	Stephan (1993)	BCF_T4F was used as a surrogate.
Copper (7440508)			
BCF_T3F	0	Stephan (1993)	
BCF_T3W	0	Stephan (1993)	
BCF_T4F	0	Stephan (1993)	
BCF_T4W	0	Stephan (1993)	
Cobalt (7440484)			
No Data			
Cyanide (57125)			
No Data			
Fluoride (16984488)			
No Data			
Manganese (7439965)			
No Data			
Molybdenum (7439987)			
BCF_T3F	4	Eisler (1989)	BCF_T4F was used as a surrogate.
BCF_T3W	4	Eisler (1989)	BCF_T4F was used as a surrogate.
BCF_T4F	4	Eisler (1989)	Geomean of values found on pages 27 and 28. Species were rainbow trout and steelhead trout.
BCF_T4W	4	Eisler (1989)	BCF_T4F was used as a surrogate.
Nickel (7440020)			
BCF_T3F	0.8	Stephan (1993)	BCF_T4F was used as a surrogate.
BCF_T3W	0.8	Stephan (1993)	BCF_T4F was used as a surrogate.
BCF_T4F	0.8	Stephan (1993)	Derived from Calamari et al. (1982) (as cited in Stephan, 1993).
BCF_T4W	0.8	Stephan (1993)	BCF_T4F was used as a surrogate.

(continued)

Fish Bioconcentration Factors (continued)

Parameter[a]	Value (L/kg)	Reference	Comment
Selenium (7782492)			
BCF_T3F	490	Lemly (1985)	Based on threadfin shad and blueback herring. Units corrected.
BCF_T3W	490	Lemly (1985)	BCF_T3F was used as a surrogate.
BCF_T4F	1,700	Lemly (1985)	Based on threadfin shad and blueback herring. Units corrected.
BCF_T4W	1,700	Lemly (1985)	BCF_T4F was used as a surrogate.
Silver (7440224)			
BCF_T3F	0	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T3W	0	Barrows et al. (1980)	Species was sunfish.
BCF_T4F	0	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T4W	0	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
Strontium (7440246)			
No Data			
Thallium (7440280)			
BCF_T3F	34	Barrows et al. (1980)	BCF_T3W was used as a surrogate.
BCF_T3W	34	Barrows et al. (1980)	Species was sunfish.
BCF_T4F	130	Stephan (1993)	Derived from Zitko et al. (1975) (as cited in Stephan, 1993).
BCF_T4W	130	Stephan (1993)	BCF_T4F was used as a surrogate.
Total Nitrate Nitrogen (14797558)			
No Data			
Vanadium (7440622)			
No Data			
Zinc (7440666)			
BCF_T3F	350	Murphy et al. (1978)	BCF_T3W was used as a surrogate.
BCF_T3W	350	Murphy et al. (1978)	Geomean of converted dry weight concentration in Table 1 of bluegills at Site A and B.
BCF_T4F	350	Murphy et al. (1978)	BCF_T3W was used as a surrogate.
BCF_T4W	350	Murphy et al. (1978)	BCF_T3W was used as a surrogate.

[a] BCF_T3F = Bioconcentration factor for trophic level 3 fish, filet
BCF_T3W= Bioconcentration factor for trophic level 3 fish, whole
BCF_T4F = Bioconcentration factor for trophic level 4 fish, filet
BCF_T4W= Bioconcentration factor for trophic level 4 fish, whole

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Appendix K. Screening Analysis Results

Table K-1. CCW Surface Impoundment (SI) Human Health Screening Results: Groundwater-to-Drinking-Water Pathway

Chemical	Benchmark Type	HBN (mg/L)	2002 SI Porewater	
			90th Percentile	HQ(Cancer Risk)
***Analytes Exceeding Risk Criteria*[1]**				
Antimony	Noncancer	1.17E-02	6.40E-02	5.45E+00
Arsenic	Cancer	2.86E-03	5.18E+00	(1.81E-02)
Arsenic	Noncancer	8.81E-03	5.18E+00	5.88E+02
Boron	Noncancer	5.87E+00	7.52E+01	1.28E+01
Cadmium	Noncancer	1.47E-02	1.31E-01	8.91E+00
Chromium (VI)	Noncancer	8.81E-02	3.66E-01	4.15E+00
Cobalt	Noncancer	8.81E-03	6.27E+00	7.13E+02
Fluoride	Noncancer	3.52E+00	1.91E+01	5.42E+00
Lead	MCL	1.50E-02	1.77E-01	1.18E+01
Manganese	Noncancer	1.38E+00	7.67E+00	5.56E+00
Molybdenum	Noncancer	1.47E-01	1.00E+00	6.81E+00
Nickel	Noncancer	5.87E-01	7.49E-01	1.27E+00
Nitrate	MCL	1.00E+01	6.02E+02	6.02E+01
Nitrite	Noncancer	2.94E+00	5.22E+00	1.78E+00
Selenium	Noncancer	1.47E-01	3.56E-01	2.43E+00
Thallium	Noncancer	2.35E-03	4.52E-02	1.93E+01
Vanadium	Noncancer	2.06E-01	4.78E-01	2.33E+00
***Analytes Below Risk Criteria*[1]**				
Aluminum	Noncancer	2.94E+01	2.30E+01	7.84E-01
Barium	Noncancer	5.89E+00	3.02E-01	5.15E-02
Beryllium	Noncancer	5.87E-02	5.68E-03	9.67E-02
Chromium (III)	Noncancer	4.40E+01	3.66E-01	8.31E-03
Copper	Noncancer	2.93E-01	2.84E-01	9.69E-01
Mercury	Noncancer	8.81E-03	2.50E-04	2.84E-02
Silver	Noncancer	1.47E-01	5.00E-03	3.41E-02
Strontium	Noncancer	1.76E+01	8.74E+00	4.96E-01
Zinc	Noncancer	8.81E+00	6.70E-01	7.60E-02

[1] Risk criteria are 1E-05 cancer risk or a hazard quotient (HQ) of 1E+00 for noncancer endpoints.
HBN = health-based number
90th percentile = 90th percentile SI porewater concentration
HQ = hazard quotient
MCL = maximum contaminant level

Table K-2. CCW Surface Impoundment (SI) Human Health Screening Results: Groundwater-to-Surface-Water (Fish Ingestion) Pathway

			2002 SI Porewater	
Chemical	**Benchmark Type**	**HBN (mg/L)**	**90th Percentile**	**HQ (Cancer Risk)**
Analytes Exceeding Risk Criteria[1]				
Arsenic	Cancer	0.23	5.18E+00	(2.24E-04)
Arsenic	Noncancer	0.71	5.18E+00	7.28E+00
Cadmium	Noncancer	0.035	1.31E-01	3.73E+00
Mercury	Noncancer	3.85E-06	2.50E-04	6.50E+01
Selenium	Noncancer	0.038	3.56E-01	9.50E+00
Thallium	Noncancer	0.008	4.52E-02	5.69E+00
Analytes Below Risk Criteria[1]				
Antimony	AWQ	4.3	6.40E-02	1.49E-02
Beryllium	Noncancer	1.00	5.68E-03	5.69E-03
Chromium (III)	Noncancer	23,700	3.66E-01	1.54E-05
Chromium (VI)	Noncancer	47	3.66E-01	7.72E-03
Copper[2]	AWQ	1.3	2.84E-01	2.18E-01
Molybdenum	Noncancer	12	1.00E+01	8.43E-02
Nickel	Noncancer	237	7.49E-01	3.16E-03
Zinc	Noncancer	8.13	6.70E-01	8.24E-02

[1] Risk criteria are 1E-05 cancer risk or a hazard quotient (HQ) of 1E+00 for noncancer endpoints.
[2] Fish bioconcentration factor values for copper are zero. HBN based on National Ambient Water Quality Criteria.
HBN = health-based number
90th percentile = 90th percentile SI porewater concentration
HQ = hazard quotient
AWQ = National Ambient Water Quality Criteria
MCL = maximum contaminant level

Table K-3. CCW Landfill Leachate Human Health Screening Results: Groundwater-to-Drinking-Water Pathway

Chemical	Benchmark Type	HBN (mg/L)	2002 Landfill Leachate	
			90th Percentile	HQ(Cancer Risk)
***Analytes Exceeding Risk Criteria*[1]**				
Antimony	Noncancer	1.17E-02	2.61E-01	2.22E+01
Arsenic	Cancer	2.86E-03	3.94E-01	(1.38E-03)
Arsenic	Noncancer	8.81E-03	3.94E-01	4.48E+01
Boron	Noncancer	5.87E+00	1.06E+01	1.80E+00
Cadmium	Noncancer	1.47E-02	4.94E-02	3.37E+00
Chromium (VI)	Noncancer	8.81E-02	2.00E-01	2.27E+00
Cobalt	Noncancer	8.81E-03	8.25E-02	9.33E+00
Fluoride	Noncancer	3.52E+00	6.34E+00	1.80E+00
Lead	MCL	1.50E-02	2.39E-01	1.59E+01
Molybdenum	Noncancer	1.47E-01	6.16E-01	4.20E+00
Nitrite	Noncancer	2.94E+00	3.47E+00	1.18E+00
Selenium	Noncancer	1.47E-01	1.76E-01	1.20E+00
Thallium	Noncancer	2.35E-03	5.00E-02	2.13E+01
Vanadium	Noncancer	2.06E-01	4.50E-01	2.19E+00
***Analytes Below Risk Criteria*[1]**				
Aluminum	Noncancer	2.94E+01	1.05E+01	3.58E-01
Barium	Noncancer	5.89E+00	1.60E+00	2.73E-01
Beryllium	Noncancer	5.87E-02	1.58E-02	2.70E-01
Chromium (III)	Noncancer	4.40E+01	2.00E-01	4.54E-03
Copper	Noncancer	2.93E-01	1.50E-01	5.12E-01
Cyanide	Noncancer	5.87E-01	6.32E-02	1.08E-01
Manganese	Noncancer	1.38E+00	1.37E+00	9.92E-01
Mercury	Noncancer	8.81E-03	2.69E-03	3.06E-01
Nickel	Noncancer	5.87E-01	3.09E-01	5.27E-01
Nitrate	MCL	1.00E+01	2.83E+00	2.83E-01
Silver	Noncancer	1.47E-01	3.95E-02	2.69E-01
Strontium	Noncancer	1.76E+01	9.70E+00	5.51E-01
Zinc	Noncancer	8.81E+00	1.94E+00	2.20E-01

[1] Risk criteria are 1E-05 cancer risk or a hazard quotient (HQ) of 1E+00 for noncancer endpoints, applied to 90th percentile concentrations.

HBN = health-based number

90th percentile = 90th percentile concentration

HQ = hazard quotient

MCL = maximum contaminant level

Table K-4. CCW Landfill Leachate Human Health Screening Results: Groundwater-to-Surface-Water Pathway

Chemical	Benchmark Type	HBN (mg/L)	2002 Landfill Leachate	
			90th Percentile	HQ (Cancer Risk)
Analytes Exceeding Risk Criteria[1]				
Arsenic	Cancer	0.23	3.94E-01	(1.71E-05)
Cadmium	Noncancer	0.035	4.94E-02	1.41E+00
Mercury	Noncancer	3.85E-06	2.69E-03	7.00E+02
Selenium	Noncancer	0.038	1.76E-01	4.69E+00
Thallium	Noncancer	0.008	5.00E-02	6.29E+00
Analytes Below Risk Criteria[1]				
Antimony	AWQ	4.3	2.61E-01	6.07E-02
Arsenic	Noncancer	0.71	3.94E-01	5.54E-01
Beryllium	Noncancer	1.00	1.58E-02	1.59E-02
Chromium (III)	Noncancer	23,700	2.00E-01	8.44E-06
Chromium (VI)	Noncancer	47	2.00E-01	4.22E-03
Copper[2]	AWQ	1.3	1.50E-01	1.15E-01
Cyanide	AWQ	222	6.32E-02	2.85E-04
Molybdenum	Noncancer	12	6.16E-01	5.20E-02
Nickel	Noncancer	237	3.09E-01	1.30E-03
Zinc	Noncancer	8.13	1.94E+00	2.38E-01

1 Risk criteria are 1E-05 cancer risk or a hazard quotient (HQ) of 1E+00 for noncancer endpoints, applied to 90th percentile concentrations.

2 Fish bioconcentration factor values for copper are zero. HBN based on National Ambient Water Quality Criteria.

HBN = health-based number90th percentile = 90th percentile concentration
HQ = hazard quotient
AWQ = National Ambient Water Quality Criteria
MCL = maximum contaminant level

Table K-5. Surface Impoundment Ecological Screening Results: Direct Surface Impoundment and Groundwater-to-Surface-Water Pathways

Chemical	CSCL (mg/L)	2002 SI Porewater 90th Percentile (mg/L)	2002 SI Porewater HQ	1998 SI Water 95th Percentile (mg/L)	1998 SI Water HQ
Analytes Exceeding Risk Criterion [1]					
Aluminum	8.70E-02	2.30E+01	2.65E+02	5.11E+00	5.87E+01
Arsenic III	1.50E-01	5.18E+00	3.45E+01	5.50E-01	3.67E+00
Arsenic IV	8.10E-03	5.18E+00	6.39E+02	5.50E-01	6.79E+01
Barium	4.00E-03	3.02E-01	7.54E+01	7.12E-01	1.78E+02
Boron	1.60E-03	7.52E+01	4.70E+04	4.60E+02	2.88E+05
Cadmium	2.50E-03	1.31E-01	5.23E+01	2.50E-01	1.00E+02
Chromium VI	1.10E-02	3.66E-01	3.33E+01	2.67E-02	2.43E+00
Cobalt	2.30E-02	6.27E+00	2.73E+02	1.00E-02	4.35E-01
Copper	9.30E-03	2.84E-01	3.05E+01	3.90E-01	4.19E+01
Lead	3.01E-04	1.77E-01	5.88E+02	2.50E-01	8.31E+02
Mercury	1.90E-07	2.50E-04	1.32E+03	1.50E-03	7.89E+03
Nickel	5.20E-02	7.49E-01	1.44E+01	6.00E-01	1.15E+01
Selenium IV	2.80E-02	3.56E-01	1.27E+01	7.80E+00	2.79E+02
Selenium total	5.00E-03	3.56E-01	7.13E+01	7.80E+00	1.56E+03
Selenium VI	9.50E-03	3.56E-01	3.75E+01	7.80E+00	8.21E+02
Silver	3.60E-04	5.00E-03	1.39E+01	5.00E-03	1.39E+01
Vanadium	2.00E-02	4.78E-01	2.39E+01	8.00E-01	4.00E+01
Analytes Not Exceeding Risk Criterion [1]					
Antimony	3.00E-02	6.40E-02	2.13E+00	1.37E-01	4.57E+00
Beryllium	6.60E-04	5.68E-03	8.61E+00	1.00E-03	1.52E+00
Chromium III	8.60E-02	3.66E-01	4.26E+00	4.00E-01	4.65E+00
Molybdenum	3.70E-01	1.00E+00	2.70E+00	5.00E-01	1.35E+00
Thallium	1.20E-02	4.52E-02	3.77E+00	5.00E-02	4.17E+00
Zinc	1.20E-01	6.70E-01	5.58E+00	6.70E-01	5.58E+00

[1] Risk criterion is a hazard quotient (HQ) of 10 (for direct exposure to impoundment waters).
SI = surface impoundment
CSCL = chemical stressor concentration level

Table K-6. Landfill Ecological Screening Results: Groundwater-to-Surface-Water Pathway

Chemical	CSCL (mg/L)	2002 - Landfill Leachate	
		90th Percentile (mg/L)	**HQ**
***Analytes Exceeding Risk Criterion*[1]**			
Aluminum	8.70E-02	1.05E+01	1.21E+02
Arsenic IV	8.10E-03	3.94E-01	4.87E+01
Barium	4.00E-03	1.60E+00	4.01E+02
Beryllium	6.60E-04	1.58E-02	2.40E+01
Boron	1.60E-03	1.06E+01	6.61E+03
Cadmium	2.50E-03	4.94E-02	1.98E+01
Chromium VI	1.10E-02	2.00E-01	1.82E+01
Copper	9.30E-03	1.50E-01	1.61E+01
Lead	3.01E-04	2.39E-01	7.94E+02
Mercury	1.90E-07	2.69E-03	1.42E+04
Selenium total	5.00E-03	1.76E-01	3.52E+01
Selenium VI	9.50E-03	1.76E-01	1.85E+01
Silver	3.60E-04	3.95E-02	1.10E+02
Vanadium	2.00E-02	4.50E-01	2.25E+01
Zinc	1.20E-01	1.94E+00	1.61E+01
***Analytes Not Exceeding Risk Criterion*[1]**			
Antimony	3.00E-02	2.61E-01	8.70E+00
Arsenic III	1.50E-01	3.94E-01	2.63E+00
Chromium III	8.60E-02	2.00E-01	2.33E+00
Cobalt	2.30E-02	8.25E-02	3.59E+00
Molybdenum	3.70E-01	6.16E-01	1.67E+00
Nickel	5.20E-02	3.09E-01	5.95E+00
Selenium IV	2.80E-02	1.76E-01	6.28E+00
Thallium	1.20E-02	5.00E-02	4.17E+00

[1] Risk criterion is a hazard quotient (HQ) of 10
CSCL = chemical stressor concentration level

Appendix L. Time to Peak Concentration at Receptor Well for Selected CCW Constituents

L.1 Introduction

This appendix presents plots of arrival times for the peak well concentrations used to calculate groundwater-to-drinking-water risks for selected CCW constituents (arsenic III and V, boron, cobalt, selenium IV and VI, and thallium[1]). The arrival times are plotted as cumulative distributions for surface impoundments and landfills. These constituents were selected to represent the chemicals with the highest estimated risks and to span the range of mobility in the subsurface.

Groundwater pathway modeling conducted in support of the CCW risk assessment consisted of probabilistic fate and transport simulations of mostly metal constituents present in three different waste types (ash, ash and coal, and fluidized bed combustion wastes) managed in landfills and surface impoundments. Three liner designs were also considered: no liner; a 3-foot clay liner; and a composite liner (a composite of geomembrane, geosynthetic clays, and/or compacted clays), assigned to each CCW waste management unit (WMU) based on liner type data in the EPRI database (see **Appendix B**). The predicted groundwater concentrations were used to estimate potential risks to humans and the environment exposed to the modeled CCW constituents.

Among the inputs to the model were distributions of infiltration rates of water through the landfills and surface impoundments corresponding to each of the three liner types. Among the outputs generated by the groundwater pathway fate and transport model were the peak concentration observed at the receptor well and the time at which the peak was observed. For each probabilistic simulation scenario (a constituent in a particular waste type managed in a particular type of WMU), approximately 10,000 sets of model inputs generated an equivalent number of groundwater observations. Some were non-zero concentrations, others were zero. For these zero-value observations, the model also assigned a value of zero to arrival time. Zero-value observations can be attributed to zero-value infiltration rates (which occur only for WMUs with composite liners); in that case, no mass leaves the WMU and there is no time of travel. Zero-value observations can also be attributed to fate and transport conditions that retard the movement of a constituent from the WMU through the subsurface to the extent that the dissolved component was not observed within the established maximum allowable timeframe (10,000 years). In this case, the time of travel is greater than 10,000 years.

To better understand the time frames in which risks associated with exposures to contaminated groundwater may occur, an analysis was performed to graphically represent distributions of arrival time of the peak groundwater concentrations at the nearby drinking water well. The analysis was performed across all waste types with respect to liner and WMU type.

[1] Thallium was not modeled in the surface impoundment scenario, and thus no arrival times were calculated here.

What follows is a description of how the peak concentrations and their arrival times were treated to create the plots presented in this appendix, including the treatment of zero-value observations.

L.2 Methodology

Given a constituent managed in a particular type of WMU (e.g., arsenic in landfills), all infiltration rates and their corresponding peak concentrations and arrival times predicted by the model were extracted from the input/output data for simulations across all waste types in which the selected constituent was found. The triplets of data needed to prepare the graphs—infiltration rate, peak concentration, and arrival time—were then filtered from the data and segregated by liner type. Zero-value observed concentrations were treated in the following manner:

- Zero-value observations corresponding to zero-value infiltration rates were assigned an arbitrary value of -1, effectively excluding those data from the graphs. This was appropriate, because when infiltration is zero, there is no plume and no contaminants enter or are transported in groundwater. Only the composite liner scenarios produced zero-value infiltration rates.

- Zero-value observations corresponding to non-zero infiltration rates were assigned an arbitrary arrival time greater than (>) 10,000 years, the maximum simulation timeframe. These data points are also not shown in the plots, as only times up to 10,000 years were visible.

Table L-1 shows the distribution of zero-value concentration observations by WMU and composite liner scenario. The total observations in this table include data points with a modeled arrival time of >10,000 years and those with zero infiltration rates. Note that for surface impoundments, there are fewer model runs (observations) for thallium because thallium results are not available for ash and coal waste streams because of very limited data in the CCW constituent database.

Table L-1. Distribution of Zero-Value Concentrations

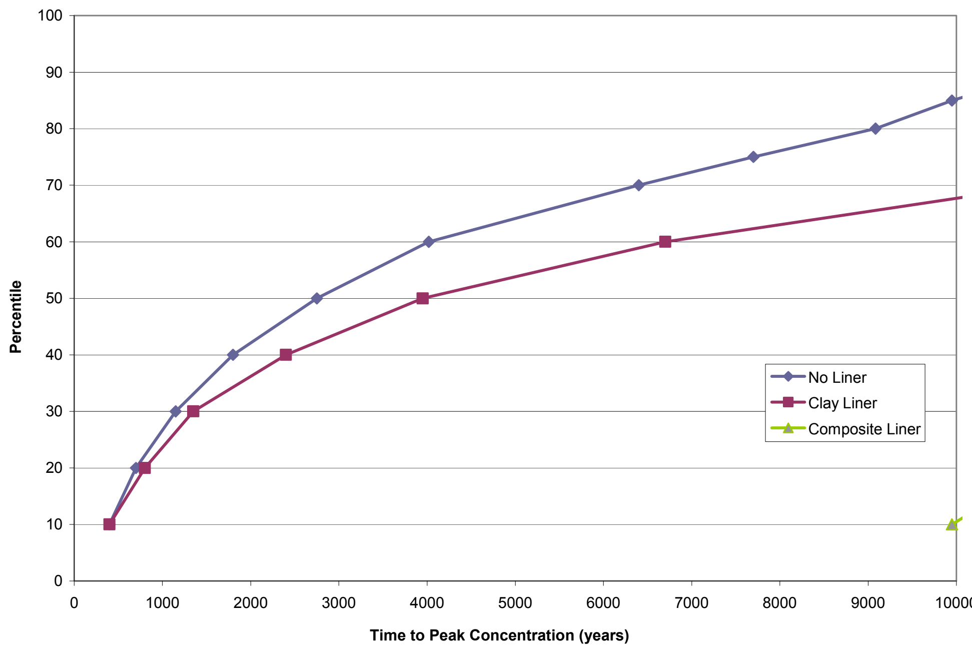
WMU Type	Total Observations[a] (Number)	Zero Infiltration Rates (Number)	Zero Infiltration Rates[b] (%)	Composite Liner Observations (Number)	Composite Liner Zero Infiltration Rates (%)
Landfill	29,717	3,538	11.9%	4,847	73.0%
Surface Impoundment (As, B, Se)[c]	19,825	500	2.5%	1,406	35.6%
Surface Impoundment (Tl)[d]	9,905	389	3.9%	1,130	34.4%

[a] Per constituent across all waste types and liners.
[b] Out of all observations.
[c] Observations for arsenic, boron, cobalt, and selenium; all were modeled in both ash and ash and coal waste streams managed in surface impoundments.
[d] Observations for thallium only, which was detected only in ash waste streams managed in surface impoundments.

After zero infiltration rate observations were filtered from each data set, percentiles of arrival time of the peak observed concentration were plotted on the y-axis by liner type and WMU (**Figures L-1** through **L-21**). The x-axis range for landfills is 0 to 10,000 years. For surface impoundments, plots are provided on both the full 0 to 10,000-year time frame and a shorter time frame, so that the shape of the cumulative distribution can be seen for the lower time-of-travel range characteristic of these facilities.

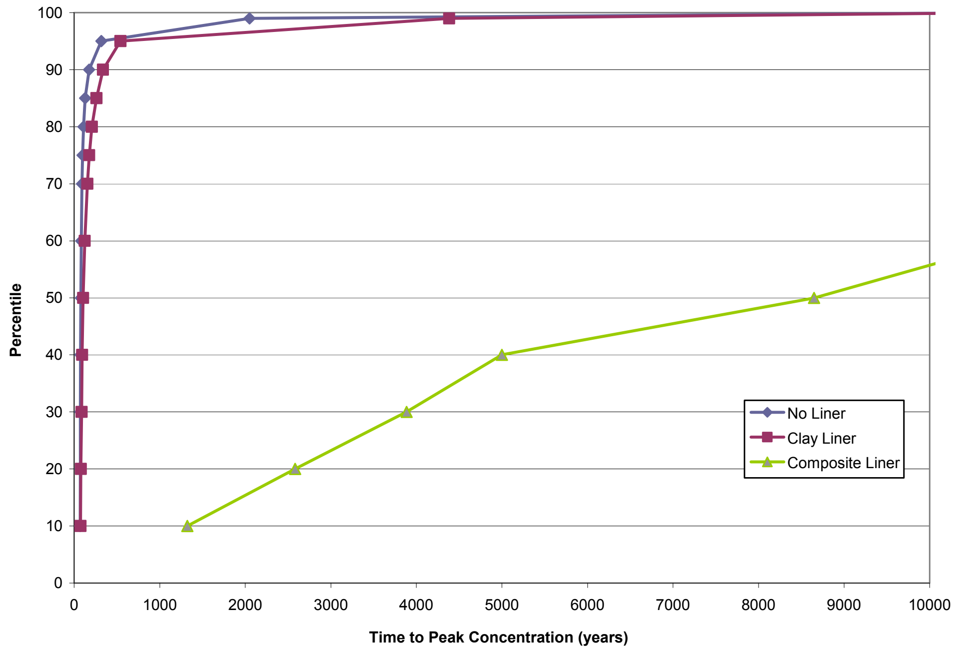
The figures are organized alphabetically by metal, and there are three figures for each metal: landfills, surface impoundments (0–10,000 years), and surface impoundments (shorter time frame).

The shorter arrival times for clay-lined landfills compared to unlined landfills are an artifact of the fact that liners were modeled at each landfill as reported in the EPRI survey, and each landfill location has a different subsurface geology. The shorter arrival times mainly reflect more transmissive soils and aquifer materials at the clay-lined facility locations.



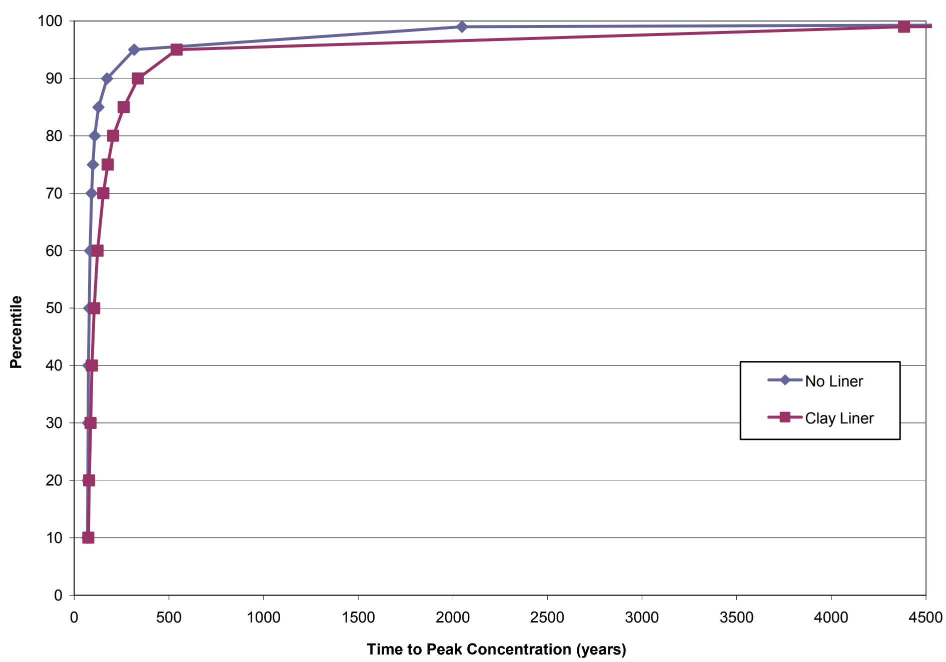
73% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-1. Time to peak distribution for arsenic III: landfills, all waste types.



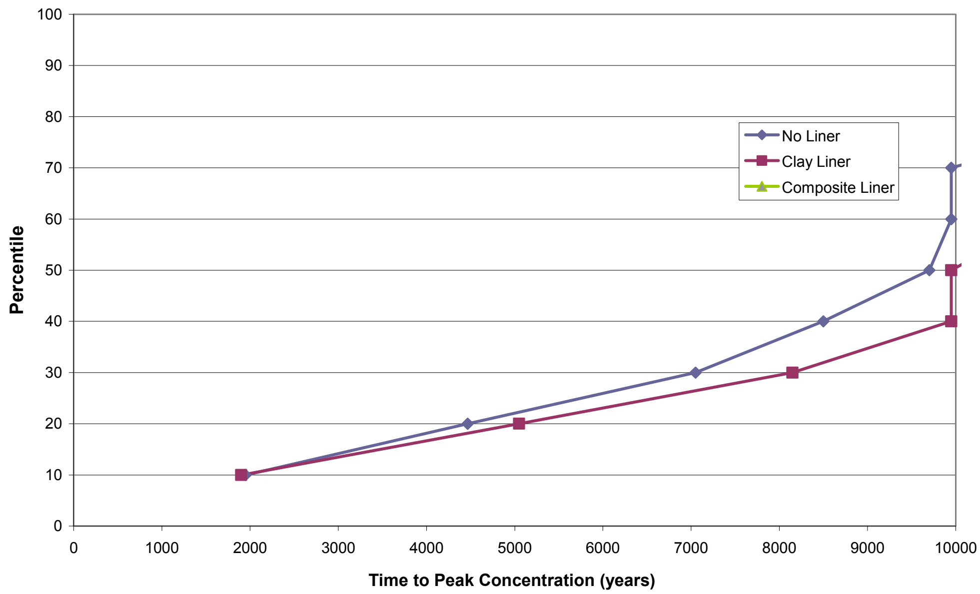
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-2. Time to peak distribution for arsenic III: surface impoundments, all waste types, full 10,000 year time frame.



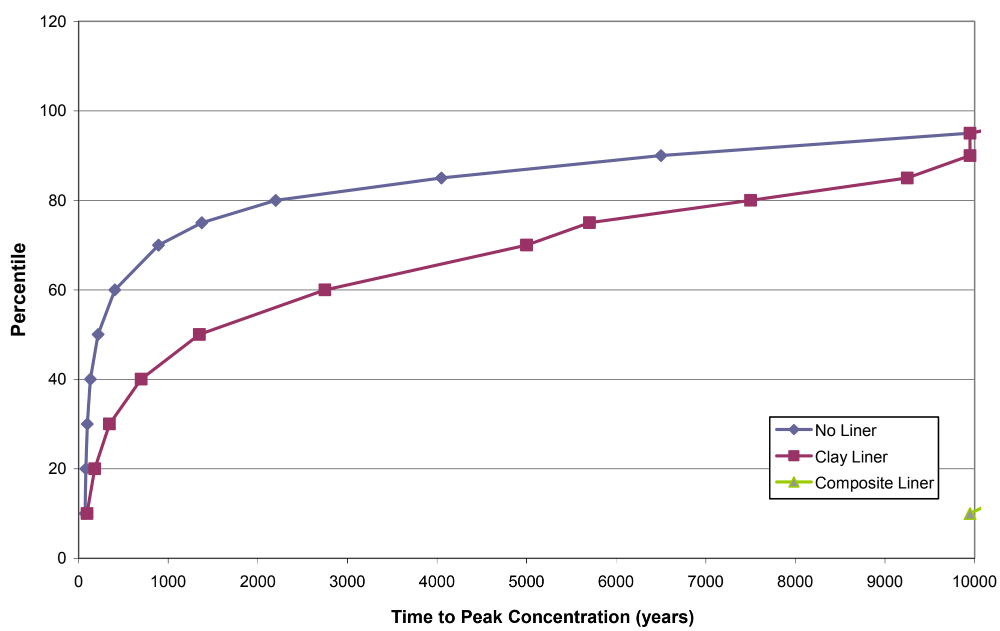
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-3. Time to peak distribution for arsenic III: surface impoundments, all waste types, shorter time frame.



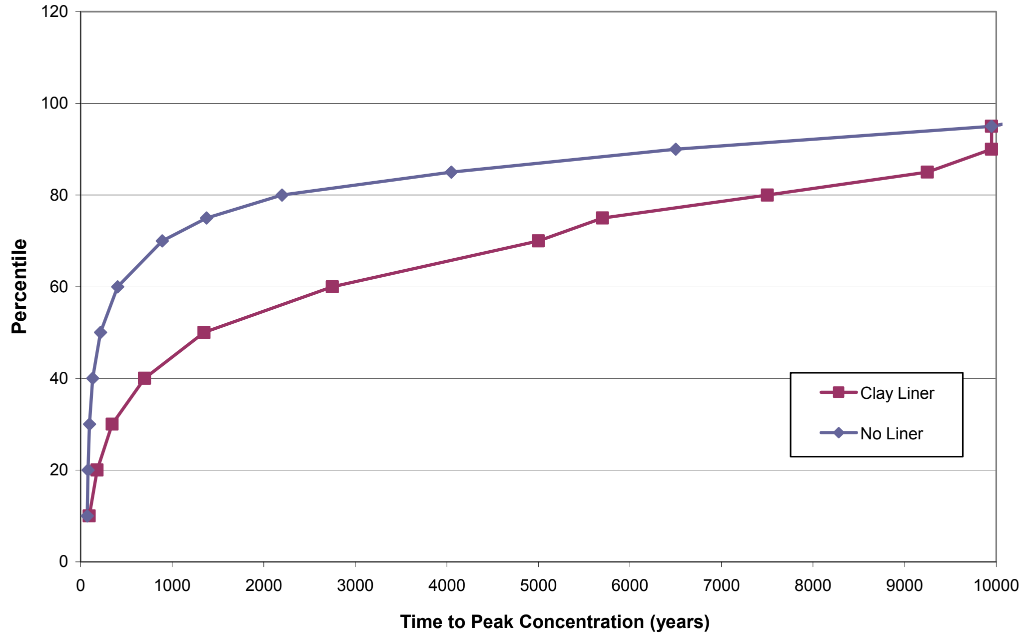
73% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-4. Time to peak distribution for arsenic V: landfills, all waste types.



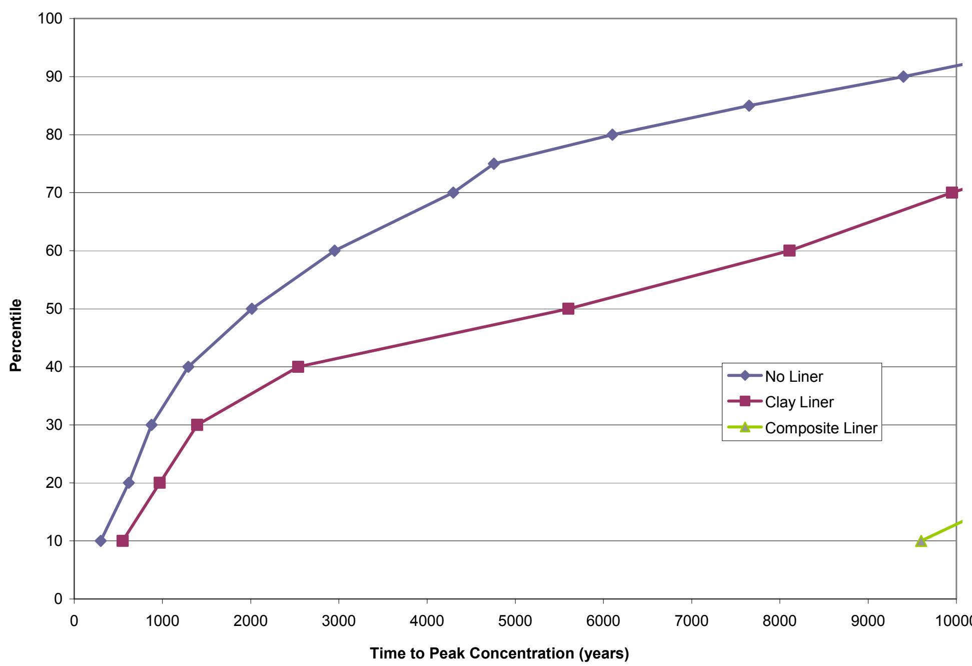
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-5. Time to peak distribution for arsenic V: surface impoundments, all waste types, full 10,000 year time frame.



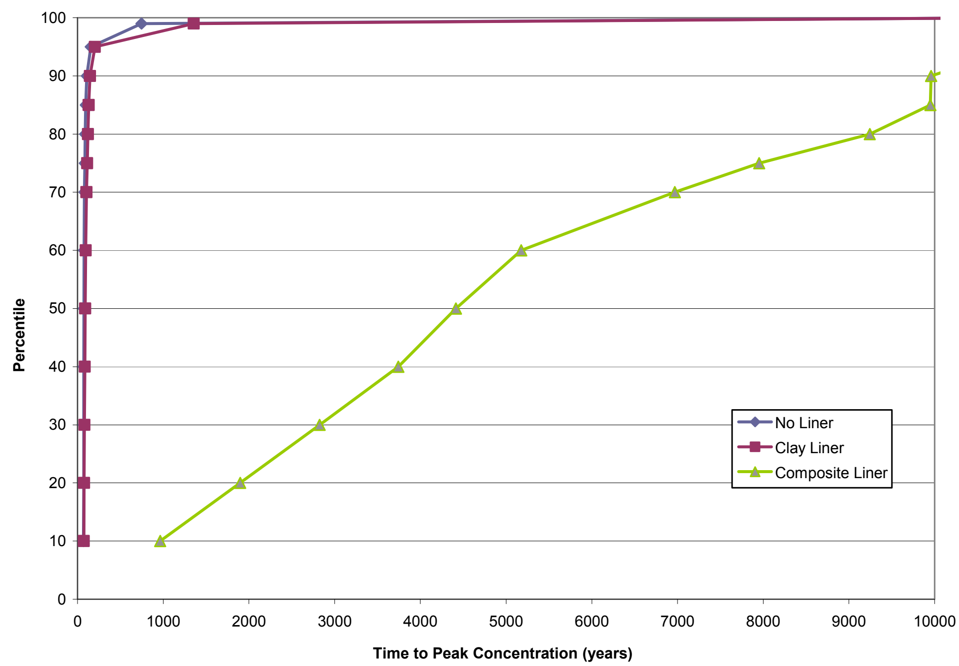
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-6. Time to peak distribution for arsenic V: surface impoundments, all waste types, shorter time frame.



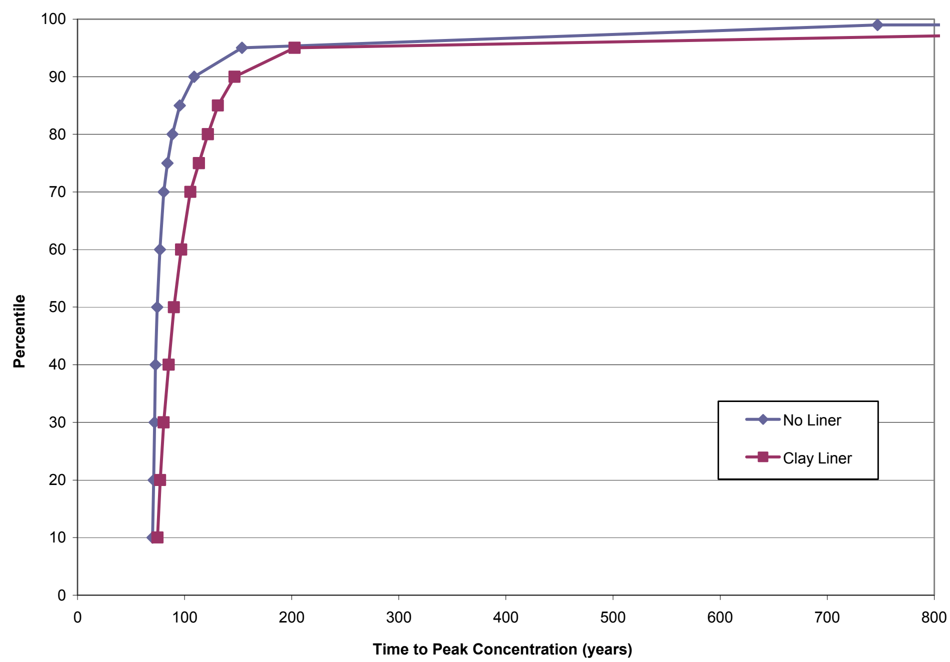
73% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-7. Time to peak distribution for boron: landfills, all waste types.



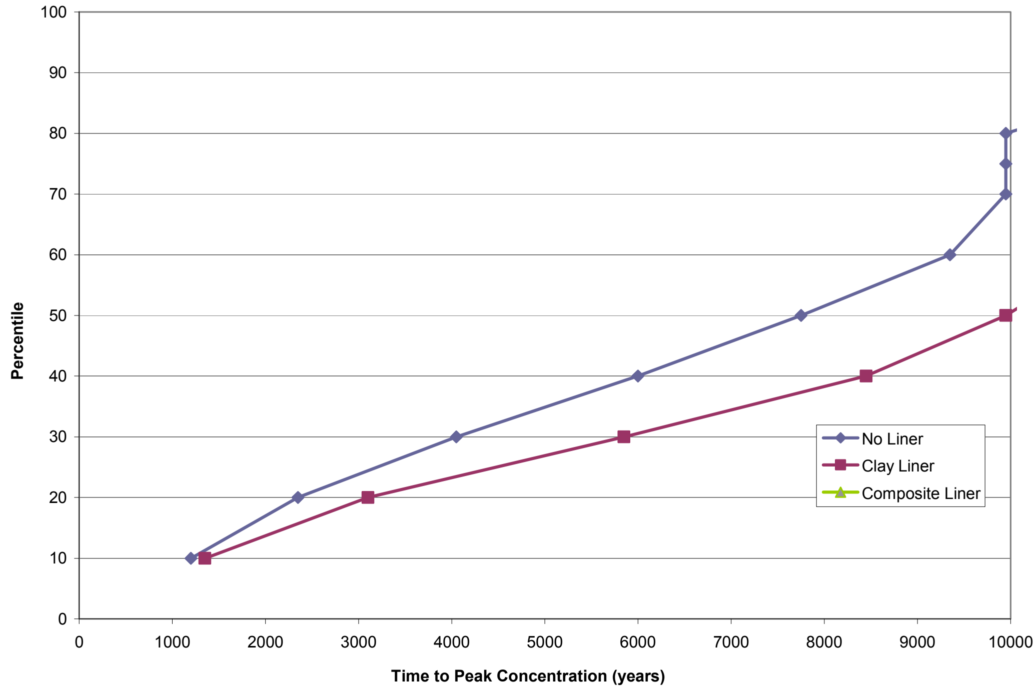
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-8. Time to peak distribution for boron: surface impoundments, all waste types, full 10,000 year time frame.



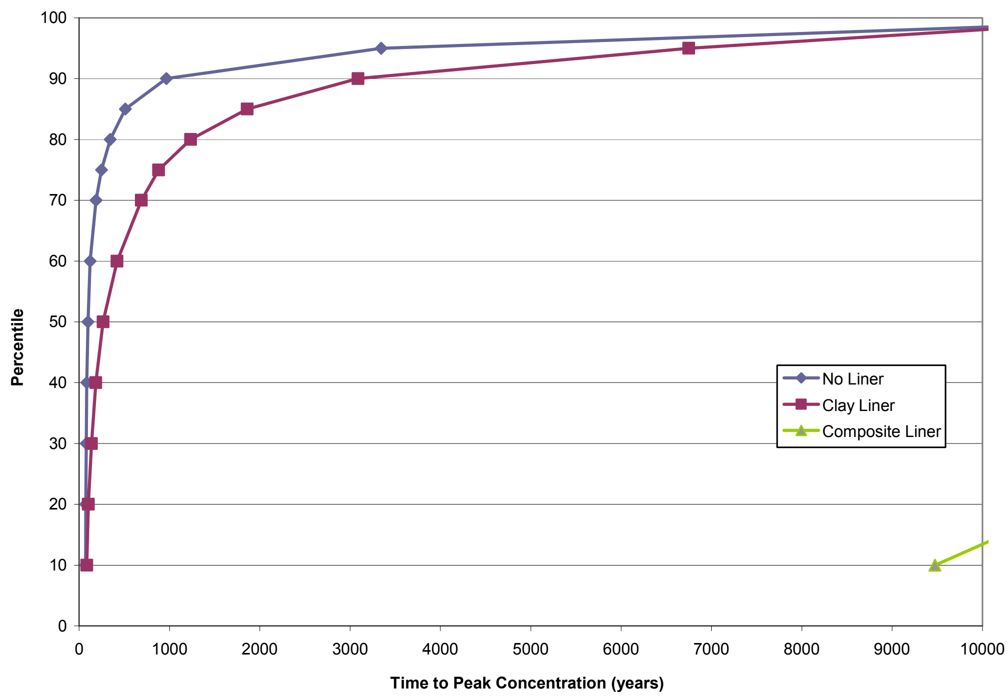
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-9. Time to peak distribution for boron: surface impoundments, all waste types, shorter time frame.



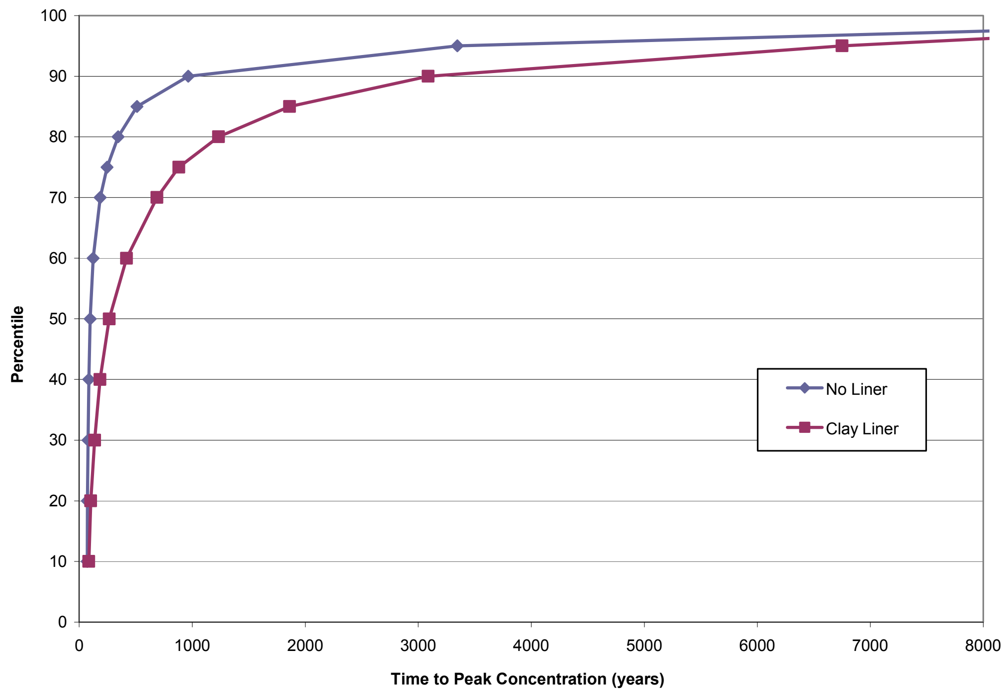
73% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-10. Time to peak distribution for cobalt: landfills, all waste types.



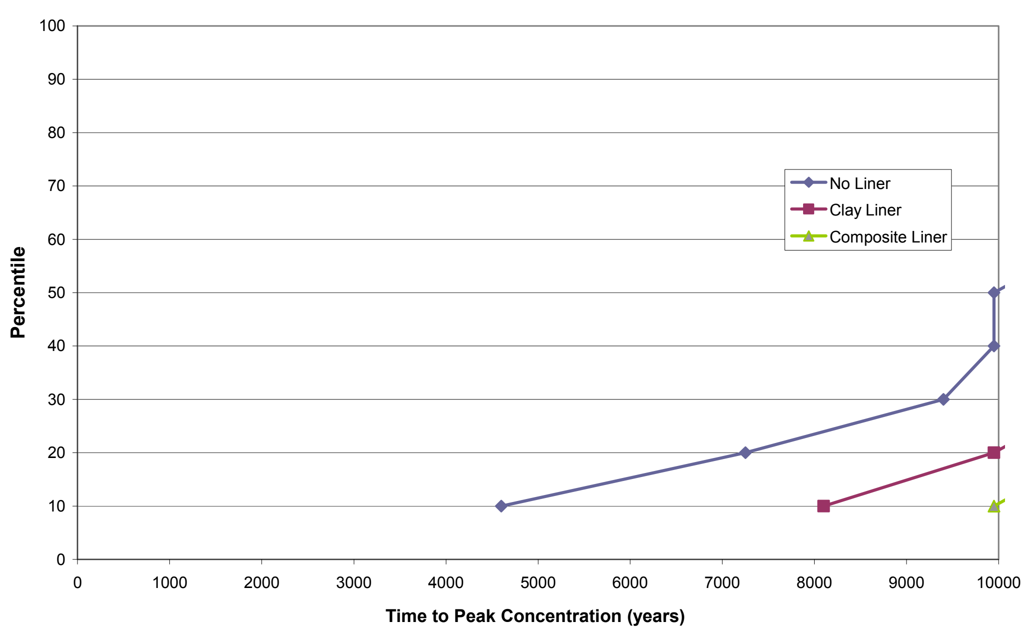
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-11. Time to peak distribution for cobalt: surface impoundments, all waste types, full 10,000 year time frame.



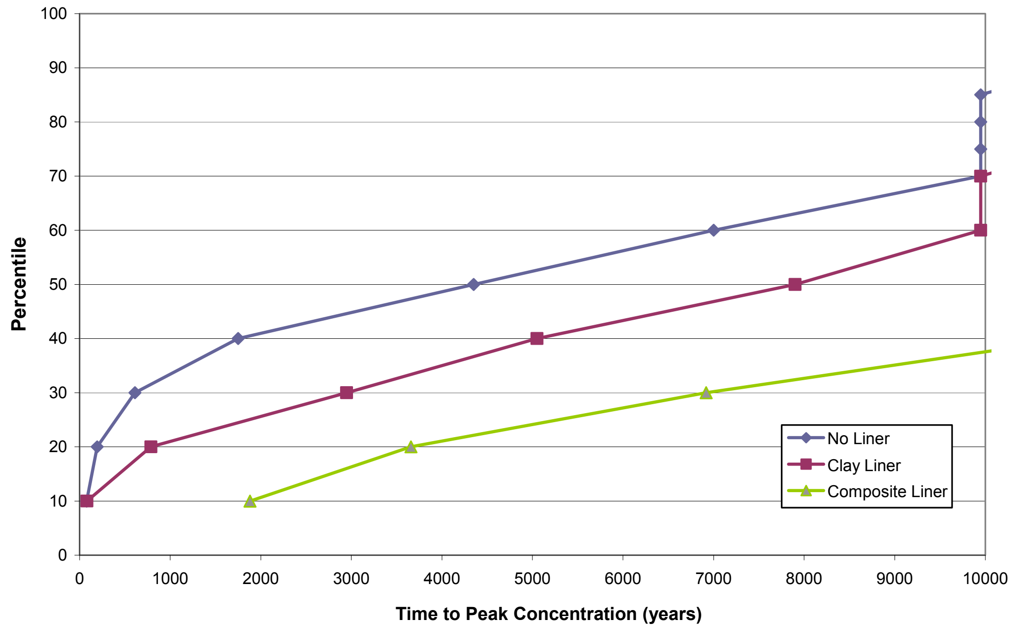
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-12. Time to peak distribution for cobalt: surface impoundments, all waste types, shorter time frame.



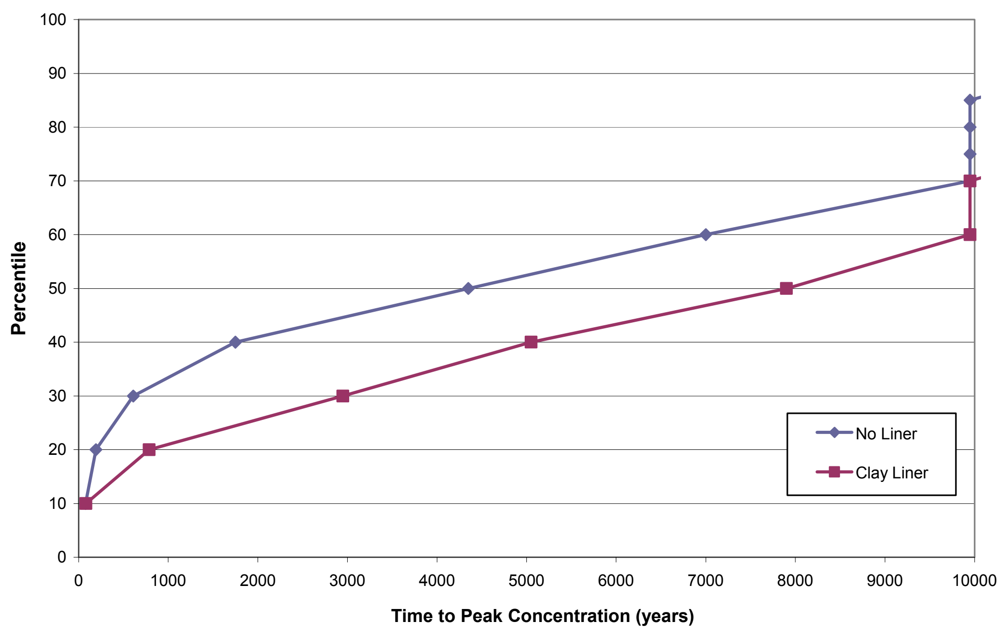
73% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-13. Time to peak distribution for selenium IV: landfills, all waste types.



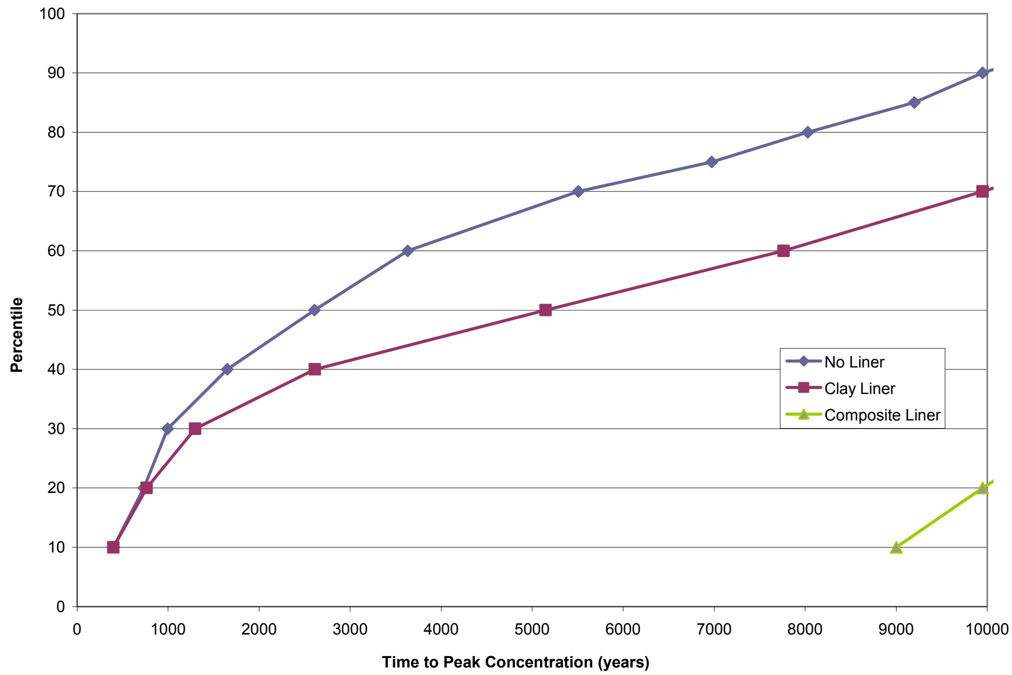
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-14. Time to peak distribution for selenium IV: surface impoundments, all waste types, full 10,000 year time frame.



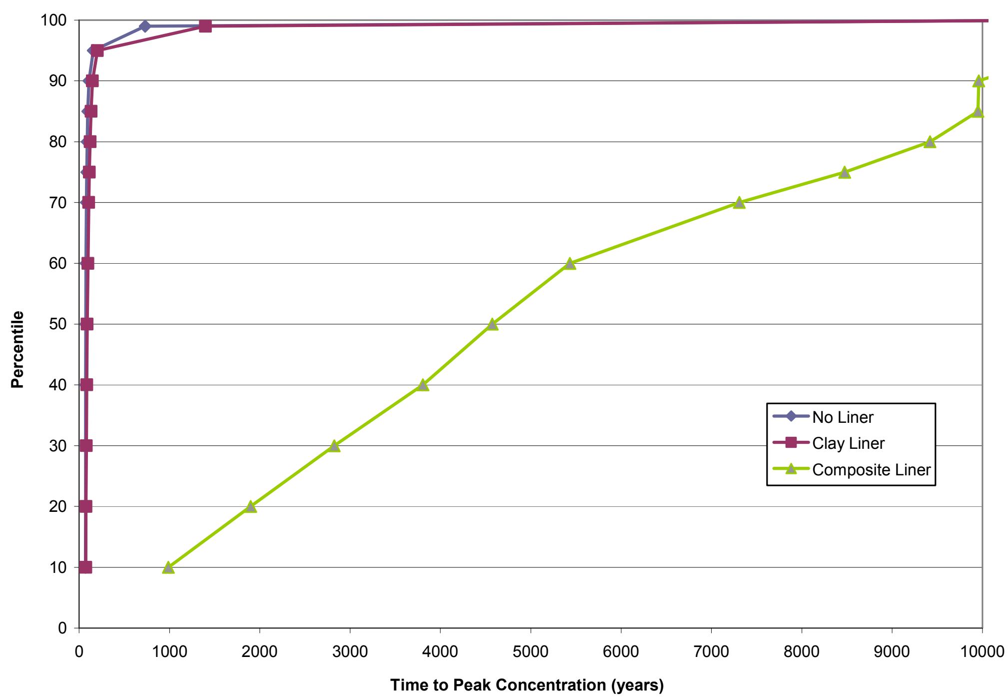
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-15. Time to peak distribution for selenium IV: surface impoundments, all waste types, shorter time frame.



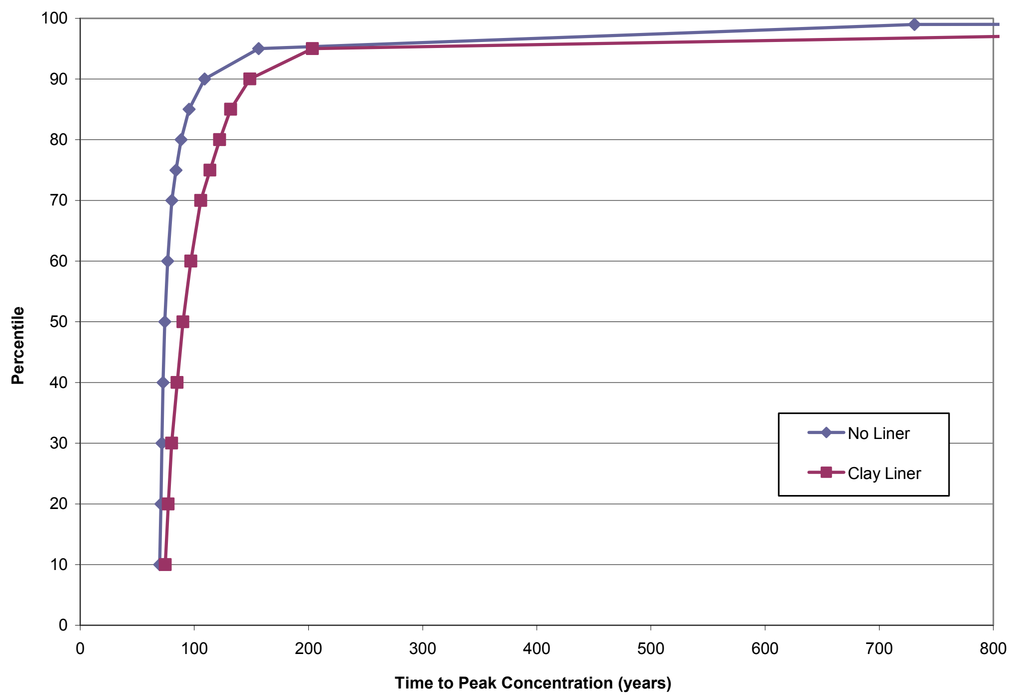
73% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-16. Time to peak distribution for selenium VI: landfills, all waste types.



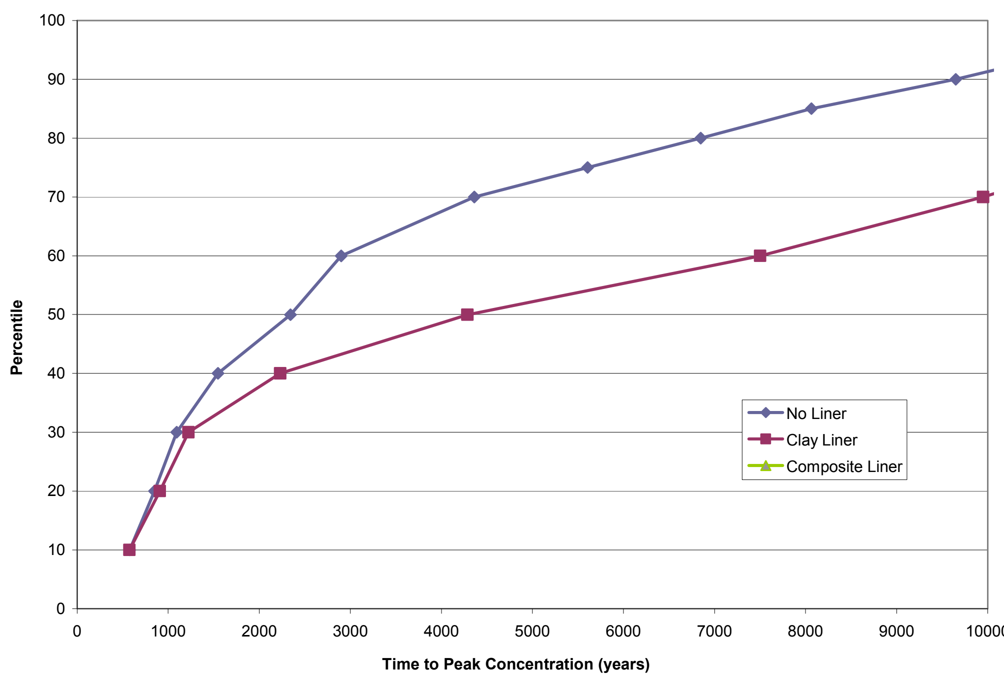
35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-17. Time to peak distribution for selenium VI: surface impoundments, all waste types, full 10,000 year time frame.



35.6% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-18. Time to peak distribution for selenium VI: surface impoundments, all waste types, shorter time frame.



73% of composite liner results have no infiltration and are not plotted on this graph.

Figure L-19. Time to peak distribution for thallium: landfills, all waste types.

USEPA Part II - Federal Register -Proposed Rule (2010, 06-21)

Federal Register

Monday,
June 21, 2010

Part II

Environmental Protection Agency

40 CFR Parts 257, 261, 264 et al.

Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals From Electric Utilities; Proposed Rule

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 257, 261, 264, 265, 268, 271 and 302

[EPA–HQ–RCRA–2009–0640; FRL–9149–4]

RIN–2050–AE81

Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals From Electric Utilities

AGENCY: Environmental Protection Agency (EPA).

ACTION: Proposed rule.

SUMMARY: The Environmental Protection Agency (EPA or Agency) is proposing to regulate for the first time, coal combustion residuals (CCRs) under the Resource Conservation and Recovery Act (RCRA) to address the risks from the disposal of CCRs generated from the combustion of coal at electric utilities and independent power producers. However, the Agency is considering two options in this proposal and, thus, is proposing two alternative regulations. Under the first proposal, EPA would reverse its August 1993 and May 2000 Bevill Regulatory Determinations regarding coal combustion residuals (CCRs) and list these residuals as special wastes subject to regulation under subtitle C of RCRA, when they are destined for disposal in landfills or surface impoundments. Under the second proposal, EPA would leave the Bevill determination in place and regulate disposal of such materials under subtitle D of RCRA by issuing national minimum criteria. Under both alternatives EPA is proposing to establish dam safety requirements to address the structural integrity of surface impoundments to prevent catastrophic releases.

EPA is not proposing to change the May 2000 Regulatory Determination for beneficially used CCRs, which are currently exempt from the hazardous waste regulations under Section 3001(b)(3)(A) of RCRA. However, EPA is clarifying this determination and seeking comment on potential refinements for certain beneficial uses. EPA is also not proposing to address the placement of CCRs in mines, or non-minefill uses of CCRs at coal mine sites in this action.

DATES: Comments must be received on or before September 20, 2010. EPA will provide an opportunity for a public hearing on the rule upon request. Requests for a public meeting should be submitted to EPA's Office of Resource Conservation and Recovery by July 21, 2010. *See* the **FOR FURTHER INFORMATION CONTACT** section for contact information. Should EPA receive requests for public meetings within this timeframe, EPA will publish a document in the **Federal Register** providing the details of such meetings.

ADDRESSES: Submit your comments, identified by Docket ID No. EPA–HQ–RCRA–2009–0640, by one of the following methods:

- *http://www.regulations.gov:* Follow the on-line instructions for submitting comments.
- *E-mail:* Comments may be sent by electronic mail (e-mail) to *rcra-docket@epa.gov,* Attention Docket ID No. EPA–HQ–RCRA–2009–0640. In contrast to EPA's electronic public docket, EPA's e-mail system is not an "anonymous access" system. If you send an e-mail comment directly to the Docket without going through EPA's electronic public docket, EPA's e-mail system automatically captures your e-mail address. E-mail addresses that are automatically captured by EPA's e-mail system are included as part of the comment that is placed in the official public docket, and made available in EPA's electronic public docket.
- *Fax:* Comments may be faxed to 202–566–0272; Attention Docket ID No. EPA–HQ–RCRA–2009–0640.
- *Mail:* Send your comments to the Hazardous Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals From Electric Utilities Docket, Attention Docket ID No., EPA–HQ–RCRA–2009–0640, Environmental Protection Agency, *Mailcode:* 5305T, 1200 Pennsylvania Ave., NW., Washington, DC 20460. Please include a total of two copies.
- *Hand Delivery:* Deliver two copies of your comments to the Hazardous Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals From Electric Utilities Docket, Attention Docket ID No., EPA–HQ–RCRA–2009–0640, EPA/DC, EPA West, Room 3334, 1301 Constitution Ave., NW., Washington, DC 20460. Such deliveries are only accepted during the Docket's normal hours of operation, and special arrangements should be made for deliveries of boxed information.

Instructions: Direct your comments to Docket ID No. EPA–HQ–RCRA–2009–0640. EPA's policy is that all comments received will be included in the public docket without change and may be made available online at *http://www.regulations.gov,* including any personal information provided, unless the comment includes information claimed to be Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Do not submit information that you consider to be CBI or otherwise protected through *http://www.regulations.gov* or e-mail. The *http://www.regulations.gov* Web site is an "anonymous access" system, which means EPA will not know your identity or contact information unless you provide it in the body of your comment. If you send an e-mail comment directly to EPA without going through *http://www.regulations.gov,* your e-mail address will be automatically captured and included as part of the comment that is placed in the public docket and made available on the Internet. If you submit an electronic comment, EPA recommends that you include your name and other contact information in the body of your comment and with any disk or CD–ROM you submit. If EPA cannot read your comment due to technical difficulties and cannot contact you for clarification, EPA may not be able to consider your comment. Electronic files should avoid the use of special characters, any form of encryption, and be free of any defects or viruses. For additional information about EPA's public docket, visit the EPA Docket Center homepage at *http://www.epa.gov/epahome/dockets.htm.* For additional instructions on submitting comments, go to the **SUPPLEMENTARY INFORMATION** section of this document.

Docket: All documents in the docket are listed in the *http://www.regulations.gov* index. Although listed in the index, some information is not publicly available, *e.g.,* CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, will be publicly available only in hard copy. Publicly available docket materials are available either electronically in *http://www.regulations.gov* or in hard copy at the Hazardous Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals From Electric Utilities Docket, EPA/DC, EPA West, Room 3334, 1301 Constitution Ave., NW., Washington, DC 20460. This Docket Facility is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The Docket telephone number is (202) 566–0270. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566–1744.

FOR FURTHER INFORMATION CONTACT: Alexander Livnat, Office of Resource Conservation and Recovery, Environmental Protection Agency, 5304P; *telephone number:* (703) 308–7251; *fax number:* (703) 605–0595; *e-mail address: livnat.alexander@epa.gov,* or Steve Souders, Office of Resource Conservation and Recovery, Environmental Protection Agency, 5304P; *telephone number:* (703) 308–8431; *fax number:* (703) 605–0595; *e-mail address: souders.steve@epa.gov.* For technical information on the CERCLA aspects of this rule, contact Lynn Beasley, Office of Emergency Management, Regulation and Policy Development Division (5104A), U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue, NW., Washington, DC 20460, [*E-mail address and telephone number: Beasley.lynn@epa.gov* (202–564–1965).]

For more information on this rulemaking please visit *http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/index.htm.*

SUPPLEMENTARY INFORMATION:

A. Does this action apply to me?

The proposed rule would apply to all coal combustion residuals (CCRs) generated by electric utilities and independent power producers. However, this proposed rule does not address the placement of CCRs in minefills. The U. S. Department of Interior (DOI) and EPA will address the management of CCRs in minefills in a separate regulatory action(s), consistent with the approach recommended by the National Academy of Sciences, recognizing the expertise of DOI's Office of Surface Mining Reclamation and Enforcement in this area.[1] In addition, under either alternative proposal, EPA is not proposing to affect the current status of coal combustion residuals that are beneficially used.[2] (*See* section IV. D for further details on proposed clarifications of beneficial use.) CCRs from non-utility boilers burning coal are not included within today's proposed rule. EPA will decide on an appropriate action for these wastes after completing this rulemaking effort.

The proposed rule may affect the following entities: electric utility facilities and independent power producers that fall under the North American Industry Classification System (NAICS) code 221112, and hazardous waste treatment and disposal facilities that fall under NAICS code 562211. The industry sector(s) identified above may not be exhaustive; other types of entities not listed could also be affected. The Agency's aim is to provide a guide for readers regarding those entities that potentially could be affected by this action. To determine whether your facility, company, business, organization, etc., is affected by this action, you should refer to the applicability criteria contained in section IV of this preamble. If you have any questions regarding the applicability of this action to a particular entity, consult the person listed in the preceding **FOR FURTHER INFORMATION CONTACT** section.

B. What should I consider as I prepare my comments for EPA?

1. *Submitting confidential business information (CBI).* Do not submit information that you consider to be CBI through *http://www.regulations.gov* or by e-mail. Send or deliver information identified as CBI only to the following address: RCRA CBI Document Control Officer, Office of Resource Conservation and Recovery (5305P), U.S. EPA, 1200 Pennsylvania Avenue, NW., Washington DC 20460, Attention Docket No, EPA–HQ–RCRA–2009–0640. You may claim information that you submit to EPA as CBI by marking any part or all of the information as CBI (if you submit CBI on a disk or CD ROM, mark the outside of the disk or CD ROM as CBI and then identify electronically within the disk or CD ROM the specific information that is claimed as CBI). Information so marked will not be disclosed, except in accordance with the procedures set forth in 40 CFR part 2. In addition to one complete version of the comment that includes information claimed as CBI, a copy of the comment that does not contain the information claimed as CBI must be submitted for inclusion in the public docket. If you submit the copy that does not contain CBI on disk or CD ROM, mark the outside of the disk or CD ROM clearly that it does not contain CBI. Information not marked as CBI will be included in the public docket and EPA's electronic public docket without prior notice. If you have questions about CBI or the procedures for claiming CBI, please contact: LaShan Haynes, Office of Resource Conservation and Recovery (5305P), U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue, NW., Washington DC 20460–0002, telephone (703) 605–0516, e-mail address *haynes.lashan@epa.gov.*

2. *Tips for Preparing Your Comments.* When submitting comments, remember to:

- Identify the rulemaking by docket number and other identifying information (subject heading, **Federal Register** date and page number).
- Follow directions—The Agency may ask you to respond to specific questions or organize comments by referencing a Code of Federal Regulations (CFR) part or section number.
- Explain why you agree or disagree, suggest alternatives, and substitute language for your requested changes, and explain your interest in the issue you are attempting to address.
- Describe any assumptions and provide any technical information and/or data that you used.
- If you estimate potential costs or burdens, explain how you arrived at your estimate in sufficient detail to allow for it to be reproduced.
- Provide specific examples to illustrate your concerns, and suggest alternatives.
- Explain your views as clearly as possible.
- Make sure to submit your comments by the comment period deadline identified.

3. *Docket Copying Costs.* The first 100-copied pages are free. Thereafter, the charge for making copies of Docket materials is 15 cents per page.

C. Definitions, Abbreviations and Acronyms Used in This Preamble (Note: Any term used in this proposed rulemaking that is not defined in this section will either have its normal dictionary meaning, or is defined in 40 CFR 260.10.)

Acre-foot means the volume of one acre of surface area to a depth of one foot.

Beneficial Use of Coal Combustion Products (CCPs) means the use of CCPs that provides a functional benefit; replaces the use of an alternative material, conserving natural resources that would otherwise need to be obtained through practices such as extraction; and meets relevant product specifications and regulatory standards (where these are available). CCPs that are used in excess quantities (*e.g.,* the field-applications of FGD gypsum in amounts that exceed scientifically-supported quantities required for enhancing soil properties and/or crop

[1] The National Research Council (NRC) Committee on Mine Placement of Coal Combustion Wastes stated: "The committee believes that OSM and its SMCRA state partners should take the lead in developing new national standards for CCR use in mines because the framework is in place to deal with mine-related issues." National Academy of Sciences. Managing Coal Combustion Residues in Mines; The National Academies Press, Washington, DC, 2006.

[2] The NRC committee recommended "that secondary uses of CCRs that pose minimal risks to human health and the environment be strongly encouraged." *Ibid.*

yields), placed as fill in sand and gravel pits, or used in large scale fill projects, such as for restructuring the landscape, are excluded from this definition.

Boiler slag means the molten bottom ash collected at the base of slag tap and cyclone type furnaces that is quenched with water. It is made up of hard, black, angular particles that have a smooth, glassy appearance.

Bottom ash means the agglomerated, angular ash particles, formed in pulverized coal furnaces that are too large to be carried in the flue gases and collect on the furnace walls or fall through open grates to an ash hopper at the bottom of the furnace.

CCR Landfill means a disposal facility or part of a facility where CCRs are placed in or on land and which is not a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit. For purposes of this proposed rule, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills.

CCR Surface Impoundment or *impoundment* means a facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), which is designed to hold an accumulation of CCRs containing free liquids, and which is not an injection well. Examples of CCR surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons. CCR surface impoundments are used to receive CCRs that have been sluiced (flushed or mixed with water to facilitate movement), or wastes from wet air pollution control devices, often in addition to other solid wastes.

Cenospheres are lightweight, inert, hollow spheres comprised largely of silica and alumina glass.

Coal Combustion Products (CCPs) means fly ash, bottom ash, boiler slag, or flue gas desulfurization materials, that are beneficially used.

Coal Combustion Residuals (CCRs) means fly ash, bottom ash, boiler slag, and flue gas desulfurization materials destined for disposal. CCRs are also known as coal combustion wastes (CCWs) and fossil fuel combustion (FFC) wastes, when destined for disposal.

Electric Power Sector (Electric Utilities and Independent Power Producers) means that sector of the power generating industry that comprises electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

Existing CCR Landfill means a landfill which was in operation or for which construction commenced prior to the effective date of the final rule. A CCR landfill has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill to be completed within a reasonable time.

Existing CCR Surface Impoundment means a surface impoundment which was in operation or for which construction commenced prior to the effective date of the final rule. A CCR surface impoundment has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which can not be cancelled or modified without substantial loss—for physical construction of the CCR surface impoundment to be completed within a reasonable time.

Flue Gas Desulfurization (FGD) material means the material produced through a process used to reduce sulfur dioxide (SO_2) emissions from the exhaust gas system of a coal-fired boiler. The physical nature of these materials varies from a wet sludge to a dry powdered material, depending on the process, and their composition comprises either sulfites, sulfates or a mixture thereof.

Fly ash means the very fine globular particles of silica glass which is a product of burning finely ground coal in a boiler to produce electricity, and is removed from the plant exhaust gases by air emission control devices.

Hazard potential means the possible adverse incremental consequences that result from the release of water or stored contents due to failure of a dam (or impoundment) or mis-operation of the dam or appurtenances.[3]

High hazard potential surface impoundment means a surface impoundment where failure or mis-operation will probably cause loss of human life.

Significant hazard potential surface impoundment means a surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environment damage, disruption of lifeline facilities, or impact other concerns.

Low hazard potential surface impoundment means a surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Less than low hazard potential surface impoundment means a surface impoundment not meeting the definitions for High, Significant, or Low Hazard Potential.

Independent registered professional engineer or hydrologist means a scientist or engineer who is not an employee of the owner or operator of a CCR landfill or surface impoundment who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in groundwater hydrology and related fields as may be demonstrated by state registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgments regarding groundwater monitoring, contaminant fate and transport, and corrective action.

Lateral expansion means a horizontal expansion of the waste boundaries of an existing CCR landfill, or existing CCR surface impoundment made after the effective date of the final rule.

Maximum Contaminant Level (MCL) means the highest level of a contaminant that is allowed in drinking water under the Safe Drinking Water Act (SDWA). MCLs are set as close to the MCL goals as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards for drinking water.

Minefill means a project involving the placement of CCRs in coal mine voids for use as fill, grouting, subsidence control, capping, mine sealing, and

[3] The Hazard Potential Classification System for Dams was developed by the U.S. Army Corps of Engineers for the National Inventory of Dams (*see https://rsgis.crrel.usace.army.mil/apex/f?p=397:1:913698079375545*). Hazard potential ratings do not provide an estimate of the probability of failure or mis-operation, but rather what the consequences of such a failure or mis-operation would be.

treating acid mine drainage, whether for purposes of disposal or for beneficial use, such as mine reclamation.

Natural water table means the natural level at which water stands in a shallow well open along its length and penetrating the surficial deposits just deeply enough to encounter standing water at the bottom. This level is uninfluenced by groundwater pumping or other engineered activities.

Organosilanes are organic compounds containing at least one carbon to silicon bond, and are typically used to promote adhesion.

Potential damage case means those cases with documented MCL exceedances that were measured in ground water beneath or close to the waste source. In these cases, while the association with CCRs has been established, the documented exceedances had not been demonstrated at a sufficient distance from the waste management unit to indicate that waste constituents had migrated to the extent that they could cause human health concerns.

Pozzolanic material means primarily vitreous siliceous materials, such as many types of CCRs that, when combined with calcium hydroxide and in the presence of water, exhibit cementitious properties.

Proven damage case means those cases with (i) Documented exceedances of primary maximum contaminant levels (MCLs) or other health-based standards measured in ground water at sufficient distance from the waste management unit to indicate that hazardous constituents have migrated to the extent that they could cause human health concerns, and/or (ii) where a scientific study provides documented evidence of another type of damage to human health or the environment (*e.g.,* ecological damage), and/or (iii) where there has been an administrative ruling or court decision with an explicit finding of specific damage to human health or the environment. In cases of co-management of CCRs with other industrial waste types, CCRs must be clearly implicated in the reported damage.

Sand and gravel pit, and/or quarry means an excavation for the commercial extraction of aggregate for use in construction projects. CCRs have historically been used to fill sand and gravel pits and quarries. CCRs are not known to be used to fill metal mines.

Secondary Drinking Water Standards are non-enforceable federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water.

Special Wastes means any of the following wastes that are managed under the modified subtitle C requirements: CCRs destined for disposal.

Surface Water means all water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.).

Uniquely associated wastes means low-volume wastes other than those defined as CCRs that are related to the coal combustion process. Examples of uniquely associated wastes are precipitation runoff from coal storage piles at the electric utility, waste coal or coal mill rejects that are not of sufficient quality to burn as a fuel, and wastes from cleaning boilers used to generate steam.

CCPs Coal Combustion Products
CCRs Coal Combustion Residuals
CFR Code of Federal Regulations
CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
EPA U.S. Environmental Protection Agency
EPCRA Emergency Planning and Community Right-to-Know Act
MCL Maximum Contaminant Level
m/L milligrams per liter
NPDES National Pollutant Discharge Elimination System
NRC National Response Center
PDWS Primary Drinking Water Standard
OSM Office of Surface Mining Reclamation and Enforcement, U.S. Department of the Interior
RCRA Resource Conservation and Recovery Act (42 USCA 6901)
RQ Reportable Quantity
SDWS Secondary Drinking Water Standard
SMCRA Surface Mining Control and Reclamation Act
μg/L micrograms per liter
WQC Federal water quality criteria

D. The Contents of This Preamble Are Listed in the Following Outline

I. Background

A. Why is EPA proposing two options?

1. Basis of Why EPA Is Proceeding With Today's Co-Proposals

EPA is revisiting its regulatory determination for CCRs under the Bevill amendment. This decision is driven in part by the failure of a surface impoundment retaining wall in Kingston, TN in December 2009. Deciding upon the appropriate course of action to address over 100 million tons per year of CCRs is an extremely important step. In developing this proposal, EPA conducted considerable data gathering and analysis. While the public was able to comment on significant portions of our analyses in August 2007, as part of a Notice of Data Availability, there are differing views regarding the meaning of EPA's information and what course of action EPA should take. In part, the differing views are fueled by the complex data, analyses, legislation, implications of available options, possible unintended consequences, and a decision process, all of which pose considerations that could justify EPA selecting a RCRA subtitle C approach or selecting a RCRA subtitle D approach.

Deciding whether or not to maintain the Bevill exemption for CCRs, entails an evaluation of the eight RCRA Section 8002(n) study factors:

- Source and volumes of CCRs generated per year
- Present disposal and utilization practices
- Potential danger, if any, to human health and the environment from the disposal and reuse of CCRs
- Documented cases in which danger to human health or the environment from surface runoff or leachate has been proved
- Alternatives to current disposal methods
- The cost of such alternatives
- The impact of the alternatives on the use of coal and other natural resources
- The current and potential utilization of CCRs

Ultimately, the approach selected will need to ensure that catastrophic releases such as occurred at the Tennessee Valley Authority's (TVA's) Kingston, Tennessee facility do not occur and that other types of damage cases associated with CCR surface impoundments and landfills are prevented. Thus, this process requires EPA to balance the eight factors, which ultimately rests on a policy judgment. This is further complicated in this case because the facts identified under each of the individual factors are even subject to widely varying perspectives. For example, in considering the alternatives to current disposal methods, some claim that RCRA subtitle C would significantly lessen beneficial use while others *see* beneficial use expanding as disposal becomes more costly; some *see* damage cases as substantial, while others note very few incidences of significant off-site contamination.

Given the inherently discretionary nature of the decision, the complexities of the scientific analyses, and the controversy of the issue, EPA wants to ensure that the ultimate decision is based on the best available data, and is taken with the fullest possible extent of public input. As discussed in section IV in greater detail, there are a number of issues on which additional or more recent information would be useful in allowing the Agency to reach a final decision. In the absence of this information, EPA has not yet reached a conclusion as to how to strike the appropriate balance among these eight factors and so is presenting two proposals for federal regulation of CCRs.

As EPA weighs the eight Bevill study factors to reach our ultimate decision, EPA will be guided by the following principles, which are reflected in the discussions throughout this preamble. The first is that EPA's actions must ultimately be protective of human health and the environment. Second, any decision must be based on sound science. Finally, in conducting this rulemaking, EPA wants to ensure that our decision processes are transparent and encourage the greatest degree of public participation. Consequently, to further the public's understanding and ability to comment on all the issues facing the Agency, within this proposal, EPA identifies a series of scientific, economic, and materials management issues on which we are seeking comment from the public to strengthen our knowledge of the impact of EPA's decision.

There are three key areas of analyses where EPA is seeking comment: The extent of existing damage cases, the extent of the risks posed by the mismanagement of CCRs, and the adequacy of State programs to ensure proper management of CCRs (*e.g.,* is groundwater monitoring required of CCR landfills and surface impoundments). Since the 2007 NODA, EPA received new reports from industry and environmental and citizen groups regarding damage cases. Industry provided information indicating that many of EPA's listed proven damage cases do not meet EPA's criteria for a damage case to be proven. Environmental and citizen groups, on the other hand, reported that there are additional damage cases of which EPA is unaware. EPA's analysis, as well as the additional information from industry and environmental and citizen groups, which is in the docket for this proposal, needs to undergo public review, with the end result being a better understanding of the nature and number of damage cases. In addition, as discussed at length in sections II and IV, a number of technical questions have been raised regarding EPA's quantitative groundwater risk assessment. The Agency would implement similar technical controls under RCRA subtitle C or D. Therefore, a central issue is the adequacy of State programs. Under either regulatory approach, State programs will have key implementation roles. This is a very complex area to evaluate. For example, as EPA reports that 36% of the States do not have minimum liner requirements for CCR landfills, and 67% do not have liner requirements for CCR surface impoundments, we also observe that nearly all new CCR landfills and surface impoundments are constructed with liners. It should also be recognized that while states currently have considerable expertise in their State dam safety programs, those programs do not tend to be part of State solid waste or clean water act programs, and so, oversight may not be adequately captured in EPA's existing data. In several areas, there are these types of analytical tensions that warrant careful consideration by the public and EPA. This proposal requests states and others to provide further information on state programs, including the prevalence of groundwater monitoring at existing facilities (an area where our information is nearly 15 years old) and why state programs may address groundwater monitoring and risks differently for surface impoundments located proximate to rivers.

The results of the risk analysis demonstrate significant risks from surface impoundments. A common industry practice, however, is to place surface impoundments right next to water bodies. While the Agency's population risk assessment analysis accounted for adjacent water bodies, the draft risk assessment that presents individual risk estimates does not account for the presence of adjacent water bodies in the same manner that the population risk assessment did. EPA is requesting public comment on the exact locations of CCR waste management units so that the Agency can more fully account for water bodies that may exist between a waste management unit and a drinking water well (and thus, could potentially intercept a contaminated groundwater plume). EPA is also requesting comments on how the risk assessment should inform the final decision.

While the Agency believes the analyses conducted are sound, today's co-proposal of two options reflects our commitment to use the public process fully to ensure the best available scientific and regulatory impact analyses are considered in our decision. The final course of action will fully consider these legitimate and complex issues, and will result in the selection of a regulatory structure that best addresses the eight study factors identified in section 8002(n) of RCRA, and ensures protection of human health and the environment.

2. Brief Description of Today's Co-Proposals

a. Summary of Subtitle C Proposal

In combination with its proposal to reverse the Bevill determination for CCRs destined for disposal, EPA is proposing to list as a special waste, to be regulated under the RCRA subtitle C regulations, CCRs from electric utilities and independent power producers when destined for disposal in a landfill or surface impoundment. These CCRs would be regulated from the point of their generation to the point of their final disposition, including during and after closure of any disposal unit. This would include the generator and transporter requirements and the requirements for facilities managing CCRs, such as siting, liners (with modification), run-on and run-off controls, groundwater monitoring, fugitive dust controls, financial assurance, corrective action, including facility-wide corrective action, closure of units, and post-closure care (with certain modifications). In addition, facilities that dispose of, treat, or, in many cases, store, CCRs also would be required to obtain permits for the units in which such materials are disposed, treated, and stored. The rule would also regulate the disposal of CCRs in sand and gravel pits, quarries, and other large fill operations as a landfill.

To address the potential for catastrophic releases from surface impoundments, we also are proposing requirements for dam safety and stability for impoundments that, by the effective date of the final rule, have not closed consistent with the requirements. We are also proposing land disposal restrictions and treatment standards for CCRs, as well as a prohibition on the disposal of treated CCRs below the natural water table.

b. Summary of Subtitle D Proposal

In combination with today's proposal to leave the Bevill determination in place, EPA is proposing to regulate CCRs disposed of in surface impoundments or landfills under RCRA subtitle D requirements which would establish national criteria to ensure the safe disposal of CCRs in these units. The units would be subject to, among other things, location standards, composite liner requirements (new landfills and surface impoundments would require composite liners; existing surface impoundments without liners would have to retrofit within five years, or cease receiving CCRs and close); groundwater monitoring and corrective action standards for releases from the unit; closure and post-closure care requirements; and requirements to address the stability of surface impoundments. We are also soliciting comments on requiring financial assurance. The rule would also regulate the disposal of CCRs in sand and gravel pits, quarries, and other large fill operations as a landfill. The rule would not regulate the generation, storage or treatment of CCRs prior to disposal. Because of the scope of subtitle D authority, the rule would not require permits, nor could EPA enforce the requirements. Instead, states or citizens could enforce the requirements under RCRA citizen suit authority; the states could also enforce any state regulation under their independent state enforcement authority.

EPA is also considering a potential modification to the subtitle D option, called "D prime" in the following table. Under this option, existing surface impoundments would not have to close or install composite liners but could continue to operate for their useful life. In the "D prime" option, the other elements of the subtitle D option would remain the same.

3. Summary of Estimated Regulatory Costs and Benefits

For the purposes of comparing the estimated regulatory compliance costs to the monetized benefits for each regulatory option, the Regulatory Impact Analysis (RIA) computed two comparison indicators: Net benefits (*i.e.,* benefits minus costs), and benefit/cost ratio (*i.e.,* benefits divided by costs). Table 1 below provides a summary of estimated regulatory costs and benefits for three regulatory options, based on the 7% discount rate base case and the 50-year period-of-analysis applied in the RIA. Furthermore, this benefit and cost summary table displays ranges of net benefit and benefit/cost results across three different scenarios concerning the potential impacts of each option on the future annual beneficial use of CCRs under each option. The first scenario presents the potential impact scenario that assumes that the increased future annual cost of RCRA-regulated CCR disposal will induce coal-fired electric utility plants to increase beneficial use of CCRs. The second scenario presents a potential market stigma effect under the subtitle C option which will induce a decrease in future annual CCR beneficial use. The third scenario assumed that beneficial use of CCRs continues according to its recent trend line without any future change as a result of any of the regulatory options. The RIA estimates both the first and second scenario incrementally in relation to the third scenario no change trend line. Table 1 shows the range of impacts and associated ranges of net benefits and benefit-cost ratios across these three beneficial use scenarios for each regulatory option. While each of these three scenario outcomes may be possible, EPA's experience with the RCRA program indicates that industrial generators of RCRA-regulated wastes are often able to increase recycling and materials recovery rates after a subtitle C regulation. Section XII in this preamble provides additional discussion of these estimates.

TABLE 1—SUMMARY TABLE COMPARISON OF REGULATORY BENEFITS TO COSTS—RANGING OVER ALL THREE BENEFICIAL USE SCENARIOS

[$Millions @ 2009$ prices and @ 7% discount rate over 50-year future period-of-analysis 2012 to 2061]

	Subtitle C "Special waste"	Subtitle D	Subtitle "D prime"
A. Present Values:			
1. Regulatory Costs:	$20,349	$8,095	$3,259.
2. Regulatory Benefits:	$87,221 to $102,191	$34,964 to $41,761	$14,111 to $17,501.
3. Net Benefits (2–1)	($251,166) to $81,842	($6,927) to $33,666	($2,666) to $14,242.
4. Benefit/Cost Ratio (2/1)	(11.343) to 5.022	0.144 to 5.159	0.182 to 5.370.
B. Average Annualized Equivalent Values:*			
1. Regulatory Costs	$1,474	$587	$236.
2. Regulatory Benefits:	$6,320 to $7,405	$2,533 to $3,026	$1,023 to $1,268.
3. Net Benefits (2–1)	($18,199) to $5,930	($502) to $2,439	($193) to $1,032.
4. Benefit/Cost Ratio (2/1)	(11.347) to 5.022	0.145 to 5.159	0.182 to 5.370.

* **Note:** Average annualized equivalent values calculated by multiplying 50-year present values by a 50-year 7% discount rate "capital recovery factor" of 0.07246.

B. What is the statutory authority for this action?

These regulations are being proposed under the authority of sections 1008(a), 2002(a), 3001, 3004, 3005, and 4004 of the Solid Waste Disposal Act of 1970, as amended by the Resource Conservation and Recovery Act of 1976 (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA), 42 U.S.C. 6907(a), 6912(a), 6921,6924, 6925 and 6944. These statutes, combined, are commonly referred to as "RCRA."

RCRA section 1008(a) authorizes EPA to publish "suggested guidelines for solid waste management." 42 U.S.C. 6907(a). Such guidelines must provide a technical and economic description of the level of performance that can be achieved by available solid waste management practices that provide for protection of human health and the environment.

RCRA section 2002 grants EPA broad authority to prescribe, in consultation with federal, State, and regional authorities, such regulations as are necessary to carry out the functions under federal solid waste disposal laws. (42 U.S.C. 6912(a)).

RCRA section 3001(b) requires EPA to list particular wastes that will be subject to the requirements established under subtitle C. (42 U.S.C. 6921(b)). The regulation listing such wastes must be based on the listing criteria established pursuant to section 3001(a), and codified at 40 CFR 261.11.

Section 3001(b)(3)(A) of RCRA established a temporary exemption for fly ash waste, bottom ash waste, slag waste, and flue gas emission control waste generated primarily from the combustion of coal or other fossil fuels, among others, and required the Agency to conduct a study of those wastes and, after public hearings and an opportunity for comment, determine whether these wastes should be regulated pursuant to subtitle C requirements (42 U.S.C. 6921 (b)(3)(A)).

Section 3004 of RCRA generally requires EPA to establish standards applicable to the treatment, storage, and disposal of hazardous waste to ensure that human health and the environment are protected. 42 U.S.C. 6924. Sections

3004(c) and (d) prohibit free liquids in hazardous waste landfills. Sections 3004(g) and (m) prohibit land disposal of hazardous wastes, unless, before disposal, those wastes meet treatment standards established by EPA that will "substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats are minimized." (42 U.S.C. 6924(c), (d), (g), and (m)).

RCRA section 3004(x) allows the Administrator to tailor certain specified requirements for particular categories of wastes, including those that are the subject of today's proposal, namely "fly ash waste, bottom ash waste, and flue gas emission control wastes generated primarily from the combustion of coal or other fossil fuels" (42 U.S.C. 6924(x)). EPA is authorized to modify the requirements of sections 3004 (c), (d), (e), (f), (g), (o), and (u), and section 3005(j), to take into account the special characteristics of the wastes, the practical difficulties associated with implementation of such requirements, and site-specific characteristics, including but not limited to the climate, geology, hydrology and soil chemistry at the site. EPA may only make such modifications, provided the modified requirements assure protection of human health and the environment. (42 U.S.C. 6924(x)).

RCRA section 3005 generally requires any facility that treats, stores, or disposes of wastes identified or listed under subtitle C, to have a permit. 42 U.S.C. 6925(a). This section also generally imposes requirements on facilities that become newly subject to the permitting requirements as a result of regulatory changes, and so can continue to operate for a period until they obtain a permit—*i.e.,* "interim status facilities." 42 U.S.C. 6925(e), (i), (j). Congress imposed special requirements on interim status surface impoundments in section 3005(j). In order to continue receiving wastes, interim status surface impoundments are generally required to retrofit the impoundment within 4 years, to install a double liner, with a leachate collection system, and groundwater monitoring. 42 U.S.C. 6925(j)(6). In addition, wastes disposed into interim status surface impoundments must meet the land disposal restrictions in EPA's regulations, or the unit must be annually dredged. 42 U.S.C. 6925(j)(11).

RCRA Section 4004 generally requires EPA to promulgate regulations containing criteria for determining which facilities shall be classified as sanitary landfills (and not open dumps) so that there is no reasonable probability of adverse effects on health or the environment from disposal of solid wastes at such facilities.

C. Regulation of Wastes Under RCRA Subtitle C

Solid wastes may become subject to regulation under subtitle C of RCRA in one of two ways. A waste may be subject to regulation if it exhibits certain hazardous properties, called "characteristics," or if EPA has specifically listed the waste as hazardous. *See* 42 U.S.C. 6921(a). EPA's regulations in the Code of Federal Regulations (40 CFR) define four hazardous waste characteristic properties: Ignitability, corrosivity, reactivity, or toxicity (*See* 40 CFR 261.21–261.24). All generators must determine whether or not a waste exhibits any of these characteristics by testing the waste, or by using knowledge of the process that generated the waste (*see* § 262.11(c)). While not required to sample the waste, generators will be subject to enforcement actions if found to be improperly managing wastes that exhibit one or more of the characteristics.

EPA may also conduct a more specific assessment of a waste or category of wastes and "list" them if they meet the criteria set out in 40 CFR 261.11. Under the third criterion, at 40 CFR 261.11(a)(3), a waste will be listed if it contains hazardous constituents identified in 40 CFR part 261, Appendix VIII, and if, after considering the factors noted in this section of the regulations, we "conclude that the waste is capable of posing a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed." We place a chemical on the list of hazardous constituents on Appendix VIII only if scientific studies have shown a chemical has toxic effects on humans or other life forms. When listing a waste, we also add the hazardous constituents that serve as the basis for listing the waste to 40 CFR part 261, Appendix VII.

The regulations at 40 CFR 261.31 through 261.33 contain the various hazardous wastes that EPA has listed to date. Section 261.31 lists wastes generated from non-specific sources, known as "F-wastes," that are usually generated by various industries or types of facilities, such as "wastewater treatment sludges from electroplating operations" (*see* EPA Hazardous Waste No. F006). Section 261.32 lists wastes generated from specific industry sources, known as "K-wastes," such as "Spent potliners from primary aluminum production" (*see* EPA Hazardous Waste No. K088). Section 261.33 contains lists of commercial chemical products and other materials, known as "P-wastes" or "U-wastes," that become hazardous wastes when they are discarded or intended to be discarded.

As discussed in greater detail later in this proposal, EPA is considering whether to codify a listing of CCRs that are disposed of in landfills or surface impoundments, in a new section of the regulations, as "Special Wastes." EPA is considering creating this new category of wastes, in part, to reflect the fact that these wastes would be subject to modified regulatory requirements using the authority provided under section 3004(x) of RCRA (*e.g.,* the modified CCR landfill and surface impoundment liner and leak detection system requirements, the effective dates for the land disposal restrictions, and the surface impoundment retrofit requirements).

If a waste exhibits a hazardous characteristic or is listed under subtitle C, then it is subject to the requirements of RCRA subtitle C, and the implementing regulations found in 40 CFR parts 260 through 268, parts 270 to 279, and part 124. These requirements apply to persons who generate, transport, treat, store or dispose of such waste and establish rules governing every phase of the waste's management from its generation to its final disposition and beyond. Facilities that treat, store or dispose of hazardous wastes require a permit which incorporates all of the design and operating standards established by EPA rules, including standards for piles, landfills, and surface impoundments. Under RCRA subtitle C requirements, land disposal of hazardous waste is prohibited unless the waste is first treated to meet the treatment standards (or meets the treatment standards as generated) established by EPA that minimize threats to human health and the environment posed by the land disposal of the waste, or unless the waste is disposed in a unit from which there will be no migration of hazardous constituents for as long as the waste remains hazardous. In addition, RCRA subtitle C facilities are required to clean up any releases of hazardous waste or constituents from solid waste management units at the facility, as well as beyond the facility boundary, as necessary to protect human health and the environment. RCRA subtitle C also requires that permitted facilities demonstrate that they have adequate financial resources (*i.e.,* financial assurance) for obligations, such as closure, post-closure care, necessary clean up, and any liability from facility operations.

The RCRA subtitle C requirements are generally implemented under state programs that EPA has authorized to operate in lieu of the federal program, based upon a determination that the state program is no less stringent than the federal program. In a state that operates under an authorized program, any revisions made to EPA requirements are generally effective as part of the federal RCRA program in that state only after the state adopts the revised requirement, and EPA authorizes the state requirement. The exception applies with respect to requirements implementing statutory provisions added to subtitle C by the 1984 Hazardous and Solid Waste Amendments to RCRA; such requirements are immediately effective in all states, and are enforced by EPA.

All RCRA hazardous wastes are also hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as defined in section 101(14)(C) of the CERCLA statute. This applies to wastes listed in §§ 261.31 through 261.33, as well as any wastes that exhibits a RCRA hazardous characteristic. Table 302.4 at 40 CFR 302.4 lists the CERCLA hazardous substances along with their reportable quantities (RQs). Anyone spilling or releasing a hazardous substance at or above its RQ must report the release to the National Response Center, as required in CERCLA Section 103. In addition, Section 304 of the Emergency Planning and Community Right-to-Know Act (EPCRA) requires facilities to report the release of a CERCLA hazardous substance at or above its RQ to State and local authorities. Today's rule proposes an approach for estimating whether released CCRs exceed an RQ. Wastes listed as special wastes will generally be subject to the same requirements under RCRA subtitle C and CERCLA as are hazardous wastes, although as discussed elsewhere in this preamble, EPA is proposing to revise certain requirements under the authority of section 3004(x) of RCRA to account for the large volumes and unique characteristics of these wastes.

D. Regulation of Solid Wastes Under RCRA Subtitle D

Solid wastes that are neither a listed and/or characteristic hazardous waste are subject to the requirements of RCRA subtitle D. Subtitle D of RCRA establishes a framework for Federal, State, and local government cooperation in controlling the management of nonhazardous solid waste. The federal role in this arrangement is to establish the overall regulatory direction, by providing minimum nationwide standards for protecting human health and the environment, and to providing technical assistance to states for planning and developing their own environmentally sound waste management practices. The actual planning and direct implementation of solid waste programs under RCRA subtitle D, however, remains a state and local function, and the act authorizes States to devise programs to deal with State-specific conditions and needs. That is, EPA has no role in the planning and direct implementation of solid waste programs under RCRA subtitle D.

Under the authority of sections 1008(a)(3) and 4004(a) of subtitle D of RCRA, EPA first promulgated the Criteria for Classification of Solid Waste Disposal Facilities and Practices (40 CFR part 257) on September 13, 1979. These subtitle D Criteria establish minimum national performance standards necessary to ensure that "no reasonable probability of adverse effects on health or the environment" will result from solid waste disposal facilities or practices. Practices not complying with the criteria constitute "open dumping" for purposes of the Federal prohibition on open dumping in section 4005(a). EPA does not have the authority to enforce the prohibition directly (except in situations involving the disposal or handling of sludge from publicly-owned treatment works, where Federal enforcement of POTW sludge-handling facilities is authorized under the CWA). States and citizens may enforce the prohibition on open dumping using the authority under RCRA section 7002. EPA, however, may act only if the handling, storage, treatment, transportation, or disposal of such wastes may present an imminent and substantial endangerment to health or the environment (RCRA 7003). In addition, the prohibition may be enforced by States and other persons under section 7002 of RCRA.

In contrast to subtitle C, RCRA subtitle D requirements relate only to the disposal of the solid waste, and EPA does not have the authority to establish requirements governing the generation, transportation, storage, or treatment of such wastes prior to disposal. Moreover, EPA would not have administrative enforcement authority to enforce any RCRA subtitle D criteria for CCR facilities, authority to require states to issue permits for them or oversee those permits, nor authority for EPA to determine whether any state permitting program for CCR facilities is adequate. Subtitle D of RCRA also provides less extensive authority to establish requirements relating to the cleanup (or corrective action) and financial assurance at solid waste facilities.

EPA regulations affecting RCRA subtitle D facilities are found at 40 CFR parts 240 through 247, and 255 through 258. The existing part 257 criteria include general environmental performance standards addressing eight major topics: Floodplains (§ 257.3–1), endangered species (§ 257.3–2), surface water (§ 257.3–3), ground water (§ 257.3–4), land application (§ 257.35), disease (§ 257.3–6), air (§ 257.3–7), and safety (§ 257.3–8). EPA has also established regulations for RCRA subtitle D landfills that accept conditionally exempt small quantity generator hazardous wastes, and household hazardous wastes (*i.e.,* "municipal solid waste") at 40 CFR Part 258, but these are of limited relevance to CCRs, which fall into neither category of wastes.

E. Summary of the 1993 and 2000 Regulatory Determinations

Section 3001(b)(3)(A)(i) of RCRA (known as the Bevill exclusion or exemption) excluded certain large-volume wastes generated primarily from the combustion of coal or other fossil fuels from being regulated as hazardous waste under subtitle C of RCRA, pending completion of a Report to Congress required by Section 8002(n) of RCRA and a determination by the EPA Administrator either to promulgate regulations under RCRA subtitle C or to determine that such regulations are unwarranted.

In 1988, EPA published a Report to Congress on Wastes from the Combustion of Coal by Electric Utility Power Plants (EPA, 1988). The report, however, did not address co-managed utility CCRs, other fossil fuel wastes that are generated by utilities, and wastes from non-utility boilers burning any type of fossil fuel. Further, because of other priorities, EPA did not complete its Regulatory Determination on fossil fuel combustion (FFC) wastes at that time.

In 1991, a suit was filed against EPA for failure to complete a Regulatory Determination on FFC wastes (*Gearhart* v. *Reilly* Civil No. 91–2345 (D.D.C.), and on June 30, 1992, the Agency entered into a Consent Decree that established a schedule for EPA to complete the Regulatory Determinations for all FFC wastes. Specifically, FFC wastes were divided into two categories: (1) Fly ash, bottom ash, boiler slag, and flue gas emission control waste from the combustion of coal by electric utilities and independent commercial power producers, and (2) all remaining wastes subject to RCRA Sections 3001(b)(3)(A)(i) and 8002(n)—that is, large volume coal combustion wastes generated at electric utility and independent power producing facilities that are co-managed together with certain other coal combustion wastes; coal combustion wastes generated at non-utilities; coal combustion wastes generated at facilities with fluidized bed combustion technology; petroleum coke combustion wastes; wastes from the combustion of mixtures of coal and other fuels (*i.e.,* co-burning of coal with other fuels where coal is at least 50% of the total fuel); wastes from the combustion of oil; and wastes from the combustion of natural gas.

On August 9, 1993, EPA published its Regulatory Determination for the first category of wastes (58 FR 42466, *http://www.epa.gov/epawaste/nonhaz/industrial/special/mineral/080993.pdf*), concluding that regulation under subtitle C of RCRA for these wastes was not warranted. To make an appropriate determination for the second category, or "remaining wastes," EPA concluded that additional study was necessary. Under the court-ordered deadlines, the Agency was required to complete a Report to Congress by March 31, 1999, and issue a Regulatory Determination by October 1, 1999.

In keeping with its court-ordered schedule, and pursuant to the requirements of Section 3001(b)(3)(A)(i) and Section 8002(n) of RCRA, EPA prepared a Report to Congress on the remaining FFC wastes in March 1999 (*http://www.epa.gov/epaoswer/other/fossil/volume_2.pdf*). The report addresses the eight study factors required by Section 8002(n) of RCRA for FFC wastes (*see* discussion in section IV. B).

On May 22, 2000, EPA published its Regulatory Determination on wastes from the combustion of fossil fuels for the remaining wastes (65 FR 32214, *http://www.epa.gov/fedrgstr/EPA-WASTE/2000/May/Day-22/f11138.htm*). In its Regulatory Determination, EPA concluded that the remaining wastes were largely identical to the high-volume monofilled wastes, which remained exempt based on the 1993 Regulatory Determination. The high volume wastes simply dominate the waste characteristics even when co-managed with other wastes, and thus the May 2000 Regulatory Determination addressed not only the remaining wastes, but effectively reopened the decision on CCRs that went to monofills.

EPA concluded that these wastes could pose significant risks if not properly managed, although the risk information was limited. EPA identified and discussed a number of documented proven damage cases, as well as cases indicating at least a potential for damage to human health and the environment, but did not rely on its quantitative groundwater risk assessment, as EPA concluded that it was not sufficiently reliable. However, EPA concluded that significant improvements were being made in waste management practices due to increasing state oversight, although gaps remained in the current regulatory regime. On this basis, the Agency concluded to retain the Bevill exemption, and stated we would issue a regulation under subtitle D of RCRA, establishing minimum national standards. Those subtitle D standards have not yet been issued. (Today's proposal could result in the development of the subtitle D standards consistent with the May 2000 Regulatory Determination, or with a revision of the determination, or the issuance of subtitle C standards under RCRA.)

EPA also explicitly stated in the May 2000 Regulatory Determination that the Agency would continue to review the issues, and would reconsider its decision that subtitle C regulations were unwarranted based on a number of factors. EPA noted that its ongoing review would include (1) "the extent to which [the wastes] have caused damage to human health or the environment;" (2) the adequacy of existing regulation of the wastes; (3) the results of an NAS report regarding the adverse human health effects of mercury;[4] and (4) "risk posed by managing coal combustion solid wastes if levels of mercury or other hazardous constituents change due to any future Clean Air Act air pollution control requirements for coal burning utilities" and that these efforts could result in a subsequent revision to the Regulatory Determination. For a further discussion of the basis for the Agency's determination, *see* section IV below.

F. What are CCRs?

CCRs are residuals from the combustion of coal. For purposes of this proposal, CCRs are fly ash, bottom ash, boiler slag (all composed predominantly of silica and aluminosilicates), and flue gas desulfurization materials (predominantly Ca-SO_X compounds) that were generated from processes intended to generate power.

[4] Toxicological Effects of Methylmercury, National Academy of Sciences, July 2000 (*http://books.nap.edu/catalog.php?record_id=9899#toc*). EPA has not taken any actions regarding the May 2000 Regulatory Determination as a result of the NAS report.

Fly ash is a product of burning finely ground coal in a boiler to produce electricity. Fly ash is removed from the plant exhaust gases primarily by electrostatic precipitators or baghouses and secondarily by wet scrubber systems. Physically, fly ash is a very fine, powdery material, composed mostly of silica. Nearly all particles are spherical in shape.

Bottom ash is comprised of agglomerated coal ash particles that are too large to be carried in the flue gas. Bottom ash is formed in pulverized coal furnaces and is collected by impinging on the furnace walls or falling through open grates to an ash hopper at the bottom of the furnace. Physically, bottom ash is coarse, with grain sizes spanning from fine sand to fine gravel, typically grey to black in color, and is quite angular with a porous surface structure.

Boiler slag is the molten bottom ash collected at the base of slag tap and cyclone type furnaces that is quenched with water. When the molten slag comes in contact with the quenching water, it fractures, crystallizes, and forms pellets. This boiler slag material is made up of hard, black, angular particles that have a smooth, glassy appearance.

Flue Gas Desulfurization (FGD) material is produced through a process used to reduce sulfur dioxide (SO_2) emissions from the exhaust gas system of a coal-fired boiler. The physical nature of these materials varies from a wet sludge to a dry powdered material, depending on the process. The wet sludge generated from the wet scrubbing process using a lime-based reagent is predominantly calcium sulfite, while the wet sludge generated from the wet scrubbing process using a limestone-based reagent is predominantly calcium sulfate. The dry powdered material from dry scrubbers that is captured in a baghouse consists of a mixture of sulfites and sulfates.

CCRs are managed in either wet or dry disposal systems. In wet systems, materials are generally sluiced via pipe to a surface impoundment. The material can be generated wet, such as FGD, or generated dry and water added to facilitate transport (*i.e.* sluiced) through pipes. In dry systems, CCRs are transported in its dry form to landfills for disposal.

1. Chemical Constituents in CCRs

The chemical characteristics of CCRs depend on the type and source of coal, the combustion technology, and the pollution control technology employed. For the 1999 Report to Congress and the May 2000 Regulatory Determination, EPA developed an extensive database on the leaching potential of CCR constituents using the toxicity characteristic leaching procedure (TCLP) from a number of sources. More recent data on the composition of CCRs, including their leaching potential, have been collected and are discussed in the next sub-section. The CCR constituent database (available in the docket to this proposal) contains data on more than 40 constituents. Table 2 presents the median compositions of trace element TCLP leachates of each of the main four types of large volume CCRs (fly ash, bottom ash, boiler slag, and FGD gypsum). (Additional information, including the range of TCLP values, is available in the docket or on-line in the documents identified in the footnotes to the following table.)

TABLE 2—TCLP MEDIAN COMPOSITIONS OF COAL-FIRED UTILITY LARGE-VOLUME CCRS [5] (MG/L)

Constituent	Fly ash	Bottom ash	Boiler slag	FGD
As	0.066	0.002	0.002	0.290
Ba	0.289	0.290	0.260	0.532
B	0.933	0.163	n/a	—
Cd	0.012	0.005	0.0018	0.010
Cr^{VI}	0.203	0.010	0.003	0.120
Cu	n/a	n/a	0.050	n/a
Pb	0.025	0.005	0.0025	0.120
Hg	0.0001	0.0001	0.0002	0.0001
Se	0.020	0.0013	0.0025	0.280
Ag	0.005	0.0050	0.0001	0.060
V	0.111	0.0050	0.010	—
Zn	0.285	0.015	0.075	—

n/a = data not available.
-- = too few data points to calculate statistics.
Source: Data from supporting documentation to the 1993 Regulatory Determination; values below the detection limit were treated as one-half the detection limit.

The composition of FGD gypsum depends on the position within the air emissions control system where the SO_2 component is subject to scrubbing: If scrubbing takes place up stream of the removal of fly ash particulates, the FGD would actually comprise a mix of both components. Table 3 presents mean TCLP trace element compositions of FGD gypsum generated by a scrubbing operation that is located down stream from the particulate collection elements of the air emissions control system; it therefore represents an 'end member' FGD gypsum.

TABLE 3—FGD GYPSUM TCLP COMPOSITIONS (MG/L) FROM: (1) TWO OHIO POWER PLANTS *[6] (MEAN DATA); (2) 12 SAMPLES OF COMMERCIAL WALLBOARD PRODUCED FROM SYNTHETIC GYPSUM **[7] (MEDIAN DATA)

Constituent	Cardinal Plant *	Bruce Mansfield Plant *	Synthetic Gypsum **
As	<0.006	0.0075	0.00235
Ba	0.373	0.270	0.043
B	0.137	0.0255	n/a
Cd	0.00167	0.00055	0.00145
Cr	0.00587	0.00575	0.0047
Cu	<0.001	<0.001	n/a
Pb	<0.003	<0.003	0.0006
Hg	1.8×10^{-5}	2.6×10^{-6}	<0.0003
Se	0.0123	<0.011	0.044
V	<0.001	0.002	n/a
Zn	0.170	0.0560	n/a
Ag	n/a	n/a	<0.00005

n/a = data not available.

The contaminants of most environmental concern in CCRs are antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver and thallium. Although these metals rarely exceed the RCRA hazardous waste toxicity characteristic (TC), because of the mobility of metals and the large size of typical disposal units, metals (especially arsenic) have leached at levels of concern from unlined landfills and surface impoundments. In addition, it should also be noted that since the Agency announced its May 2000 Regulatory Determination, EPA has revised the maximum contaminant level (MCL) for arsenic,[8] without a corresponding revision of the TC. As a result, while arsenic levels are typically well below the TC, drinking water risks from contaminated groundwater due to releases from landfills and impoundments may still be high. Also, as discussed below, a considerable body of evidence has emerged indicating that the TCLP alone is not a good predictor

[5] Compiled from Tables 3–1, 3–3, 3–5 and 3–7, in: Technical Background Document for the Report to Congress on Remaining Wastes from Fossil Fuel Combustion: Waste Characteristics, March 15, 1999 (*http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/ffc2_399.pdf*).

[6] Compiled from: Table 3–5, in: An Evaluation of Flue Gas Desulfurization Gypsum for Abandoned Mine Land Reclamation, Rachael A. Pasini, Thesis, The Ohio State University, 2009.

[7] Compiled from: Table 10, in: Fate of Mercury in Synthetic Gypsum Used for Wallboard Production, J. Sanderson *et al.,* USG Corporation, Final Report prepared for NETL, June 2008.

of the mobility of metals in CCRs under a variety of different conditions. This issue is further discussed in the following subsection.

From Tables 2 and 3 above, it is evident that each of the main four types of CCRs, when subjected to a TCLP leach test, yields a different amount of trace element constituents. EPA is soliciting public comments on whether, in light of these differences in the mobility of hazardous metals between the four major types of CCRs, regulatory oversight should be equally applied to each of these CCR types when destined for disposal.

2. Recent EPA Research on Constituent Leaching From CCRs

Changes to fly ash and other CCRs are expected to occur as a result of increased use and application of advanced air pollution control technologies in coal-fired power plants. These technologies include flue gas desulfurization (FGD) systems for SO_2 control, selective catalytic reduction (SCR) systems for NO_X control, and activated carbon injection systems for mercury control. These technologies are being installed or are expected to be installed in response to federal regulations, state regulations, legal consent decrees, and voluntary actions taken by industry to adopt more stringent air pollution controls. Use of more advanced air pollution control technology reduces air emissions of metals and other pollutants in the flue gas of a coal-fired power plant by capturing and transferring the pollutants to the fly ash and other air pollution control residues. The impact of changes in air pollution control on the characteristics of CCRs and the leaching potential of metals is the focus of ongoing research by EPA's Office of Research and Development (ORD). This research is being conducted to identify any potential cross-media transfers of mercury and other metals and to meet EPA's commitment in the Mercury Roadmap (*http://www.epa.gov/hg/roadmap.htm*) to report on the fate of mercury and other metals from implementation of multi-pollutant control at coal-fired power plants.

Over the last few years, in cooperation with Electric Power Research Institute (EPRI) and the utility industry, EPA obtained 73 different CCRs from 31 coal-fired boilers spanning a range of coal types and air pollution control configurations. Samples of CCRs were collected to evaluate differences in air pollution control, such as addition of post-combustion NO_X controls (*i.e.,* selective catalytic reduction), FGD scrubbers, and enhanced sorbents for mercury capture. A series of reports have been developed to document the results from the ORD research: The first report (Characterization of Mercury-Enriched Coal Combustion Residuals from Electric Utilities Using Enhanced Sorbents for Mercury Control, EPA–600/R–06/008, February 2006; *http://www.epa.gov/ORD/NRMRL/pubs/600r06008/600r06008.pdf*) was developed to document changes in fly ash resulting from the addition of sorbents for enhanced mercury capture. The second report (Characterization of Coal Combustion Residuals from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control; EPA–600/R–08/077, July 2008, *http://www.epa.gov/nrmrl/pubs/600r08077/600r08077.pdf*) was developed to evaluate residues from the expanded use of wet scrubbers. The third report (Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data, EPA–600/R–09/151, December 2009, *http://www.epa.gov/nrmrl/pubs/600r09151/600r09151.html*) updates the data in the earlier reports and provides data on an additional 40 samples to cover the range of coal types and air pollution control configurations, including some not covered in the two previous reports.

Data from these studies is being used to identify potential trends in the composition and leaching behavior of CCRs resulting from changes in air pollution controls. Summary data on the higher volume CCRs is provided for 34 fly ashes (Table 4) and 20 FGD gypsum samples (Table 5). The report provides analysis of other types of CCRs (*i.e.,* non-gypsum scrubber residues (primarily scrubber sludge containing calcium sulfite), blended CCRs (non-gypsum scrubber residues, fly ash, and lime), and wastewater treatment filter cake). For each of the metals that are reported (Sb, As, Ba, B, Cd Cr, Co, Hg, Pb, Mo, Se, and Tl) from the leaching test results, "box and whisker" plots have been developed comparing the different materials and providing comparison to field leachate data.

The purpose of this research was to try to understand how power plant air pollution control residues, and their leaching potential, are likely to change with the increased use of multi-pollutant and mercury controls, anticipated in response to new Clean Air Act regulations. An initial focus was to identify appropriate leach testing methods to assess leaching potential under known or expected CCR management conditions (beneficial use or disposal). The EPA's Science Advisory Board and the National Academy of Sciences have in the past raised concerns over the use of single-point pH tests that do not reflect the range of actual conditions under which wastes are plausibly managed.[9] Because metal leaching rates change with changing environmental conditions (especially pH), single point tests may not be the most accurate predictor of potential environmental release of mercury or other metals because they do not provide estimates of leaching under some disposal or reuse conditions that can plausibly occur.

In response to these concerns, a review of available leaching test methods was conducted. A leaching test method[10] based on research conducted at Vanderbilt University in the United States and the Energy Research Center of the Netherlands, among others, was selected to address some of these concerns.

While EPA/ORD's research relied on the Vanderbilt method, similar methods (i.e, tests evaluating leaching at different plausible disposal pH values) have been used to evaluate the leaching behavior and support hazardous waste listings of other materials as well.[11] Because of their general utility, the research methods have been drafted into the appropriate format and are being evaluated for inclusion in EPA's waste analytical methods guidance, SW–846[12]

[8] *See http://www.epa.gov/safewater/arsenic/regulations.html.*

[9] National Academy of Sciences, Managing Coal Combustion Residues in Mines; The National Academies Press, Washington, DC, 2006.

[10] Kosson, D.S.; Van Der Sloot, H.A.; Sanchez, F.; Garrabrants, A.C., An Integrated Framework for Evaluating Leaching in Waste Management and Utilization of Secondary Materials. Environmental Engineering Science 2002, 19, 159–204.

[11] *See* 65 FR 67100 (November 8, 2000) for a discussion of EPA's use of multi-pH leach testing in support of listing a mercury-bearing sludge from VCM–A production, and EPA/600/R–02/019, September 2001, *Stabilization and Testing of Mercury Containing Wastes: Borden Catalyst.*

[12] Five different methods have been developed for use depending upon the information needed and the waste form.

1. Draft Method 1313—Liquid-Solid Partitioning as a Function of Eluate pH using a Parallel Batch Extraction Test

2. Draft Method 1314—Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using an Up-flow Column Test

3. Draft Method 1315—Mass Transfer in Monolithic or Compacted Granular Materials Using a Semi-dynamic Tank Leach Test

4. Draft Method 1316—Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Parallel Batch Test

5. Draft Method 1317—Concise Test for Determining Consistency in Leaching Behavior

The test methods were developed to identify differences in the constituent leaching rate resulting from the form of the tested material, as well as the effects of pH and the liquid/solid ratio. Fine grained

Continued

to facilitate their routine use for evaluating other wastes or reuse materials (*http://www.epa.gov/osw/hazard/testmethods/sw846/index.htm*).

For the ORD research, equilibrium batch test methods that identify changes in leaching at different pH and liquid/solid ratio values were used to evaluate CCRs resulting from different air pollution controls at coal-fired power plants. This allowed evaluation of leaching potential over a range of field conditions under which CCRs are anticipated to be managed during either disposal or beneficial use applications. Landfill field leachate data from EPA [13] and EPRI [14] studies were used to establish the range of pH conditions expected to be found in actual disposal. From this data set, and excluding the extreme values (below 5th percentile and above 95th percentile), a pH range of 5.4 and 12.4 was determined to represent the range of plausible management conditions (with regard to pH) for CCRs. This means that approximately 5% of the values had a pH below 5.4 and approximately 5% of the values had a pH greater than 12.4. However, it is important to note that 9 of the 34 fly ash samples generated a pH in deionized water (*i.e.,* the pH generated by the tested material itself) below pH 5.4. Therefore, these results might understate CCR leaching potential if actual field conditions extend beyond the pH range of 5.4 and 12.4.

In Tables 4 and 5, the total metals content of the fly ash and FGD gypsum samples evaluated is provided along with the leach test results. Reference indicators (*i.e.,* MCL,[15] TC,[16] and DWEL [17]) are also provided to provide some context in understanding the leach results. It is critical to bear in mind that the leach test results represent a distribution of potential constituent release from the material as disposed or used on the land. The data presented do not include any attempt to estimate the amount of constituent that may reach an aquifer or drinking water well. Leachate leaving a landfill is invariably diluted in ground water to some degree when it reaches the water table, or constituent concentrations are attenuated by sorption and other chemical reactions in groundwater and sediment. Also, groundwater pH may be different from the pH at the site of contaminant release, and so the solubility and mobility of leached contaminants may change when they reach groundwater. None of these dilution or attenuation processes is incorporated into the leaching values presented. That is, no dilution and attenuation factor, or DAF,[18] has been applied to these results. Thus, comparisons with regulatory health values, particularly drinking water values, must be done with caution. Groundwater transport and fate modeling would be needed to generate an assessment of the likely risk that may result from the CCRs represented by these data.

In reviewing the data and keeping these caveats in mind, conclusions to date from the research include:

(1) Review of the fly ash and FGD gypsum data (Tables 4 and 5) show a range of total constituent concentration values that vary over a much broader range than do the leach data. This much greater range of leaching values only partially illustrates what more detailed review of the data shows: That for these CCRs, the rate of constituent release to the environment is affected by leaching conditions (in some cases dramatically so), and that leaching evaluation under a single set of conditions may, to the degree that single point leach tests fail to consider actual management conditions, lead to inaccurate conclusions about expected leaching in the field.

(2) Comparison of the ranges of totals values and leachate data from the complete data set supports earlier conclusions 51[19 20 21] that the rate of constituent leaching cannot be reliably estimated based on total constituent concentration alone.

(3) From the more complete data in Report 3, distinctive patterns in leaching behavior have been identified over the range of pH values that would plausibly be encountered for CCR disposal, depending on the type of material sampled and the element. This reinforces the above conclusions based on the summary data.

(4) Based on the data (summarized in Table 4), on the leach results from evaluation of 34 fly ashes across the plausible management pH range of 5.4 to 12.4,

○ The leach results at the upper end of the leachate concentration range exceed the TC values for As, Ba, Cr, and Se (indicated by the shading in the table).

(5) Based on the data (summarized in Table 5), on the leach results from evaluation of 20 FGD gypsums across the plausible management pH range of 5.4 to 12.4,

○ The leach results at the upper end of the leachate concentration ranges exceed the TC value for Se.

(6) The variability in total content and the leaching of constituents within a material type (*e.g.,* fly ash, gypsum) is such that, while leaching of many samples exceeds one or more of the available health indicators, many of the other samples within the material type may be lower than the available regulatory or health indicators.

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materials (e.g., particle sizes of 2 mm or less) will have greater contact with leaching solutions (in a lab test) or rainfall (in the environment) than will solid materials such as concrete or CCRs that are pozzolanic when exposed to water. In applying these methods to CCRs or other materials, batch tests that are designed to reach equilibrium are used with fine-grained or particle-size reduced materials. For solid materials, the tests were designed to evaluate constituent leaching from the exposed surface (leaching of constituents that are either at the surface, or that have migrated over time to the surface), can be used. Testing at equilibrium provides an upper bound estimate of constituent leaching at each set of conditions tested. In some instances, these results may represent the real situation, since when rainfall percolation through a material in the environment is slow, the constituent concentration in the water passing through the materials may reach, or nearly reach equilibrium. Testing of solid (or “monolithic”) materials evaluates constituent leaching from materials of low permeability for which most rainfall flows around the material rather than percolating through it. This results in less contact between the rainfall and the material, and so typically, a lower rate of constituent leaching. For monolithic materials, both the equilibrium and monolith tests are conducted to understand the likely initial rates of leaching from the monolith (while it remains solid), and the upper bound on likely leaching, when the monolith degrades over time, exposing more surface area to percolating rainwater, and typically, higher constituent leaching rates. It may also be possible to avoid the cost of testing solid, monolithic materials, if the material leaches at low constituent concentrations under the equilibrium testing conditions.

[13] U.S. EPA (2000) Characterization and evaluation of landfill leachate, Draft Report. 68–W6–0068, Sept 2000.

[14] EPRI (2006) Characterization of Field Leachates at Coal Combustion Product Management Sites: Arsenic, Selenium, Chromium, and Mercury Speciation, EPRI Report Number 1012578. EPRI, Palo Alto, CA and U.S. Department of Energy, Pittsburgh, PA.

[15] MCL is the maximum concentration limit for contaminants in drinking water.

[16] TC is the toxicity characteristic and is a threshold for hazardous waste determinations.

[17] DWEL is the drinking water equivalent level to be protective for non-carcinogenic endpoints of toxicity over a lifetime of exposure. DWEL was developed for chemicals that have a significant carcinogenic potential and provides the risk manager with evaluation on non-cancer endpoints, but infers that carcinogenicity should be considered the toxic effect of greatest concern (*http://www.epa.gov/safewater/pubs/gloss2.html#D*).

[18] For example, EPA used a generic DAF values of 100 in the Toxicity Characteristic final regulation. (*See:* 55 FR 11827, March 29, 1990)

[19] Senior, C; Thorneloe, S.; Khan, B.; Goss, D. Fate of Mercury Collected from Air Pollution Control Devices; EM, July 2009, 15–21.

[20] U.S. EPA, Characterization of Mercury-Enriched Coal Combustion Residuals from Electric Utilities Using Enhanced Sorbents for Mercury Control, EPA–600/R–06/008, Feb. 2006; *http://www.epa.gov/ORD/NRMRL/pubs/600r06008/600r06008.pdf.*

[21] U.S. EPA, Characterization of Coal Combustion Residuals from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control; EPA–600/R–08/077, July 2008, *http://www.epa.gov/nrmrl/pubs/600r08077/600r08077.pdf.*

Additional or more refined assessment of the dataset may allow some distinctions regarding release potential to be made among particular sources of some CCRs, which may be particularly useful in evaluating CCRs in reuse applications.

EPA anticipates development of a fourth report that presents such additional analysis of the leaching data to provide more insight into constituent release potential for a wider range of CCR management scenarios, including beneficial use applications. This will include calculating potential release rates over a specified time for a range of management scenarios, including use in engineering and commercial applications using probabilistic assessment modeling (Sanchez and Kosson, 2005).[22] This report will be made publicly available when completed.

Finally, the Agency recognizes that this research has generated a substantial amount of data, and believes this data set can be useful as a reference for assessing additional CCR samples in the future. The docket for today's rule therefore includes the full dataset, in the form of a database to provide easier access to EPA's updated leach data.[23]

Table 4. Preliminary Leach Results for 5.4<pH< 12.4 and at "own pH" from Evaluation of Thirty-Four Fly Ashes.

	Hg	Sb	As	Ba	B	Cd	Cr	Co	Pb	Mo	Se	TI
Total in Material (mg/kg)	0.01 – 1.5	3 - 14	17 - 510	590 – 7,000	NA	0.3 – 1.8	66 - 210	16 - 66	24 - 120	6.9 - 77	1.1 - 210	0.72 - 13
Leach results (ug/L)	<0.01- 0.50	<0.3 – 11,000	0.32 – 18,000	50 – 670,000	210 – 270,000	<0.1 - 320	<0.3 – 7,300	<0.3- 500	<0.2 - 35	<0.5 – 130,000	5.7 – 29,000	<0.3 - 790
TC (ug/L)	200	-	5,000	100,000	-	1,000	5,000	-	5,000	-	1,000	-
MCL (ug/L)	2	6	10	2,000	7,000 DWEL	5	100	-	15	200 DWEL	50	2

Note: The dark shading is used to indicate where there could be a potential concern for a metal when comparing the leach results to the MCL, DWEL, or concentration level used to determine the TC. Note that MCL and DWEL values are intended to represent concentrations at a well and the point of exposure; leachate dilution and attenuation processes that would occur in groundwater before leachate reaches a well are not accounted for, and so MCL and DWEL values cannot be directly compared with leachate values.

[22] Sanchez, F., and D. S. Kosson, 2005. Probabilistic approach for estimating the release of contaminants under field management scenarios. *Waste Management* 25(5), 643–472 (2005).

[23] The database, called "Leach XS Lite" can be used to estimate the leaching potential of CCRs under any specified set of pH or infiltration conditions that may occur in the field. While the database is presented as a "Beta" version, and may be further developed, the data presented in the data base are final data, from the three EPA research reports cited above.

Table 5. Preliminary Leach Results for 5.4<pH< 12.4 and at "own pH" from Evaluation of Twenty FGD Gypsums.

	Hg	Sb	As	Ba	B	Cd	Cr	Co	Pb	Mo	Se	TI
Total in Material (mg/kg)	0.01 – 3.1	0.14 – 8.2	0.95 - 10	2.4 - 67	NA	0.11 – 0.61	1.2 – 20	0.77 – 4.4	0.51 - 12	1.1 - 12	2.3 - 46	0.24 – 2.3
Leach results (ug/L)	<0.01-0.66	<0.3 - 330	0.32 – 1,200	30 - 560	12 – 270,000	<0.2 - 370	<0.3 – 240	<0.2 – 1,100	<0.2 - 12	0.36 – 1,900	3.6 – 16,000	<0.3 – 1,100
TC (ug/L)	200	-	5,000	100,000	-	1,000	5,000	-	5,000	-	1,000	-
MCL (ug/L)	2	6	10	2,000	7,000 DWEL	5	100	-	15	200 DWEL	50	2

Note: The dark shading is used to indicate where there could be a potential concern for a metal when comparing the leach results to the MCL, DWEL, or concentration level used to determine the TC. Note that MCL and DWEL values are intended to represent concentrations at a well and the point of exposure; leachate dilution and attenuation processes that would occur in groundwater before leachate reaches a well are not accounted for, and so MCL and DWEL values cannot be directly compared with leachate values.

G. Current Federal Regulations or Standards Applicable to the Placement of CCRs in Landfills and Surface Impoundments.

CCR disposal operations are typically regulated by state solid waste management programs, although in some instances, surface impoundments are regulated under the states water programs. However, there are limited regulations of CCRs at the federal level.

The discharge of pollutants from CCR management units to waters of the United States are regulated under the National Pollutant Discharge Elimination System (NPDES) at 40 CFR Part 122, authorized by the Clean Water Act (CWA). NPDES permits generally specify an acceptable level of a pollutant or pollutant parameter in a discharge. NPDES permits ensure that a state's mandatory standards for clean water and the federal minimums are being met. A number of the damage cases discussed in the preamble also involved surface water contamination, which were violations of the NPDES permit requirements.

II. New Information on the Placement of CCRs in Landfills and Surface Impoundments

A. New Developments Since the May 2000 Regulatory Determination.

Since publication of the May 2000 Regulatory Determination, new information and data have become available, including additional damage cases, risk modeling, updated information on current management practices and state regulations associated with the disposal of CCRs, petitions from environmental and citizens groups for EPA to develop rules for the management of CCRs, an industry voluntary agreement on how they would manage CCRs, and a proposal from environmental and citizens groups for a CCR rule. Much of this new information was made available to the public in August 2007 through a Notice of Data Availability (NODA) at 72 FR 49714 (*http://www.epa.gov/fedrgstr/EPA-WASTE/2007/August/Day-29/f17138.pdf*). EPA has received extensive comments from environmental groups, industry, states and others in response to the NODA and as we have moved toward rulemaking. All of the comments and subsequent information we have received are included in the docket to this proposal. The new information on risks and the damage cases are discussed briefly below and in more detail in subsequent sections of this proposed rule; a more detailed discussion of this new information is discussed in other sections of the preamble.

At the time of the May 2000 Regulatory Determination, the Agency was aware of 14 cases of proven damages [24] and 36 cases of potential damages resulting from the disposal of

[24] As discussed later in the preamble, 11 of these documented cases of damage were to human health and the environment, while four of these cases were cases of ecological damage, one of which has now been reclassified as a potential damage case.

CCRs. The Agency has since learned of an additional 13 cases of proven damages and 4 cases of potential damages, including a catastrophic release of CCRs from a disposal unit at the Tennessee Valley Authority (TVA) Kingston facility in Harriman, Tennessee in December 2008. In total, EPA has documented 27 cases of proven damages and 40 cases of potential damages resulting from the disposal of CCRs. Proven damage cases have been documented in 12 states, and potential damage cases—in 17 states. *See* section II.C. and the Appendix to this proposal for more detailed discussions of EPA's CCR damage cases.

As part of the process for making the May 2000 Regulatory Determination for CCRs, EPA prepared a draft quantitative risk assessment. However, because of time constraints, the Agency was unable to address public comments on the draft risk assessment in time for the Regulatory Determination. Between 2000 and 2006, EPA addressed the public comments and updated the quantitative risk assessment for the management of CCR in landfills and surface impoundments. The revised risk assessment was made available for public comment in the August 2007 draft report titled "Human and Ecological Risk Assessment of Coal Combustion Wastes."

In the May 2000 Regulatory Determination, the Agency concluded that the utility industry had made significant improvements in its waste management practices for new landfills and surface impoundments since the practices reflected in the 1999 Report to Congress, and that most state regulatory programs had similarly improved. To verify its conclusion, in 2005, the U.S. Department of Energy (DOE) and EPA conducted a joint study to collect more recent information on the management practices for CCRs by the electric power industry, and state programs in 11 states. The results of the study were published in the report titled "Coal Combustion Waste Management at Landfills and Surface Impoundments, 1994–2004." Additionally, we are aware of at least one state (Maryland) that has recently amended its regulatory requirements for the management of CCRs.

In February 2004, 125 environmental and citizens groups petitioned the EPA Administrator for a rulemaking prohibiting the disposal of coal power plant wastes into groundwater and surface water until such time as EPA promulgates federally enforceable regulations pursuant to RCRA. A copy of the petition is available at *http://www.regulations.gov/fdmspublic/component/main?/main=DocumentDetail&o=09000064801cf8d1.*

In October 2006, the utility industry through their trade association, the Utility Solid Waste Activities Group (USWAG) submitted to EPA a "Utility Industry Action Plan for the Management of Coal Combustion Products." The plan outlines the utility industry's commitment to adopt groundwater performance standards and monitoring, conduct risk assessments prior to placement of CCRs in sand and gravel pits, and to consider dry-handling prior to constructing new disposal units.

In January 2007, environmental and citizens groups submitted to EPA a "Proposal for the Federal Regulation of Coal Combustion Waste." The proposal provides a framework for comprehensive regulation under subtitle D of RCRA for waste disposed of in landfills and surface impoundments generated by coal-fired power plants. Then in July 2009, environmental and citizens groups filed a second petition requesting that the EPA Administrator promulgate regulations that designate CCRs as hazardous waste under subtitle C of RCRA.[25] In support of their petition, the environmental groups cited "numerous reports and data produced by the Agency since EPA's final Regulatory Determination * * * which quantify the waste's toxicity, threat to human health and the environment, inadequate state regulatory programs, and the damage caused by mismanagement." A copy of the petition is available in the docket to this proposal. The Agency has, as yet, not made a decision as to whether to lift the Bevill exemption, and, while it has determined that federal regulation is appropriate, it has not made a determination as to whether regulations should be promulgated under subtitles C or D of RCRA. Consequently, EPA is deferring its response to the petitioner. However, the preamble discusses the issues raised in these petitions at length. In addition, the Agency is deferring its proposed response to the petitioners' request regarding the placement of CCRs in minefills as the Agency will work with OSM to address the management of CCRs in minefills in a separate rulemaking action. (*See* discussion in other parts of the preamble for the Agency's basis for its decisions.)

In August 2007, EPA published a NODA (72 FR 49714, *http://www.epa.gov/fedrgstr/EPA-WASTE/2007/August/Day-29/f17138.htm*) which made public, and sought comment on, the new information we received since the May 2000 Regulatory Determination through 2007, except for the July 2009 petition entitled, *Petition for Rulemaking Pursuant to Section 7004(a) of the Resource Conservation and Recovery Act Concerning the Regulation of Coal Combustion Waste and the Basis for Reconsideration of the 2000 Regulatory Determination Concerning Wastes from the Combustion of Fossil Fuels.* The new information included the joint DOE and EPA report entitled: *Coal Combustion Waste Management at Landfills and Surface Impoundments, 1994–2004;* the draft risk assessment; and EPA's damage case assessment. EPA also included in the docket to the NODA the February 2004 Petition for Rulemaking submitted by a number of environmental and citizens' groups to prohibit the placement or disposal of CCRs into ground water and surface water; and two suggested approaches for managing CCRs in landfills and surface impoundments. One approach is the Voluntary Action Plan that was formulated by the electric utility industry. The second approach was the January 2007 framework prepared by a number of environmental and citizens' groups proposing federal regulation under subtitle D of RCRA for CCRs generated by U.S. coal-fired power plants and disposed of in landfills and surface impoundments. The Agency received a total of 396 comments on the NODA from 375 citizens and citizen and environmental groups, 16 industry groups, and 5 state and local government organizations. In general, citizens, citizens groups, and environmental groups commented that state regulations are inadequate and called on EPA to develop enforceable regulations for the disposal of CCRs under the hazardous waste provisions of RCRA. Industry groups, on the other hand, stated that the significant recent improvement in industry management and state regulatory oversight of CCR disposal demonstrates that the conditions that once led EPA to determine that federal subtitle D regulations were warranted no longer exist and therefore, further development of subtitle D regulations is no longer necessary. In September 2008, the Environmental Council of the States (ECOS) issued a resolution that states already have regulations in place that apply to CCRs, and a federal regulation is not necessary. The 2008 ECOS resolution was revised in March 2010 and calls upon EPA to conclude that

[25] This rulemaking petition was filed by: Earthjustice; the Sierra Club; the Environmental Integrity Project; the Natural Resources Defense Council; the Southern Environmental Law Center; and Kentucky Resources Council.

additional federal CCR regulations would be duplicative of most state programs, are unnecessary, and should not be adopted, but if adopted must be developed under RCRA subtitle D rather than RCRA subtitle C (*see http://www.ecos.org/files/4018_file_Resolution_08_14_2010_version.doc*). Comments on the NODA are available in the docket to the NODA at *http://www.regulations.gov,* docket number EPA–HQ–RCRA–2006–0796.

Finally, in July and August of 2008, EPA conducted a peer review of the 2007 draft risk assessment "Human and Ecological Risk Assessment of Coal Combustion Wastes." The peer review was conducted by a team of five experts in groundwater modeling, environmental fate and transport modeling, and human health and ecological risk assessment. EPA has revised its risk assessment based on the peer review comments. Results of the peer review and the revised risk assessment are included in the docket to this proposal. Also, *see* section II.B. below and the document titled "What Are the Environmental and Health Effects Associated with Disposing of CCRs in Landfills and Surface Impoundments?" available from the docket to this notice for more detailed discussions of the risk assessment.

In summary, since the May 2000 Regulatory Determination, the Agency has (1) Documented an additional 17 cases of damage from the disposal of CCRs (13 proven and 3 potential); (2) gathered additional information on industry practices; (3) revised its risk assessment, based on comments received on the 1999 Report to Congress, conducted a peer review of the revised risk assessment, and further revised its risk assessment based on peer review comments and comments received on the August 2007 NODA; (4) received a voluntary action plan from the utility industry; (5) received two petitions for rulemaking from environmental and citizens groups; and (6) received a proposal for regulating the management of CCRs in landfills and surface impoundments from environmental and citizens groups. EPA has considered all of this information in making the decisions on the proposals in this notice.

B. CCR Risk Assessment

In making the May 2000 Regulatory Determination for CCRs, EPA prepared a draft quantitative risk assessment based on groundwater modeling. However, commenters from all sides raised fundamental scientific questions with the study, and raised issues that went beyond groundwater modeling capability at the time. EPA was unable to address these issues in the available time, and therefore did not rely on the draft risk assessment as part of its basis in making its May 2000 Regulatory Determination; rather we relied on the damage cases identified, as well as other information. In this regard, it is worth noting that EPA did not conclude that the available information regarding the extent or nature of the risks were equivocal. Rather, EPA noted that we had not definitively assessed the ground water risks, due to the criticisms of our draft risk assessment, but still concluded that there were "risks from arsenic that we cannot dismiss." Largely what drove the risks in the original risk assessment were the old units that lacked liners and ground water monitoring (for landfills, only 57% of the units had liners and 85% of the units had ground water monitoring, while for surface impoundments, only 26% of the units had liners and only 38% of the units had ground water monitoring).

Between 2000 and 2006, EPA addressed public comments and updated the quantitative risk assessment for the management of CCRs in landfills and surface impoundments. The purpose of the risk assessment is to identify CCR constituents, waste types, liner types, receptors, and exposure pathways with potential risks and to provide information that EPA can use as we continue to evaluate the risks posed by CCRs disposed of in landfills and surface impoundments. The risk assessment was designed to develop national human and ecological risk estimates that are representative of onsite CCR management settings throughout the United States. A revised draft risk assessment was made available to the public through the August 2007 NODA (which is discussed in other sections of the preamble) and is available at *http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&o=090000648027b9cc*.

EPA submitted the revised draft risk assessment report, together with public comments on the report in response to the 2007 NODA, to a peer review panel. EPA completed the risk assessment, taking into account peer review comments, in a final report titled "Human and Ecological Risk Assessment of Coal Combustion Wastes," (September 2009). The report, peer review comments, and EPA's response to the peer review comments are available in the docket for this proposal.

For purposes of this rulemaking, EPA defined the target level of protection for human health to be an incremental lifetime cancer risk of no greater than one in 100,000 (10^{-5}) for carcinogenic chemicals and a hazard quotient of 1.0 for noncarcinogenic chemicals. The hazard quotient is the ratio of an individual's chronic daily dose of a constituent to the reference dose for that constituent, where the reference dose is an estimate of the daily dose that is likely to be without appreciable risk of deleterious effects over a lifetime. These are the target levels that EPA typically uses in its listing decisions. (*See,* for example, the final rule for Nonwastewaters From Productions of Dyes, Pigments, and Food, Drug, and Cosmetic Colorants (70 FR 9144) at *http://www.epa.gov/wastes/laws-regs/state/revision/frs/fr206.pdf.*)

The results of this risk assessment provide further confirmation of the high risks presented in the mismanagement of CCRs disposed in landfills and surface impoundments. The assessment does confirm that there are methods to manage CCRs safely, although it calls into question the reliability of clay liners, especially in surface impoundments, and it points to very high potential risks from unlined surface impoundments.

Specifically, the revised draft CCR risk assessment presents results at a typical exposure (50th percentile), as well as a high-end exposure (90th percentile) risk based on a probabilistic analysis. The revised draft CCR risk assessment results at the 90th percentile suggest that the management of CCRs in unlined or clay-lined waste management units (WMUs) result in risks greater than the risk criteria of 10^{-5} for excess cancer risk to humans or an HQ greater than 1 for noncancer effects to both human and ecological receptors which are the criteria generally used in EPA's listing determination procedure.[26] While still above the criteria, clay-lined units tended to have lower risks than unlined units. However, it was the composite-lined units that effectively reduced risks from all pathways and constituents below the risk criteria. More specifically:

○ For humans exposed via the groundwater-to-drinking-water pathway, estimated risks from clay-lined landfills that dispose of CCRs or

[26] EPA's hazardous waste listing determination policy is described in the notice of proposed rulemaking for wastes from the dye and pigment industries at 59 FR 66075–66077 *available at http://www.epa.gov/fedrgstr/EPA-WASTE/1994/December/Day-22/pr-98.html* and in the final rule for Nonwastewaters From Productions of Dyes, Pigments, and Food, Drug, and Cosmetic Colorants (70 FR 9144) at *http://www.epa.gov/wastes/laws-regs/state/revision/frs/fr206.pdf.*

CCRs co-managed with coal refuse are lower than those for unlined landfills. However, the 90th percentile risk estimates, for arsenic that leaks from clay-lined landfills are still above the risk criteria—as high as 1 in 5,000 individual lifetime excess cancer risk.[27] When landfills are unlined, estimated risks above the criteria occur for antimony and molybdenum, as well as arsenic (as high as 1 in 2,000 individual lifetime excess cancer risk). In addition to arsenic, clay-lined fluidized bed combustion (FBC) landfills also presented estimated 90th percentile risks above the criteria for antimony. However, unlined FBC landfills differed in that they were estimated to exceed the risk criteria only for arsenic.[28] At the 50th percentile, only trivalent arsenic from CCRs codisposed with coal refuse was estimated to exceed the risk criteria with cancer risks of 1 in 50,000.

○ Arsenic and cobalt were the constituents with the highest estimated risks for surface impoundments. Clay-lined surface impoundments were estimated to present 90th percentile risks above the criteria for arsenic, boron, cadmium, cobalt, molybdenum, and nitrate. The 90th percentile clay-lined impoundment estimated risks and hazard quotients (HQs) were as follows: for arsenic, the estimated risk was as high as 1 in 140; cobalt's estimated HQ as high as 200, while the estimated HQs for boron, cadmium, molybdenum and nitrate ranged from 2 to 20. The 90th percentile unlined surface impoundment estimates were above the criteria for constituents that include arsenic, lead, cobalt and selenium: estimated arsenic cancer risks are as high as 1 in 50, and non-cancer effects estimates for cobalt ranged from an estimated HQ of 0.9 to 500 depending on whether CCRs were co-managed with coal refuse. At the 50th percentile, the only surface impoundment results estimated to exceed the risk criteria were arsenic and cobalt: unlined impoundments had estimated arsenic cancer risks as high as 6 in 10,000, while clay-lined impoundments had estimated arsenic cancer risks as high as 1 in 5,000. The 50th percentile noncancer HQs due to cobalt in drinking water were estimated to be as high as 20 and 6 for unlined and clay-lined surface impoundments, respectively.

○ Composite liners, as modeled in this assessment, effectively reduce risks from all constituents to below the risk criteria for both landfills and surface impoundments at the 90th and 50th percentiles.

○ The model generally predicts that groundwater risks will occur centuries later for landfills than for surface impoundments. For the groundwater-to-drinking water pathway for unlined landfills, arrival times of the peak concentrations at a receptor well peaked in the hundreds or thousands of years, while unlined surface impoundment risks typically peaked within the first 100 years. Clay liners resulted in later arrival of peak risks, nearly always in the thousands of years for landfills but still in the first few hundred years for surface impoundments. Finally, while composite liners often resulted in a failure of the plume to reach groundwater wells, composite-lined landfills with plumes that were estimated to reach groundwater wells eventually had peak arsenic-in-groundwater concentrations at approximately 10,000 years, while composite-lined surface impoundments' plumes peaked in the thousands of years.

○ For humans exposed via the groundwater-to-surface-water (fish consumption) pathway, unlined and clay-lined surface impoundments were estimated to pose risks above the criteria at the 90th percentile. For CCRs managed alone in surface impoundments, these exceedances came from selenium (estimated HQs of 3 and 2 for unlined and clay-lined units, respectively). For CCRs co-managed with coal refuse, these exceedences came from arsenic (3 in 100,000 and 2 in 100,000 estimated excess cancer risks for unlined and clay-lined units, respectively). All 50th percentile surface impoundment risks are estimated to be below the risk criteria. No constituents pose estimated risks above the risk criteria for landfills (including FBC landfills) at the 90th or 50th percentile.

○ EPA also conducted a separate draft fugitive dust screening assessment which indicates that, without fugitive dust controls, there could be exceedances of the National Ambient Air Quality Standards for fine particulate matter in the air at residences near CCR landfills.[29] The 1998 risk assessment[30] also showed risks from inhalation of chromium in fugitive dust but at levels below the criteria.[31]

EPA recognizes that there are significant uncertainties in national risk assessments of this nature, although it did attempt to address potential uncertainties through Monte Carlo and sensitivity analyses. Uncertainties discussed in the revised risk assessment include:

- The locations and characteristics of currently operating facilities;
- The failure to account for direct discharges to surface water;
- Changing conditions over the 10,000-year period modeled;
- Shifting populations and ecological receptors;
- Additive risks from multiple constituents or multiple pathways;
- Clean closure of surface impoundments;
- The speciation and bioavailability of constituents;
- The effect of compacting CCRs before disposal;
- The assumption that all disposal units are above the water table;
- Full mixing of the groundwater plume;
- The choice of iron sorbent in the soil;
- The appropriateness of the leachate data used and the treatment of nondetects;
- The distance to receptor wells and surface water bodies; and
- The potential conservativeness of human health benchmarks.

The Agency, however, does solicit comment on several specific aspects of the underlying risk assessment. In particular, EPA requests comment on whether clay liners designed to meet a $1x10^{-7}$ cm/sec hydraulic conductivity might perform differently in practice than modeled in the risk assessment. Thus, EPA solicits specific data on the hydraulic conductivity of clay liners associated with CCR disposal units. In addition to the effectiveness of various liner systems, the hydraulic conductivity of coal ash can be reduced with the appropriate addition of moisture followed by compaction to attain 95% of the standard Proctor

[27] Excess cancer risk means risk in addition to pre-existing, "background" risk from other exposures.

[28] Unlined FBC landfills showed less risk as modeled; note that the number of FBC landfills modeled was very small (seven).

[29] EPA's decision to address fugitive dust was based on a peer review comment to the draft Risk Assessment, stakeholder NODA comments, photographic documentation of fugitive dust associated with the hauling and disposal of CCRs, Agency efforts to control fugitive dust emissions from the TVA Kingston spill (see e.g., *http://www.epakingstontva.com/EPA%20Air%20Audits%20and%20Reviews/Kingston%20Fly%20Ash%20-%20EPA%20Audit.pdf*), and OSHA's requirement for MSDS sheets for coal ash.

[30] Non-Groundwater Pathways, Human Health and Ecological Risk Analysis for Fossil Fuel Combustion Phase 2 (FFC2): Draft Final Report (*http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ngwrsk1.pdf*).

[31] All chromium present in the particulate matter was assumed to be in the more toxic, hexavalent form.

maximum dry density value.[32] This concept, it has been reported, could potentially be taken further with the use of compaction coupled with the addition of organosilanes. According to recent studies, organosilanes could take the hydraulic conductivity to zero.[33] EPA solicits comments on the effectiveness of such additives, including any analysis that would reflect long-term performance, as well as the appropriateness of a performance standard that would allow such control measures in lieu of composite liners. EPA has also observed that surface impoundments are often placed right next to surface water bodies which may present complex subsurface environments not considered by the groundwater model, and therefore EPA seeks data on the distance of surface impoundments to water bodies, site specific groundwater risk analysis which accounts for the presence of a nearby surface water body, and groundwater monitoring data associated with such sites.

In characterizing CCRs and utilizing such data for the risk analysis, EPA gathered a variety of data over a long period of time. As a general matter, EPA finds these data to be an accurate characterization, and that the values are in line with recent studies EPA has conducted to characterize new air pollution controls. However, with respect to a few of the highest surface impoundment porewater concentrations (for arsenic in particular), questions have been raised regarding the representativeness of these individual data points. In one case, a facility with the highest arsenic pore water concentration (86.0 mg/L) involved values that were measured in a section of a surface impoundment where coal refuse (defined as coal waste from coal handling, crushing, and sizing operations) was disposed of at the water surface. Pore water samples taken in the coal ash sediment beneath the coal refuse involved concentrations of arsenic as low as 0.003 mg/L. Thus, there is the question of whether those pore water samples measured in the coal refuse represent what leaches out of the bottom of the surface impoundment.

The next highest arsenic values (an average of 5.37 mg/L over 4 samples with the highest concentration being 15.5 mg/L) came from site CASJ (known as SJA in the EPRI report). The concern is that arsenic in the pore water was orders of magnitude higher than in the pond water. That type of change doesn't appear to occur for other constituents in these samples or for arsenic in samples from other surface impoundments. EPA recently attempted to obtain further information that could assist us to better characterize these specific data, but the data are old, the impoundment is no longer in operation, and there are apparently no additional records upon which to draw conclusions.

Additional high concentration values, especially for lead, are associated with ash data provided by Freeman United Mining, which acquired ash for a minefilling project. None of this ash data is associated with electric utilities, but rather with other coal combusters such as John Deere, American Cyanamid, and Washington University in St. Louis, Missouri. The Agency is uncertain whether the high lead levels are associated with lead levels in the source coal, the operations at these facilities, or whether other wastes were mixed with the CCRs.

While these concerns are associated with a small fraction of the data, these data reflect the highest concentrations, and thus can be important considerations in the risk analysis. Based on the above concerns, EPA solicits comment on several questions.

- For the highest concentrations in EPA's database, such as the examples mentioned above, are there values that do not appropriately represent leaching to groundwater, and if so, why not?
- Are there any additional data that are representative of CCR constituents in surface impoundment or landfill leachate (from literature, state files, industry or other sources) that EPA has not identified?
- EPA understands that the disposal practices associated with coal refuse in surface impoundments may have improved based on the development of an industry guide.[34] EPA solicits information on the degree to which coal refuse management practices have changed since the issuance of the guide and the impacts of those changes (*e.g.*, have concentrations of arsenic been reduced in leach samples that have been taken at facilities operating in concert with the industry guide).
- For CCR surface impoundments, are there any examples of pore water concentrations for arsenic increasing orders of magnitude over pond water concentrations?

For more detailed discussions of the CCR risk assessment, *see* the document titled: "What Are the Environmental and Health Effects Associated with Disposing of CCRs in Landfills and Surface Impoundments?" and the report titled "Human and Ecological Risk Assessment of Coal Combustion Wastes" which are included in the docket to this notice.

C. Damage Cases

Under the Bevill Amendment for the "special waste" categories of RCRA, EPA was statutorily required to examine "documented cases in which danger to human health or the environment from surface runoff or leachate has been proved" from the disposal of coal combustion wastes (RCRA Section 8002(n)). The criteria used to determine whether danger to human health and the environment has been proven are described in detail in the May 2000 Regulatory Determination at 65 FR 32224.[35]

At the time of the May 2000 Regulatory Determination, the Agency was aware of 11 documented cases of proven damage to ground water and 36 cases of potential damage to human health and the environment from the improper management of CCRs in landfills and surface impoundments. Additionally, the Agency determined that another four cases were documented cases of ecological damages.[36] However, for the May 2000 Regulatory Determination, EPA did not consider these ecological damage cases because all involved some form of discharge from waste management units to nearby lakes or creeks that would be subject to the Clean Water Act regulations. Moreover, EPA concluded that the threats in those cases were not substantial enough to cause large scale, system level ecological disruptions. On review, EPA has concluded that the ecological damage cases are appropriate for consideration because, while they might involve CWA violations, they nevertheless reflect damages from CCR disposal that might be handled under RCRA controls. And, while they may or may not have involved "systems-level"

[32] The standard and modified Proctor compaction tests (ASTM D 698 and D 1557 respectively) are used to determine the maximum achievable density of soils and aggregates by compacting the soil or aggregate in a standardized mould at a standardized compactive force. The maximum dry density value (or maximum achievable dry density value) is determined by dividing the mass of the compacted material (weight divided by the gravitational force) by the volume of the compacted material.

[33] "Organo-silane Chemistry: A Water Repellant Technology for Coal Ash and Soils," John L. Daniels, Mimi S. Hourani, and Larry S. Harper, 2009 World of Coal Ash Conference. *Available at http://www.flyash.info/2009/025-daniels2009.pdf* and in the docket to this proposal.

[34] Guidance for Comanagement of Mill Rejects at Coal-Fired Power Plants, Electric Power Research Institute, 1999. Available in the docket to this proposal.

[35] For definition of "proven damage case," see section C in the Supplementary Information section.

[36] Ecological damages are damages to mammals, amphibians, fish, benthic layer organisms and plants.

disruption, they were significant enough to lead to state response actions, *e.g.,* fish advisories. EPA now believes that ecological damages warranting state environmental response are generally appropriate for inclusion as damage cases, and to fail to include them would lead to an undercounting of real and recognized damages. Accordingly, at the time of the May 2000 Regulatory Determination, in total, 15 cases of proven damages had occurred. Subsequently, one of the 15 proven damage cases has been reclassified as a potential damage case, resulting in a total of 14 proven cases of damage, as of the May 2000 Regulatory Determination.

Since the May 2000 Regulatory Determination, additional damage cases, including ecological damage cases, have occurred, and were discussed in the August 2007 NODA. Specifically, EPA has gathered or received information on 135 alleged damage cases. Six of the alleged damage cases have been excluded from this analysis because they involved minefills, a management method which is outside the scope of this proposal, while sixty-two of the damage cases have not been further assessed because there was little or no information supporting the concerns identified. Of the remaining 67 damage cases evaluated, EPA determined that 24 were proven cases of damage (which includes the 14 proven damage cases from the May 2000 Regulatory Determination); of the 24 damage cases, eight were determined to be proven damages to surface water and sixteen were determined to be proven damages to ground water, with four of the cases to groundwater being from unlined landfills, five coming from unlined surface impoundments, one was from a surface impoundment where it was unclear whether it was lined, and the remaining six cases coming from unlined sand and gravel pits. Another 43 cases (which includes the 36 potential damage cases from the May 2000 Regulatory Determination) were determined to be potential damages to groundwater or surface water; however, four of the potential damage cases were attributable to oil combustion wastes and thus are outside the scope of this proposal; therefore, resulting in 39 CCR potential damage cases. The remaining 10 alleged damage cases were not considered to be proven or potential damage cases due to a lack of evidence that damages were uniquely associated with CCRs; therefore, they were not considered to be CCR damage cases.

Finally, within the last couple of years, EPA has learned of an additional five cases of claimed damage. Two of the cases involve the structural failure of the surface impoundment; *i.e.,* dam safety and structural integrity issues, a pathway which EPA did not consider at the time of the May 2000 Regulatory Determination. These cases are (1) a 0.5 million cubic yard release of water and fly ash to the Delaware River at the Martin's Creek Power Plant in Pennsylvania in 2005, leading to a response action costing $37 million, and (2) the catastrophic failure of a dike at TVA's Kingston, Tennessee facility, leading to the release of 5.4 million cubic yards of fly ash sludge over an approximately 300 acre area and into a branch of the Emory River, followed by a massive cleanup operation overseen by EPA and the state of Tennessee. EPA classifies these as proven damage cases. Another case involved the failure of a discharge pipe at the TVA Widows Creek plant in Stevenson, Alabama, resulting in a 6.1 million gallon release from an FGD pond, leading to $9.2 million in cleanup costs. EPA did not classify this as a damage case, because samples at relevant points of potential exposure did not exceed applicable standards. Two other cases involved the placement of coal ash in large scale fill operations. The first case, the BBBS Sand and Gravel Quarries in Gambrills, Maryland, involved the disposal of fly ash and bottom ash (beginning in 1995) in two sand and gravel quarries. EPA considers this site a proven damage case, because groundwater samples from residential drinking wells near the site include heavy metals and sulfates at or above groundwater quality standards, and the state of Maryland is overseeing remediation. The second case is the Battlefield Golf Course in Chesapeake, Virginia where 1.5 million yards of fly ash were used as fill and for contouring of a golf course. Groundwater contamination above drinking water levels has been found at the edges and corners of the golf course, but not in residential wells. An EPA study in April 2010 established that residential wells near the site were not impacted by the fly ash and, therefore, EPA does not consider this site a proven damage case. However, due to the onsite groundwater contamination, EPA considers this site to be a potential damage case. Thus, the Agency has classified three of the five new cases as proven damage cases, one as a potential damage case, and the other as not being a damage case (*i.e.,* not meeting the criteria to be considered either a proven or potential damage case). This brings the total number of proven damage cases to 27 and 40 potential cases of damage from the mismanagement of CCRs being disposed.

The Martins Creek and TVA Kingston fly ash impoundment failures underscore the need for surface impoundment integrity requirements. In the case of the Martins Creek failure, 0.5 million cubic yards of fly ash slurry was released into the Delaware River when a dike failed. Fortunately, there are no homes in the path of the release and all the damage was confined to power plant property and the Delaware River. On the other hand, the 5.4 million cubic yards of fly ash sludge released as a result of the TVA Kingston impoundment failure covered an area of approximately 300 acres, flowed into a branch of the Emory River, disrupted power, ruptured a gas line, knocked one home off its foundation and damaged others. Fortunately, there were no injuries.

While much of our risk modeling deals with ground water contamination, based on historical facts, EPA recognizes that failures of large CCR impoundments can lead to catastrophic environmental releases and large cleanup costs. It is critical to understand as well, however, that the structural integrity requirements and the requirements for conversion or retrofitting of existing or new impoundments are designed to avoid such releases and that the benefits of avoiding such catastrophic failures are very significant. As discussed in more detail in Section XII of today's proposal and as fully explained in our Regulatory Impact Analysis (RIA), EPA estimated the benefits of avoiding the future cleanup costs of or impoundment failures. Depending on the regulatory option chosen, the annualized benefits range from $29 million to $1,212 million per year, and the net present value of these ranges from $405 million to $16,732 million. In addition, the RIA did not quantify or monetize several other additional benefits consisting of future avoided social costs associated with ecological and socio-economic damages. These include avoided damages to natural resources, damages to property and physical infrastructure, avoided litigation costs associated with such events, and reduction of toxic chemical-contaminated effluent discharges from impoundments to surface waters.

In December 2009, EPA received a new report from EPRI challenging our conclusions on many of the proven damage cases often noting that there was not significant off-site contamination.

The report, "Evaluation of Coal Combustion Product Damage Cases (Volumes 1 and 2), Draft Report, November 2009," is available in the docket to this proposal. EPA solicits comments on EPRI's report and welcomes additional data regarding the proven damage cases identified by EPA, especially the degree to which there was off-site contamination.

EPA notes that several stakeholders have very recently identified additional claimed damage cases, and the agency has not had the time to review them closely.[37] Similarly, other stakeholders have recently provided valuable information on CCR risks, costs of different possible options, and characterization data, which EPA has also not had time to review in detail or to respond to. Generally, these reports include information that is relevant to today's proposal. EPA will review this information carefully as we proceed to a final rule, and we encourage commenters on the proposal to consider this material, which EPA has placed in the rulemaking docket, as they prepare comments.

For a more detailed discussion of the damage cases, *see* the Appendix to this notice, the table "Summary of Proven Cases with Damages to Groundwater and to Surface Water" at the end of the Appendix, and the document "Coal Combustion Wastes Damage Case Assessments" available at *http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=EPA-HQ-RCRA-2006-0796-0015*.

III. Overview and Summary of the Bevill Regulatory Determination and the Proposed Subtitle C and Subtitle D Regulatory Options

In today's notice, EPA is reevaluating its August 1993 and May 2000 Bevill Regulatory Determinations regarding CCRs generated at electric utilities and independent power producers. In the May 2000 determination, EPA concluded that disposal of CCRs did not warrant regulation under RCRA subtitle C as a hazardous waste, but did warrant federal regulation as a solid waste under subtitle D of RCRA. However, EPA never issued federal regulations under subtitle D of RCRA for CCRs. (As noted previously, today's proposal could result in the development of subtitle D standards consistent with the May 2000 Regulatory Determination, or with a revision of the determination, or the issuance of subtitle C standards under RCRA.) Today, EPA is reconsidering this determination, and is soliciting comments on two alternative options: (1) to reverse the Bevill determination (with respect to disposal of CCRs in surface impoundments and landfills), and regulate such CCRs as special wastes under RCRA subtitle C, and (2) to leave the Bevill determination in place and regulate CCRs going to disposal under federal RCRA subtitle D standards. Today's co-proposal provides regulatory text for both options.

In determining whether or not to exclude a Bevill waste from regulation under RCRA subtitle C, EPA must evaluate and weigh eight factors. In section IV. B. of this preamble, EPA discusses CCRs from electric utilities in light of these factors, and we highlight the considerations that might lead us to reversing the August 1993 and May 2000 Regulatory Determinations (and therefore regulate CCR disposal under RCRA subtitle C), or to leave the determination in place (and regulate CCR disposal under RCRA subtitle D).

At the same time, EPA continues to believe the Bevill exclusion should remain in place for CCRs going to certain beneficial uses, because of the important benefits to the environment and the economy from these uses, and because the management scenarios for these products are very different from the risk case being considered for CCR disposal in surface impoundments and landfills. EPA makes it clear that CCRs in sand and gravel pits, quarries, and other large fill operations is not beneficial use, but disposal. As such, it would be regulated under whichever option is finalized. EPA solicits comments, however, on whether unencapsulated uses of CCRs warrant tighter federal control.

A. Summary of Subtitle C Proposal

In combination with its proposal to reverse the Bevill determination for CCRs destined for disposal, EPA is proposing to list as a special waste, CCRs from electric utilities and independent power producers when destined for disposal in a landfill or surface impoundment. These CCRs would be regulated under the RCRA subtitle C rules (as proposed to be amended here) from the point of their generation to the point of their final disposition, which includes both during and after closure of any disposal unit. In addition, EPA is proposing that all existing units that have not closed in accordance with the criteria outlined in this proposal, by the effective date of the final rule, would be subject to all of the requirements of subtitle C, including the permitting requirements at 40 CFR parts 124 and 270. As such, persons who generate, transport and treat, store or dispose of CCRs would be subject to the existing cradle-to-grave subtitle C waste management requirements at 40 CFR parts 260 through 268, parts 270 to 279, and part 124 including the generator and transporter requirements and the requirements for facilities managing CCRs, such as siting, liners (with modification), run-on and run-off controls, groundwater monitoring, fugitive dust controls, financial assurance, corrective action, including facility-wide corrective action, closure of units, and post-closure care (with certain modifications). In addition, facilities that dispose of, treat, or, in many cases, store, CCRs also would be required to obtain permits for the units in which such materials are disposed, treated, and stored. EPA is also considering and seeking comment on a modification, which would not require the closure or installation of composite liners in existing surface impoundments; rather, these surface impoundments could continue to operate for the remainder of their useful life. The rule would also regulate the disposal of CCRs in sand and gravel pits, quarries, and other large fill operations as a landfill.

To address the potential for catastrophic releases from surface impoundments, we also are proposing requirements for dam safety and stability for impoundments that, by the effective date of the final rule, have not closed consistent with the requirements. Finally, we are proposing land disposal restrictions and treatment standards for CCRs, as well as a prohibition on the disposal of treated CCRs below the natural water table.

B. Summary of Subtitle D Proposal

In combination with its proposal to leave the Bevill determination in place, EPA is proposing to regulate CCRs disposed of in surface impoundments or landfills under the RCRA subtitle D requirements, which would establish national criteria to ensure the safe disposal of CCRs in these units. The units would be subject to, among other things, location standards, composite liner requirements (new landfills and surface impoundments would require composite liners; existing surface impoundments without liners would have to retrofit within five years, or cease receiving CCRs and close); groundwater monitoring and corrective action for releases from the unit standards; closure and post-closure care requirements; and requirements to address the stability of surface impoundments. We solicit comments on requiring financial assurance and on

[37] On February 24, the Environmental Integrity Project and EarthJustice issued a report on 31 'new' alleged CCRs damage cases which is available at: *http://www.environmentalintegrity.org/news_reports/documents/OutofControl-MountingDamagesFromCoalAshWasteSites.pdf.*

how the requirements apply to surface impoundments that continue to receive CCRs after the effective date of the rule; specifically, EPA is requesting comment on an alternative under which existing surface impoundments would be allowed to continue to operate without requiring the facility to retrofit the unit to install a composite liner. The rule would also regulate the disposal of CCRs in sand and gravel pits, quarries, and other large fill operations as a landfill. The rule would not regulate the generation, storage or treatment of CCRs prior to disposal. Because of the scope of subtitle D authority, the rule would not require permits, nor could EPA enforce the requirements. Instead, states or citizens could enforce the requirements under RCRA citizen suit authority; the states could also enforce any state regulation under their independent state enforcement authority.

EPA is also considering, and is seeking comment on, a potential modification to the subtitle D option, called "D prime." Under the "D prime" option, existing surface impoundments would not have to close or install composite liners but could continue to operate for their useful life. In the "D prime" option, the other elements of the subtitle D option would remain the same.

IV. Bevill Regulatory Determination Relating to CCRs From Electric Utilities

As discussed in the preceding sections, EPA originally conditioned its May 2000 Regulatory Determination on continued review of, among other factors, "the extent to which [the wastes] have caused damage to human health or the environment; and the adequacy of existing regulation of the wastes." (*See* 65 FR 32218.) Review of the information developed over the past ten years has confirmed EPA's original risk concerns, and has raised significant questions regarding the accuracy of the Agency's predictions regarding anticipated improvements in management and state regulatory oversight of these wastes. Consequently, the Agency has determined that reconsideration of its May 2000 Regulatory Determination is appropriate, and is revaluating whether regulation of CCRs under RCRA subtitle C is necessary in light of the most recent information. The scientific analyses, however, are complex and present legitimate questions for comment and further consideration. Thus, while EPA has concluded that federal regulation of this material is necessary, the Agency has yet not reached a conclusion as to whether the Bevill determination should be revised, or whether regulation under RCRA subtitle C or D is appropriate, but is soliciting comments on the two options described in the previous section.

As stated earlier, EPA's application of its discretion in weighing the eight Bevill factors—and consequently our ultimate decision—will be guided by the following principles. The first is that EPA's actions must be protective of human health and the environment. Second, any decision must be based on sound science. Finally, in conducting this rulemaking, EPA will ensure that its decision processes are transparent, and encourage the greatest degree of public participation. Consequently, to further the public's understanding and ability to comment on the issues facing the Agency, EPA provides an extensive discussion of the technical issues associated with the available information, as well as the policy considerations and the key factors that will weigh in the Agency's ultimate decision.

A. Basis for Reconsideration of May 2000 Regulatory Determination

EPA decided in May 2000 that regulation under RCRA subtitle C was not warranted in light of the trends in present disposal and utilization practices, the current and potential utilization of the wastes, and the concerns expressed against duplication of efforts by other federal and state agencies. In addition, EPA noted that the utility industry has made significant improvements in its waste management practices with respect to new management units over recent years, and most state regulatory programs are similarly improving. In particular, EPA noted that, of the new units constructed between 1985 and 1995, 60% of the new surface impoundments were lined and 65% had groundwater monitoring. Further, the risk information available was limited, although we also noted that we expected that the limited number of damage cases identified in the Regulatory Determination was an underestimate. However, EPA did not conclude that the available information regarding the extent or nature of the risks were equivocal. However, the Agency noted that "* * * we identified a potential for risks from arsenic that we cannot dismiss * * *."[38] EPA further noted that "[i]n the absence of a more complete groundwater risk assessment, we are unable at this time to draw quantitative conclusions regarding the risks due to arsenic or other contaminants posed by improper waste management." Existing older units that lacked liners and groundwater monitoring (for surface impoundments, only 26% of all units had liners and only 38% of all units had groundwater monitoring) were the major risk drivers in the study.

As discussed in greater detail in section II.B, EPA has revised the draft quantitative risk assessment made available when it solicited public comment on the 1999 Report to Congress to account for the concerns raised by the public during the public comment period. The results of these risk analyses show that certain management practices—the disposal of both wet and dry CCRs in unlined waste management units, but particularly in unlined surface impoundments, and the prevalence of wet handling, can pose significant risks to human health and the environment from releases of CCR toxic constituents to ground water and surface water. The Agency has estimated that there are approximately 300 CCR landfills and 584 CCR surface impoundments or similar management units in use at roughly 495 coal-fired power plants. (Data also indicate that a small number of utilities dispose of CCRs off-site, typically near the generating utility.) Many of these units—particularly surface impoundments—lack liners and groundwater monitoring systems. EPA's revised CCR risk assessment[39] estimated the cancer risk from arsenic[40] that leaches into groundwater from CCRs managed in units without composite liners to exceed EPA's typical risk thresholds of 10^{-4} to 10^{-6}. For example, depending on various assumptions about disposal practices (*e.g.,* whether CCRs are co-disposed with coal refuse), groundwater interception and arsenic speciation, the 90th percentile risks from unlined surface impoundments ranged from 2×10^{-2} to 1×10^{-4}. The risks from clay-lined surface impoundments ranged from 7×10^{3} to 4×10^{-5}. Similarly, estimated risks from unlined landfills ranged between 5×10^{-4} to 3×10^{-6}, and

[38] *See* 65 FR 32216 at *http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/ff2f-fr.pdf.*

[39] "Human and Ecological Risk Assessment of Coal Combustion Wastes," (April 2010).

[40] The risk estimates for arsenic presented in the revised risk assessment are based on the existing cancer slope factor of 1.5 $mg/kg/d^{-1}$ in EPA's Integrated Risk Information System (IRIS). However, EPA is currently evaluating the arsenic cancer slope factor and it is likely to increase. In addition, the National Resources Council (NRC) of the National Academy of Sciences (NAS) made new recommendations regarding new toxicity information in the NRC document, "Arsenic in Drinking Water, 2001 Update." Using this NRC data analysis, EPA calculated a new cancer slope factor of 26 $mg/kg/d^{-1}$ which would increase the individual risk estimates by about 17 times.

from 2×10^{-4} to 5×10^{-9} for clay-lined landfills. EPA's risk assessment also estimated HQs above 1 for other metals, including selenium and lead in unlined and clay-lined units. EPA also notes in this regard that recent research indicates that traditional leach procedures (*e.g.,* TCLP and SPLP) may underestimate the actual leach rates of toxic constituents from CCRs under different field conditions.

Recent events also have demonstrated that, if not properly controlled, these wastes have caused greater damage to human health and the environment than EPA originally estimated in its risk assessments. On December 22, 2008, a failure of the northeastern dike used to contain fly ash occurred at the dewatering area of the TVA's Kingston Fossil Plant in Harriman, Tennessee. Subsequently, approximately 5.4 million cubic yards of fly ash sludge was released over an approximately 300 acre area. The ash slide disrupted power, ruptured a gas line, knocked one home off its foundation and damaged others. A root-cause analysis report developed for TVA, accessible at *http://www.tva.gov/kingston/rca/index.htm,* established that the dike failed because it was expanded by successive vertical additions, to a point where a thin, weak layer of fly ash ('slime') on which it had been founded, failed by sliding. The direct costs to clean up the damage from the TVA Kingston incident are well into the billions, and is currently estimated to exceed $1.2 billion.[41]

Although the TVA spill was the largest, it was not the only damage case to involve impoundment stability. A smaller, but still significant incident occurred in August 2005, when a gate in a dam confining a 40-acre CCR surface impoundment in eastern Pennsylvania failed. The dam failure, a violation of the facility's state-issued solid waste disposal permit and Section 402 of the Clean Water Act, resulted in the discharge of 0.5 million cubic yards of coal-ash and contaminated water into the Oughoughton Creek and the Delaware River.

Moreover, documented cases of the type of damage that EPA originally identified to result from improper management of CCR have continued to occur, leading EPA to question whether the risks that EPA originally identified have been sufficiently mitigated since our May 2000 Regulatory Determination. As discussed in more detail below, and in materials contained in the docket, there is a growing record of proven damage cases to groundwater and surface water, as well as a large number of potential damage cases. Since the May 2000 Regulatory Determination, EPA has documented an additional 13 proven damage cases and 4 potential damage cases.

Further, recently collected information regarding the existing state regulatory programs[42] calls into question whether those programs, in the absence of national minimum standards, have sufficiently improved to address the gaps that EPA had identified in its May 2000 Regulatory Determination such that EPA can continue to conclude that in the absence of federal oversight, the management of these wastes will be adequate to protect human health and the environment. Many state regulatory programs for the management of CCRs, including requirements for liners and groundwater monitoring, are lacking, and while industry practices may be improving, EPA continues to *see* cases of inappropriate management or cases in which key protections (*e.g.,* groundwater monitoring at existing units) are absent. Although the joint DOE and EPA study entitled, Coal Combustion Waste Management at Landfills and Surface Impoundments, 1994–2004, indicates that most new units appear to be better designed, in that they are lined and have installed groundwater monitoring systems, and therefore the total percentages of unprotected units have decreased, it appears that a large amount of waste is still being disposed into units that lack the necessary protections of liners, and groundwater monitoring. Furthermore, while corrective action has generally been taken at the proven damage cases, the RCRA regulatory program is designed to prevent contamination in the first place, if at all practicable, rather than one in which contamination is simply remedied after discovery.[43] This information also highlights that EPA still lacks details regarding the manner and degree to which states are regulating the management of this material. All of these factors emphasize the need for prompt federal rulemaking and have led EPA to reconsider its May 2000 Regulatory Determination.

In sum, as a result of the significant new information accumulated on two of the four considerations specifically identified in the May 2000 Regulatory Determination (65 FR 32218), the Agency has determined that reevaluation of its original conclusions in light of all of the RCRA Section 8002(n) study factors is necessary. Based on its consideration of these statutory factors, EPA has not yet reached a decision on whether to revise the Bevill Regulatory Determination. Rather, EPA has summarized the information available for each of the factors, and identifies those considerations on which EPA believes that critical information is lacking. Accordingly, EPA is soliciting further information and public input on each of these considerations that will factor into the Agency's determination as to whether regulation under RCRA subtitle C or D is warranted.

As stated previously and as fully explained in Section XII of today's proposal and in our Regulatory Impact Analysis, our proposed requirements for surface impoundment structural stability and conversion or retrofitting of units, will have substantial benefits in avoided future clean up costs.

B. RCRA Section 8002(n) Study Factors

Section 8002(n) of RCRA requires the Administrator to conduct a detailed and comprehensive study and submit a report on the adverse effects on human health and the environment, if any, of the disposal and utilization of fly ash waste, bottom ash waste, slag waste, flue gas emission control waste, and other by-product materials generated primarily from the combustion of coal or other fossil fuels. The study was to include an analysis of the eight factors required under section 8002(n) of RCRA. EPA addressed these study factors in the 1988 and 1999 Reports to

[41] $3.0 billion is EPA's "social cost" estimate assigned in the April 2010 RIA to the December 2008 TVA Kingston, TN impoundment release event. Social cost represents the opportunity costs incurred by society, not just the monetary costs for cleanup. OMB's 2003 "Circular A–4: Regulatory Analysis" (page 18) instructs Federal agencies to estimate "opportunity costs" for purpose of valuing benefits and costs in RIAs. This $3.0 billion social cost estimate is larger than TVA's $933 million to $1.2 billion cleanup cost estimate (i.e., TVA's estimate as of 03 Feb 2010), because EPA's social cost estimate consists of three other social cost elements in addition to TVA's cleanup cost estimate: (a) TVA cleanup cost, (b) response, oversight and ancillary costs associated with local, state, and other Federal agencies, (c) ecological damages, and (d) local (community) socio-economic damages. Appendix Q to the April 2010 RIA provides EPA's documentation and calculation of these four cost elements, which total $3.0 billion in social cost.

[42] ASTSWMO Survey Conducted Feb.—Mar. 2009 (Excel spreadsheet) available in the docket for this proposal.

[43] As noted in Appendix I on Damage Cases, of the 16 proven cases of damages to groundwater, the Agency has been able to confirm that corrective actions have been completed in seven cases and are ongoing in the remaining nine cases. Corrective action measures at these CCR management units vary depending on site specific circumstances and include formal closure of the unit, capping, re-grading of ash and the installation of liners over the ash, groundwater treatment, ground-water monitoring, installation of a barrier wall, and combinations of these measures.

Congress. The findings of these two Reports to Congress were the basis for our decisions in the August 1993 and the May 2000 Regulatory Determinations to maintain the Bevill exemption for CCRs. In considering whether to retain or to reverse the August 1993 and May 2000 Regulatory Determinations regarding the Bevill exemption of CCRs destined for disposal, we have reexamined the RCRA section 8002(n) study factors against the data on which we made the May 2000 Regulatory Determination, as well as the most recent data we have available.

1. Source and volumes of CCR generated per year: In the mid-1990s, according to various sources, between 62 and 71 million tons of CCRs were generated by coal-fired electric power plants.[44] In comparison, much larger volumes are being generated now (primarily due to the increase in coal-fired power plants), with 136 million tons of CCRs generated by coal-fired electric power plants in 2008.[45]

2. Present disposal and utilization practices: In 2008, 34% (46 million tons) of CCRs were landfilled, 22% (29.4 million tons) were disposed into surface impoundments,[46] nearly 37% (50.1 million tons) were beneficially used (excluding minefill operations), and nearly 8% (10.5 million tons) were placed in mines. This compares to approximately 23% (26.2 million tons) landfilled, 46% (53.2 million tons) disposed of into surface impoundments, 23% beneficially used (excluding minefill operations), and 8% (9 million tons) placed in mines in 1995. Thus, while the overall volume of CCRs going to disposal in surface impoundments and landfills has remained relatively constant, the total volume going to surface impoundments has decreased, and the total volume going to landfills has increased.

The Agency has estimated that there are approximately 300 CCR landfills and 584 CCR surface impoundments or similar management units in use at roughly 495 coal-fired power plants. The age of the disposal units varies considerably. For example, while there are new surface impoundments, 75% are greater than 25 years old, with 10% being greater than 50 years old. Similarly, information from an EPRI survey used in the 1999 Report to Congress indicates that the average planned life expectancy of a landfill is approximately 31 years, with about 12% having planned life expectancy over 50 years (with one planning for over 100 years). Many of these units—particularly surface impoundments, lack liners and ground water monitoring systems. EPA has estimated that in 2004, 31% of the CCR landfills and 62% of the CCR surface impoundments lacked liners, and 10% of the CCR landfills and 58% of the CCR surface impoundments lacked groundwater monitoring.[47] In the mid-1990s, there were approximately 275 CCR landfills and 286 CCR surface impoundments in use.[48] EPA does not believe the increased number of surface impoundments identified in today's rule reflects an actual change of practice, but rather more stringent definitions, as well as possibly, the greater availability of more accurate information. For example, much of the increase in surface impoundments likely results from counting units that receive wastewater that has been in contact with even small amounts of coal ash, and thus includes many units which were not included in EPA's mid-1990 estimates.

a. *Existing State Regulatory Oversight.* The results of the joint DOE and EPA study entitled, Coal Combustion Waste Management at Landfills and Surface Impoundments, 1994–2004 indicates that of the states evaluated in this report, state regulations have generally improved since 2000. In addition, it would appear that the industry itself is changing and improving its management practices. For example, all new surface impoundments and nearly all new landfills (97%) identified in the survey that were constructed between 1994 and 2004 were constructed with liners. Regarding the prevalence of groundwater monitoring at new units, the joint DOE/EPA study suggests that nearly all new landfills (98%) and most new surface impoundments (81%) constructed between 1994 and 2004 were constructed with groundwater monitoring systems. Moreover, the frequency of dry handling in landfills appears to have increased; approximately two-thirds of the new units are landfills, while the remaining one-third are surface impoundments. The number of new units from 1994 to 2004 was 56. Assuming that replacement continued at a rate of 5.6 per year since 2004, we would have an additional 34 new units, but it would still be decades at this rate to replace the large collection of older units.

The DOE/EPA study also identifies significant gaps that remain under existing state regulation. For example, only 19% (3 out of 19) of the surveyed surface impoundment unit permits included requirements addressing groundwater protection standards (*i.e.,* contaminant concentrations that cannot be exceeded) or closure/post-closure care, and only 12% (2 out of 12) of surveyed units were required to obtain bonding or financial assurance. The EPA/DOE report also concluded that approximately 30 percent of the net disposable CCRs generated is potentially entirely exempt from the state solid waste permitting requirements[49] (EPA/DOE Report at pages 45–46). For example, Alabama does not currently regulate CCR disposal under any state waste authority and does not currently have a dam safety program (although the state has an initiative to develop one). Texas (the largest coal ash producer) does not require permits for waste managed on-site.[50] Tennessee currently does not regulate surface impoundments under its waste authority, but is now reconsidering this, in light of the TVA spill. Finally, a number of states only regulate surface impoundments under Clean Water Act authorities, and consequently primarily address the risks from effluent discharges to navigable waters, but do not require liners or groundwater monitoring.

The Agency recognizes that these statistics may be difficult to interpret due to the limitations of the study. The study focused on only eleven states, which account for approximately half the CCRs generated in the U.S., and it may not address all of the existing regulatory requirements that states may or could impose through other authorities to control these units. As one example, the DOE/EPA report notes that four of the six states that do not require solid waste permits rely on other state authorities to regulate these units: "In

[44] Cited in "Technical Background Document for the Report to Congress on Remaining Wastes from Fossil Fuel Combustion: Industry Statistics and Waste Management Practices," March 1999.

[45] ACAA (American Coal Ash Association). 2009. *2008 Coal Combustion Product (CCP) Production & Use Survey Report. http://acaa.affiniscape.com/associations/8003/files/2008_ACAA_CCP_Survey_Report_FINAL_100509.*

[46] Estimated from the 2009 ACAA survey and Energy Information Administration 2005 F767 Power Plant database.

[47] Estimated from the 1995 data reported in the May 2000 Regulatory Determination and the data for new units from 1994 to 2004 reported in the 2006 DOE/EPA report "*Coal Combustion Waste Management at Landfills and Surface Impoundments, 1994–2004.*"

[48] Technical Background Document, Ibid.

[49] 38.7 million tons of out of 129 million tons generated CCRs (Based on DOE/EIA 2004 data).

[50] In Texas, on-site means the same or geographically contiguous property which may be divided by public or private rights-of-way, provided the entrance and exit between the properties is at a cross-roads intersection, and access is by crossing, as opposed to going along, the right-of-way. Noncontiguous properties owned by the same person but connected by a right-of-way which he controls and to which the public does not have access, is also considered on-site property. (Title 30 TAC 335.1)

Florida, if CCWs are disposed in an on-site landfill at a coal-fired electric generating plant authorized under the Florida Power Plant Siting Act (PPSA), no separate permits, including solid waste construction and operation permits, are required. Instead, the entire facility is covered under the PPSA certification, which will contain the same substantive requirements as would otherwise have been imposed by other permits." (EPA/DOE Report at page 46). The DOE/EPA report identified whether states tightened, relaxed, or were neutral with regard to program changes. From the time of the 1999 Report to Congress to 2005, most all programs were neutral, with a couple of programs tightening requirements and none relaxing requirements. Going back to the period of the 1988 Report to Congress to 2005, two states (Alabama and Florida) are reported to have relaxed portions of their standards, while not tightening any other portions of their program. Part of the difficulty in interpreting this information stems from the fact that the survey responses contained little or no details of the state requirements; rather, the responses merely indicated (by checking a box) whether states imposed some sort of requirement relating to the issue. Consequently, the Agency lacks detailed information on the content of the requirements, and whether, for example, performance based requirements or other state programs are used to address the risks from these units. EPA also received detailed comments on this report authored by several environmental groups, who criticized several of the general conclusions. These comments are included in the rule docket (*see* comment attachment submitted by Marty Rustan on behalf of Lisa Evans, Attorney, Earthjustice; EPA–HQ–RCRA–2006–0796–0446.5).

A more recent survey conducted by the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) seems to support the view that the states still have not yet adequately implemented regulatory programs over CCR management units, although like the DOE/EPA study, it lacks details on the substance of the state requirements. According to a 2009 ASTSWMO survey of states with coal ash generation [51] (available in the docket), of the 42 states with coal fired utilities, at least 36 have permit programs for landfills used to manage CCRs, and of the 36 states that have CCR surface impoundments, 25 have permit programs. Permitting is particularly important to provide oversight and to approve implementation plans such as the placement of groundwater monitoring wells. Without a state permit program, regulatory flexibility is limited, and certification by an independent registered professional engineer is necessary. With regard to liner requirements, 36% (15 of the 42 states that responded to this question) do not have minimum [52] liner requirements for CCR landfills, while 67% (24 of the 36 states that responded to this question) do not have CCR liner requirements for surface impoundments. Similarly, 19% (8 of the 42 states that responded to this question) do not have minimum groundwater monitoring requirements for landfills and 61% (22 of the 36 states that responded to this question) do not have groundwater monitoring requirements for surface impoundments.[53] These findings are particularly significant as groundwater monitoring for these kinds of units is a minimum for any credible regulatory regime. The 2009 ASTSWMO survey also indicates that only 36 percent of the states regulate the structural stability of surface impoundments, and only 31 percent of the states require financial assurance for surface impoundments. Because structural stability of surface impoundments is largely regulated by state dam safety programs which are separate from state solid waste programs, EPA recognizes that information from the dam safety programs would be a much more meaningful measure of state regulation of the structural stability of surface impoundments, and solicits such information.

Thus, while the states seem to be regulating landfills to a greater extent, given the significant risks associated with surface impoundments, these results suggest that there continue to be significant gaps in state regulatory programs for the disposal of CCRs. (*See* Letter from ASTSWMO to Matt Hale dated April 1, 2009, a copy of which is in the docket to today's proposed rule for complete results of the survey.)

EPA is also aware of some additional information from ASTSWMO. There are 15 states (Colorado, Florida, Indiana, Iowa, Kansas, Kentucky, Maryland, Minnesota, Mississippi, Montana, New York, North Carolina, Ohio, Pennsylvania, and Virginia) that were considering changes to their CCR regulations at the time of the ASTSWMO survey (February 2009). In late November 2009, ASTSWMO also identified 15 states (Arizona, Delaware, Georgia, Idaho, Iowa, Kansas, Louisiana, Maryland, Mississippi, North Dakota, South Carolina, Tennessee, Washington, Wisconsin, and West Virginia) that had revised their CCR requirements since 2000. Finally, ASTSWMO identified 8 states (Georgia, Illinois, Indiana, Iowa, Montana, Ohio, Pennsylvania, and South Carolina) which are requiring groundwater monitoring at existing facilities that previously did not have groundwater monitoring.

Several issues complicate this assessment, however. As noted previously, EPA lacks any real details regarding how states, in practice, oversee the management of these materials when treated as wastes. For example, some states may use performance based standards or implement requirements to control CCR landfills and surface impoundments under other state programs. Also, most of the new data primarily focuses on the requirements applicable to *new* management units, which represent approximately 10% of the disposal units. EPA has little, if any information, that describes the extent to which states and utilities have implemented requirements—such as groundwater monitoring, for existing units, for the many landfills and surface impoundments that receive CCRs. The information currently in the record with respect to existing units is fifteen years old. EPA expects that it would be unlikely that states would have required existing units to install liners, states would have been more likely to have imposed groundwater monitoring for such units over the last 15 years. Finally, as discussed in the next section, the fact that many of the surface impoundments are located adjacent to water bodies—which is not accounted for in EPA's groundwater risk assessment—may affect our assessment of the extent of the liner and groundwater monitoring requirements that would be necessary. Therefore, EPA solicits detailed comments specifically on the current management practices of state programs, not only under state waste authorities, but under other authorities as well. The adequacy of state regulation is one of the key issues before the Agency, as it will address some of the more significant questions remaining regarding the extent of the

[51] ASTSWMO Survey Conducted Feb.–Mar. 2009 (Excel spreadsheet).

[52] For both landfills and surface impoundments, most of the states that responded to questions addressing their liner and groundwater monitoring program provisions had less stringent requirements, *e.g.*, allowing variance, exemption, or a case-by-case evaluation. In the absence of state-specific information, we are unable to translate these statistics into a concrete number of affected waste units.

[53] Additionally, the July 2009 Petition pointed out deficiencies in state regulatory programs.

risks presented by the disposal of CCRs. Accordingly, the Agency specifically solicits information, whether from state regulatory authorities or from members of the public, regarding details on the entire state regulatory structure, including the specific requirements that states have in place to regulate CCRs, and to provide oversight of these units. EPA would also welcome more detailed information regarding the states' historic practice in implementing its existing requirements, including for example, the states' record of enforcement and its practice in providing for public participation in the development and implementation of any existing permitting requirements. EPA is particularly interested in information on the extent to which states have implemented requirements applicable to the older, existing units, which represent the majority of the units into which CCRs are currently disposed (approximately 90%). EPA also requests information on the extent to which EPA's current information adequately reflects changes in industry practices, adopted independent of state requirements.

b. *Beneficial Use.* In the May 2000 Regulatory Determination, EPA stated: "The Agency has concluded that no additional regulations are warranted for coal combustion wastes that are used beneficially (other than for minefilling) and for oil and gas combustion wastes. We do not wish to place any unnecessary barriers on the beneficial use of fossil fuel combustion wastes so that they can be used in applications that conserve natural resources and reduce disposal costs." (65 FR 32214) (*See* separate discussion regarding minefilling in section IV. E of this preamble.) EPA identified specific beneficial uses as covered by the May 2000 determination. In particular, EPA stated that: "Beneficial purposes include waste stabilization, beneficial construction applications (*e.g.,* cement, concrete, brick and concrete products, road bed, structural fill, blasting grit, wall board, insulation, roofing materials), agricultural applications (*e.g.,* as a substitute for lime) and other applications (absorbents, filter media, paints, plastics and metals manufacture, snow and ice control, waste stabilization)." (*See* 65 FR 32229) These beneficial uses are described in more detail in EPA's Report to Congress on Wastes from the Combustion of Fossil Fuels in March 1999 (*see* Volume 2, Section 3.3.5).

Since EPA's Regulatory Determination in May 2000, there has been a significant increase in the use of CCRs and the development of established commercial sectors that utilize and depend on the beneficial use of CCRs. Additional uses have been identified; for example, the use of CCRs as ingredients in specific products, such as resin-bound products or mineral filler in asphalt. New applications of CCRs have been developed, which may hold great green house gas (GHG) benefits (for example, fly ash bricks and a process to use CO_2 emissions to produce cement). Further, EPA expects that uses could shift in the future because the composition and characteristics of CCRs are likely to change due to the addition of new air pollution controls at coal-fired utilities. (*See* section IV. D. below for a more detailed discussion on the beneficial use of CCRs.)

3. Potential danger, if any, to human health and the environment from the disposal and reuse of CCRs:

a. *From Disposal.* The contaminants of concern in CCRs include antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver and thallium. Potential human exposure pathways for these contaminants from the disposal of CCRs are ground water ingestion, inhalation, and the consumption of fish exposed to contaminants. Ecological impacts include surface water contamination, contamination of wetlands, and aquatic life exposure to contaminants of concern. As discussed in section II. B, V., and the Regulatory Impact Analysis, the risks modeled for the 2010 risk assessment often exceeded EPA's typical regulatory levels of concern. With very few exceptions, the risks modeled for the 2010 risk assessment correspond with ground water exceedances of constituents observed in EPA's damage case assessments (*e.g.,* arsenic, boron, cadmium, lead, molybdenum, and selenium were modeled and found to exceed the risk criteria in at least some instances, and were also found in at least some of the damage cases). Additionally, as discussed in section I.F.2, the potential exists for the chemical characteristics of certain CCRs (*e.g.,* fly ash and FGD) to increase, which could result in increases in releases from management units, particularly if such wastes are placed in old unlined units, as a result of the increased use and application of advanced air pollution control technologies in coal-fired power plants. Further details on the results of EPA's quantitative groundwater risk assessment, and the technical issues that remain to be addressed, and on the unquantified human and ecological risks can be found in section II and in the Regulatory Impact Analysis for today's proposal.

EPA also conducted a population risk assessment for the groundwater-arsenic pathway, as a complement to the individual risk analysis. While the RCRA program necessarily focuses on individual risks, and individual risks have been the basis of previous Bevill and hazardous waste determinations, the population risk estimate provides perspective, and was used to develop the Agency's cost benefit analyses of different regulatory approaches (discussed in section XII.A of this preamble). In this analysis, EPA calculated a best estimate that current risks from arsenic via the groundwater used as drinking water pathway are 2,509 total excess cancers, over a 75-year period.[54] (A 75-year period was used in this analysis to capture peak risk while the RIA generally covers 50 years.) These estimates are based on a cancer slope factor which represents the most recent science derived from a 2001 National Resources Council review of arsenic toxicity. It should be noted that the analysis did not include risks from other pathways or constituents, as explained in section 5A of the Regulatory Impact Analysis for this proposal.

Of the approximately 584 surface impoundments currently operating in the United States, a certain percentage of these have a great potential for loss of human life and environmental damage in the event of catastrophic failure. Based on the information collected from EPA's recent CERCLA 104(e) information request letters 109 impoundments have either a high or significant hazard potential rating,[55] thirteen of which were not designed by a professional engineer. Of the total universe of surface impoundments, approximately 186 of these units were not designed by a professional engineer. Surface impoundments are generally designed to last the typical operating life of coal-fired boilers, on the order of 40 years. However, many impoundments are aging: 56 units are older than 50 years, 96 are older than 40 years, and 340 are between 26 and 40 years old. In recent years, problems have continued to arise from these units, which appear to be related to the aging infrastructure, and the fact that many units may be nearing the end of

[54] Chapter 5, Page 121 of the Regulatory Impact Analysis for this proposal.

[55] 429 of these impoundments currently have no rating. Thus, the Agency expects the number of surface impoundments with a high or significant hazard rating may increase as additional impoundments are assigned ratings. See the definitions in the Summary section of this notice for the definitions of high and significant hazard potential.

their useful lives. For example, as a result of the administrative consent order issued after the December 2008 spill, TVA conducted testing which showed that another dike at TVA's Kingston, Tennessee plant had significant safety deficiencies. Further, in response to EPA's CERCLA 104(e) information request letter, a total of 35 units at 25 facilities reported historical releases. These range from minor spills to a spill of 0.5 million cubic yards of water and fly ash. Additional details regarding these releases can be found in the docket for this rulemaking. EPA continues its assessments of CCR surface impoundments. The most recent information on these can be found on EPA's internet site at *http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/surveys2/index.htm#surveyresults.*

b. *From Beneficial Use.* The risks associated with the disposal of CCRs stem from the specific nature of that activity and the specific risks it involves; that is, the disposal of CCRs in (often unlined) landfills or surface impoundments, with hundreds of thousands, if not millions, of tons placed in a single concentrated location. And in the case of surface impoundments, the CCRs are managed with water, under a hydraulic head, which promotes more rapid leaching of contaminants into neighboring groundwater than do landfills. The beneficial uses identified as excluded under the Bevill amendment for the most part present a significantly different picture, and a significantly different risk profile.

In 1999 EPA conducted a risk assessment of certain agricultural uses of CCRs,[56] since the use of CCRs in this manner was considered the most likely to raise concerns from a human health and environmental point of view. EPA's risk assessment estimated the risks associated with such uses to be within the range of 1×10^{-6}. The results of the risk assessment, as well as EPA's belief that the use of CCRs in agricultural settings was the most likely use to raise concerns, resulted in EPA concluding that none of the identified beneficial uses warranted federal regulation, because "we were not able to identify damage cases associated with these types of beneficial uses, nor do we now believe that these uses of coal combustion wastes present a significant risk to human health or the environment." (65 FR 32230, May 22, 2000.) EPA also cited the importance of beneficially using secondary materials and of resource conservation, as an alternative to disposal.

To date, EPA has still seen no evidence of damages from the beneficial uses of CCRs that EPA identified in its original Regulatory Determination. For example, there is wide acceptance of the use of CCRs in encapsulated uses, such as wallboard, concrete, and bricks because the CCRs are bound into products. The Agency believes that such beneficial uses of CCRs offer significant environmental benefits.

As we discuss in other sections of this preamble, there are situations where large quantities of CCRs have been used indiscriminately as unencapsulated, general fill. The Agency does not consider this a beneficial use under today's proposal, but rather considers it waste management.

Environmental Benefits

The beneficial use of CCRs offers significant environmental benefits, including greenhouse gas (GHG) reduction, energy conservation, reduction in land disposal (*i.e.,* avoidance of potential CCR disposal impacts), and reduction in the need to mine and process virgin materials and the associated environmental impacts. Specifically:

Greenhouse Gas and Energy Benefits. The beneficial use of CCRs reduces energy consumption and GHG emissions in a number of ways. One of the most widely recognized beneficial applications of CCRs is the use of coal fly ash as a substitute for Portland cement in the manufacture of concrete. Reducing the amount of cement produced by beneficially using fly ash as a substitute for cement leads to large supply chain-wide reductions in energy use and GHG emissions.[57] For example, fly ash typically replaces between 15 and 30 percent of the cement in concrete, although the percentages can and have been higher. However, assuming a 15 to 30 percent fly ash to cement replacement rate, and considering the approximate amount of cement that is produced each year, would result in a reduction of GHG emissions by approximately 12.5 to 25 million tons of CO_2 equivalent and a reduction in oil consumption by 26.8 to 53.6 million barrels of oil.[58] This estimate is likely to underestimate the total benefits that can be achieved. As an added benefit, the use of fly ash generally makes concrete stronger and more durable. This results in a longer lasting material, thereby marginally reducing the need for future cement manufacturing and corresponding avoided emissions and energy use.

Benefits From Reducing the Need To Mine and Process Virgin Materials. CCRs can be substituted for many virgin materials that would otherwise have to be mined and processed for use. These virgin materials include limestone to make cement, and Portland cement to make concrete; mined gypsum to make wallboard, and aggregate, such as stone and gravel for uses in concrete and road bed. Using virgin materials for these applications requires mining and processing them, which can impair wildlife habitats and disturb otherwise undeveloped land. It is beneficial to use secondary materials—provided it is done in an environmentally sound manner—that would otherwise be disposed of, rather than to mine and process virgin materials, while simultaneously reducing waste and environmental footprints. Reducing mining, processing and transport of virgin materials also conserves energy, avoids GHG emissions, and reduces impacts on communities.

Benefits From Reducing the Disposal of CCRs. Beneficially using CCRs instead of disposing of them in landfills and surface impoundments also reduces the need for additional landfill space and any risks associated with their disposal. In particular, the U.S. disposed of over 75 million tons of CCRs in landfills and surface impoundments in 2008, which is equivalent to the space required of 26,240 quarter-acre home sites under 8 feet of CCRs.

While the Agency recognizes the need for regulations for the management of CCRs in landfills and surface impoundments, we strongly support the beneficial use of CCRs in an environmentally sound manner because of the significant environmental benefits that accrue both locally and globally. As discussed below in section XII.A, the current beneficial use of CCRs as a replacement for industrial raw materials (*e.g.,* Portland cement, virgin stone aggregate, lime, gypsum) provides substantial annual life cycle environmental benefits for these industrial applications. Specifically,

[56] 1998 Draft Final Report; Non-groundwater Pathways, Human Health and Ecological Risk Analysis for Fossil Fuel Combustion Phase 2 (FFC2) and its appendices (A through J); available at *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/fsltech.htm.*

[57] Waste and Materials-Flow Benchmark Sector Report: Beneficial Use of Secondary Materials—Coal Combustion Products, February 12, 2008.

[58] Avoided GHG and energy saving estimates based on energy and environmental benefits estimates in the EPA report entitled, "Study on Increasing the Usage of Recovered Mineral Components in Federally Funded Projects Involving Procurement of Cement or Concrete" available at *http://www.epa.gov/osw/conserve/tools/epg/pdf/rtc/report4-08.pdf.*

beneficially using CCRs as a substitute for industrial raw materials contributes (a) $4.89 billion per year in energy savings, (b) $0.081 billion per year in water savings, (c) $0.239 billion per year in GHG [59] (*i.e.,* carbon dioxide and methane) emissions reduction, and (d) $17.8 billion per year in other air pollution reduction. In addition, these applications also result in annual material and disposal cost savings of approximately $2.93 billion. All together, the beneficial use of CCRs provides $25.9 billion in annual national economic and environmental benefits (relative to 2005 tonnage).[60]

However, as discussed in the next section, there are cases where large quantities of CCRs have been "used" indiscriminately as unencapsulated "fill," *e.g.,* to fill sand and gravel pits or quarries, or as general fill (*e.g.,* Pines, Indiana and the Battlefield Golf Course in Chesapeake, Virginia [61]). Although EPA does not consider these practices to be legitimate beneficial uses, others classify them as such. In any case, EPA has concluded that these practices raise significant environmental concerns.

4. Documented cases in which danger to human health or the environment from surface runoff or leachate has been proved: As described previously, EPA has identified 27 proven damage cases: 17 cases of damage to groundwater, and ten cases of damage to surface water, seven of which are ecological damage cases. Sixteen of the 17 proven damage cases to groundwater involved disposal in unlined units—for the one additional unit, it is unknown whether there was a liner. We have also identified 40 potential damage cases to groundwater and surface water. These numbers compare to 14 proven damage cases and 36 potential cases of damage when the Agency announced its Regulatory Determination in May 2000. The Agency believes that these numbers likely underestimate the number of proven and potential damage cases and that it is likely that additional cases of damage would be found if a more comprehensive evaluation was conducted, particularly since much of this waste has been (and continues to be) managed in unlined disposal units.

Several of the new damage cases involve activities that differ from prior damage cases, which were focused on groundwater contamination from landfills and surface impoundments. These new cases present additional risk concerns that EPA did not evaluate in the May 2000 Regulatory Determination. Specifically, some of the recent proven damage cases involved the catastrophic release due to the structural failure of CCR surface impoundments, such as the dam failures that occurred in Martins Creek, Pennsylvania and Kingston, Tennessee.

In addition, a number of proven damage cases involve the large-scale placement, akin to disposal, of CCRs, under the guise of "beneficial use." The "beneficial use" in these cases involved the filling of old, unlined quarries or gravel pits, or the regrading of landscape with large quantities of CCRs. For example, the 216-acre Battlefield Golf Course was contoured with 1.5 million yards of fly ash to develop the golf course. In late 2008, groundwater and surface water sampling was conducted. There were exceedances of primary drinking water standards in on-site groundwater for contaminants typically found in fly ash. In addition, there were exceedances of secondary drinking water standards in both on-site and off-site groundwater (in nine residential wells); however, the natural levels of both manganese and iron in the area's shallow aquifer are very high (0.14 mg/L to 0.24.mg/L and 5.0 mg/L to 13.0 mg/L, respectively), and, thus, it could not be ruled out that the elevated levels of manganese and iron are a result of the natural background levels of these two contaminants. Surface water samples showed elevated levels of aluminum, chromium, iron, lead, manganese, and thallium in one or more on-site samples. The lone off-site surface water sample had elevated levels of aluminum, iron, and manganese. In April 2010 EPA issued a Final Site Inspection Report [62] which concluded that (i) metals contaminants were below MCLs and Safe Drinking Water Act action levels in all residential wells that EPA tested; (2) the residential well data indicate that metals are not migrating from the fly ash to residential wells; and (iii) there are no adverse health effects expected from human exposure to surface water or sediments on the Battlefield Golf Course site as the metal concentrations were below the ATSDR standards for drinking water and soil. Additionally, the sediments samples in the ponds were below EPA Biological Technical Assistance Group screening levels and are not expected to pose a threat to ecological receptors. Similarly, beginning in 1995, the BBBS sand and gravel quarries in Gambrills, Maryland, used fly ash and bottom ash from two Maryland power plants to fill excavated portions of two sand and gravel quarries. Groundwater samples collected in 2006 and 2007 from residential drinking water wells near the site indicated that, in certain locations, contaminants, including heavy metals and sulfates, were present at or above groundwater quality standards. Private wells in 83 homes and businesses in areas around the disposal site were tested. MCLs were exceeded in 34 wells [arsenic (1), beryllium (1), cadmium (6), lead (20),[63] and thallium (6)]. SMCLs were exceeded in 63 wells [aluminum (44), manganese (14), and sulfate (5)]. The state concluded that leachate from the placement of CCRs at the site resulted in the discharge of pollutants to waters of the state.

Further details on these additional damage cases are provided in section II. C (above), and in the Appendix to this notice.

As mentioned in section II.C, during the development of this proposal, EPA received new reports from industry and citizen groups regarding damage cases. Industry provided information that, they suggested, shows that many of EPA's listed proven damage cases do not meet EPA's criteria for a damage case to be proven. On the other hand, citizen groups recently identified additional alleged damage cases. The Agency has not yet had an opportunity to evaluate this additional information. EPA's analysis, as well as the additional information from industry and citizen groups, all of which is available in the docket to this proposed rule, would

[59] The RIA monetizes the annual tonnage of greenhouse gas effects associated with the CCR beneficial use life cycle analysis, based on the 2009 interim social cost of carbon (i.e., interim SCC) of Table III.H.6–3, page 29617 of the joint EPA and DOT–NHTSA "Proposed Rulemaking to Establish Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards," **Federal Register**, Volume 74, No. 186, 28 Sept 2009. The value applied in the RIA is the $19.50 per ton median value from the $5 to $56 per ton range displayed in the 2007 column in that source. Furthermore, the RIA updated the 2007$ median value from 2007 to 2009 dollars using the NASA Gross Domestic Product Deflator Inflation Calculator at *http://cost.jsc.nasa.gov/inflateGDP.html.* EPA is aware that final SCC values were published on March 9, 2010 in conjunction with a Department of Energy final rule. EPA intends to use the final SCC values for the CCR final rule RIA. The final SCC values are published in the Department of Energy, Energy Efficiency & Renewable Energy Building Technologies Program, "Small Electric Motors Final Rule Technical Support Document: Chapter 16—Regulatory Impact Analysis," March 9, 2010 at *http://www1.eere.energy.gov/buildings/appliance_standards/commercial/sem_finalrule_tsd.html*).

[60] These benefits estimates are further discussed in Chapter 5C of the RIA which is available in the docket for this proposal.

[61] These instances are associated with 7 proven damage cases and 1 potential damage case.

[62] *http://www.epa.gov/reg3hwmd/CurrentIssues/finalr-battlefield_golf_club_site/redacted_DTN_0978_Final_Battlefield_SI_Report.pdf.*

[63] It is uncertain whether lead exceedances were due to CCRs or lead in the plumbing and water holding tanks.

benefit from public input and further review, in the interest of reaching a more complete understanding of the nature and number of damage cases. EPA encourages commenters to consider all of these analyses in developing their comments.

5. Alternatives to current disposal methods: There are no meaningful disposal alternatives other than land disposal. Improved disposal management practices are practical (*e.g.,* liners, groundwater monitoring, dust control), although EPA has not identified meaningful or practical treatment options prior to disposal, other than dewatering. (There are, however, available technologies, or technologies under development, to process CCRs now likely destined for disposal so that they can effectively be converted to appropriate beneficial uses.) The beneficial use of these materials as products continues to be an important alternative to disposal.

6. The cost of such alternative disposal methods: The Agency has estimated the nationwide costs to the electric utility industry (or to electric rate payers) for each alternative considered for this proposal. These estimates are discussed in the regulatory impact analysis presented within section XII.A of this preamble.

7. The impact of the alternative disposal methods on the use of coal and other natural resources: The alternative disposal methods mentioned above are not expected to impact the use of coal or other natural resources. However, we would note that some surface impoundments at coal-fired utilities are also used as wastewater treatment systems for other non-CCR wastewaters. Therefore, if facilities switch from wet to dry handling of CCRs, construction of alternative wastewater treatment systems could become necessary for other non-CCR wastewaters, especially if they involved acidic wastes that are currently neutralized by the coal ash. (Note that the issue of beneficial uses of CCRs is discussed below; if the effect of a subtitle C approach is to increase beneficial uses, it could lead to a decrease in the use of virgin materials like ingredients in cement making, aggregate, mined gypsum, etc. On the other hand, if the effect of that approach were to decrease beneficial uses, as some commenters suggested, it would have the opposite effect on the use of natural resources.)

8. The current and potential utilization of CCRs: In 2008, nearly 37% (50.1 million tons) of CCRs were beneficially used (excluding minefill operations) and nearly 8% (10.5 million tons) were placed in minefills. (This compares to 23% of CCRs that were beneficially used, excluding minefilling, at the time of the May 2000 Regulatory Determination, and represents a significant increase.)

Parties have commented that any regulation of CCRs under RCRA subtitle C will impose a crippling stigma on their beneficial use, and eliminate or significantly curtail these uses, even if EPA were to regulate only CCRs destined for disposal, without modifying the regulatory status of beneficial reuse. On the other hand, other parties have commented that increasing the cost of disposal of CCRs through regulation under subtitle C will actually increase their usage in non-regulated beneficial uses, simply as a result of the economics of supply and demand. States, at the same time, have commented that, by operation of state law, the beneficial use of CCRs would be prohibited under the states' beneficial use programs, if EPA designated CCRs as hazardous waste when disposed of in landfills or surface impoundments. At the time of the May 2000 Regulatory Determination, commenters had raised this similar concern, and without agreeing that regulation under RCRA subtitle C would necessarily affect the beneficial reuse of this material, EPA nevertheless strongly expressed concern that beneficial use not be adversely affected.

EPA is interested in additional information supporting the claims that "stigma" will drive people away from the use of valuable products, or that states will prohibit the reuse of CCRs under their beneficial use programs if EPA regulates any aspect of CCR management under subtitle C. Specifically, the Agency requests that commenters provide analyses and other data and information that demonstrate this to be the case. To date, we have received statements and declarations that regulation under subtitle C will have devastating effects on beneficial uses of CCRs. In addition, for those commenters who suggest that regulating CCRs under subtitle C of RCRA would raise liability issues, EPA requests that commenters describe the types of liability and the basis, data, and information on which these claims are based. The issue of beneficial use and stigma are more fully discussed in section VI, where we discuss the alternative of regulating CCRs under subtitle C of RCRA. EPA would also be interested in suggestions on methods by which the Agency could reduce any stigmatic impact that might indirectly arise as a result of regulation of CCRs destined for disposal as a "special" waste under RCRA subtitle C.

C. Preliminary Bevill Conclusions and Impact of Reconsideration

The Agency is proposing two different approaches to regulating CCRs: Regulation as a "special" waste listed under RCRA subtitle C if EPA decides to lift the Bevill exemption with respect to disposal; and regulation as a solid waste under RCRA subtitle D, if the Bevill exemption is retained for disposal. Under both of these approaches, requirements for liners and groundwater monitoring would be established, although there are differences with respect to the other types of requirements that can be promulgated by EPA under RCRA subtitle C and D. In addition, as discussed in greater detail below, one of the primary differences between the various approaches relates to the degree and extent of federal oversight, as this varies considerably between the alternatives. As noted previously, EPA has not yet reached a decision on whether to regulate CCRs under RCRA subtitle D or C, but continues to evaluate each of these options in light of the 8002(n) factors.

In determining the level of regulation appropriate for the management of CCRs, several considerations weigh heavily with the Agency; information on these issues will therefore be important for commenters to consider as they prepare their comments. One particularly critical question relates to the extent of the risks posed by the current management of this material, along with the corresponding degree of Federal oversight and control necessary to protect human health and the environment. As discussed in the preceding sections, since EPA's Regulatory Determination in May 2000, new information has called into question EPA's original assessment of the risks posed by the current management of CCRs that are disposed of. In summary, this includes (1) The results of EPA's 2010 risk assessment, which indicates that certain management practices—particularly units without composite liners and the prevalence of wet handling can pose significant risks; (2) the growing record of proven damage cases to ground water and surface water, as well as a large number of potential damage cases; (3) recent events, which have demonstrated that these wastes have caused greater damage to human health and the environment than originally estimated (*i.e.,* catastrophic environmental impacts from surface impoundment breaches, and damage resulting from "sham beneficial uses"); and (4) questions regarding the adequacy of state regulatory programs for the management of CCRs, as many states appear to lack key protective requirements for liners and groundwater monitoring and a permitting program to ensure that such provisions are being properly implemented, even though overall industry practices appear to be improving. All of these considerations illustrate that in many cases CCRs have not been properly managed. The question is whether federal regulation is more appropriate under subtitle C or subtitle D of RCRA.

Several significant uncertainties remain with respect to all of the identified considerations. For example, as discussed previously, the data and analyses associated with this proposal are complex, and several uncertainties remain in EPA's quantitative risk analysis. One of these uncertainties is the evolving character/composition of CCRs due to electric utility upgrades and retrofits needed to comply with the emerging CAA requirements, which could present new or otherwise unforeseen contaminant issues (*e.g.,* hexavalent chromium from post-NO_X controls). Other uncertainties relate to the extent to which some sampled data with high concentrations used in the risk assessment accurately reflect coal ash leaching from landfills or surface impoundments, and the extent to which releases from surface impoundments located in close proximity to water bodies intercept drinking water wells. For example, as explained earlier in the preamble, some data reflected pore water taken in the upper section of a surface impoundment where coal refuse was placed. There were acid generating conditions and high concentrations of arsenic, but the data demonstrated that the underlying coal ash neutralized the acid conditions and greatly reduced the arsenic which leached from the bottom of the impoundment. There are also technical issues associated with releases from surface impoundments located in close proximity to water bodies which intercept drinking water wells. For example, surface impoundments are commonly placed next to rivers, which can intercept the leachate plume and prevent contamination of drinking water wells on the other side of the river. Also, in such circumstances the direction of groundwater flow on both sides of the river may be towards the river; thus, the drinking water well on the opposite side of a river may not be impacted.

As mentioned previously, EPA has received additional reports on damage cases, one from industry and one from citizen groups. Closer analyses of these reports could have the potential to significantly affect the Agency's conclusions.

An equally significant component of the overall picture, if not more so, relates to how effectively state regulatory programs address the risks associated with improper management of this material. As discussed earlier in this preamble, the continued damage cases and the reports on state regulatory programs call into question whether the trend in improving state regulatory regimes that EPA identified in May 2000 has materialized to the degree anticipated in the Regulatory Determination. Although recent information indicates that significant gaps remain, EPA continues to lack substantial details regarding the full extent of state regulatory authority over these materials, and the manner in which states have in practice, implemented this oversight. Nevertheless, based on the information made available on state programs, the Agency is reticent to establish a regulatory program without any federal oversight. Thus, EPA seeks additional details on regulation of CCRs by states to ensure that EPA's understanding of state programs is as complete as possible. While EPA recognizes that the extent of regulation of CCRs varies between states, EPA is not yet prepared to draw overall conclusions on the adequacy of state programs, as a general matter. EPA is, therefore, requesting that commenters, and particularly state regulatory authorities, provide detailed information regarding the extent of available state regulatory authorities, and the manner in which these have been, and are currently implemented. In this regard, EPA notes that "survey" type information that does not provide these details is unlikely to be able to resolve the concerns arising from the recent information developed since the May 2000 Regulatory Determination. EPA is also soliciting comments on the extent to which the information currently available to the Agency reflects current industry practices at both older and new units. For example, EPA would be particularly interested in information that indicates how many facilities currently have groundwater monitoring systems in place, how those systems are designed and monitored, and what, if anything, they have detected.

EPA has identified several issues that will be relevant as it continues to evaluate the overall adequacy of state regulatory programs. Specifically, EPA intends to consider how state regulatory programs have, in practice, evaluated and imposed requirements to address: (1) Leachate collection; (2) groundwater monitoring; (3) whether a unit must be lined, and the type of liner needed; (4) the effectiveness of existing management units as opposed to new management units; (5) whether the state requires routine analysis of CCRs; (6) whether financial responsibility requirements are in place for the management of CCRs; (7) the extent of permit requirements, including under what authorities these disposal units are permitted, the types of controls that are included in permits, and the extent of oversight provided by the states, (8) whether state programs include criteria for siting new units; (9) the extent of requirements for corrective action, post-closure monitoring and maintenance; (10) the state's pattern of active enforcement and public involvement; and (11) whether or not these facilities have insurance against catastrophic failures.

Directly related to the level of risk presented by improper management of CCRs, EPA is also weighing the differing levels of Federal oversight and control, and the practical implementation challenges, associated with the level and type of regulation under RCRA subtitles C and D. In the interest of furthering the public understanding of this topic, EPA presents an extensive discussion of the differences and concerns raised between regulation under subtitles C and D of RCRA, including a comparison of the advantages and disadvantages of each.

The subtitle C approach proposed today would provide full national cradle-to-grave control over CCRs destined for disposal, consistently managed under federally enforceable standards and through federal permits, or permits issued by the states that EPA has authorized to regulate CCRs in lieu of EPA. Permits can be a particularly important mechanism, because they allow the regulatory Agency to scrutinize the design of disposal units and the management practices of the permit applicant. They also allow the regulator to tailor the permit conditions to the facility site conditions, including the ability to impose additional specific conditions where it deems current or proposed facility practices to be inadequate to protect human health or the environment, pursuant to the omnibus authority in RCRA section 3005(c). Additionally, permitting processes provide the public and the local community the opportunity to participate in regulatory decisions. The combined requirements under subtitle C would effectively phase-out all wet handling of CCRs and prohibit the disposal of CCRs in surface impoundments. Moreover, the subtitle C approach is the only approach that allows direct federal enforcement of the rule's requirements. The many damage cases, including more recent damage cases, suggest the value of control and oversight at the federal level.

At the same time, EPA acknowledges concerns with a subtitle C approach on the part of states, the utilities, and users of CCR-derived products. The states have expressed concern that any federal approach, including a subtitle D approach, has the potential to cause disruption to the states' implementation of CCR regulatory programs under their own authority. For example, the state of Maryland has recently upgraded its disposal standards for CCRs under its state solid waste authority, and the new state regulations address the major points in today's proposal (except the stability requirement for impoundments and the prohibition against surface impoundments). The state has expressed concern about having to revise its regulations again, and re-permit disposal units under subtitle C of RCRA. A subtitle D approach, as described in today's proposal, would eliminate or significantly reduce these concerns. EPA acknowledges these concerns, and certainly does not wish to force the states to go through unnecessary process steps. EPA nevertheless solicits comment on this issue, including more specifics on the potential for procedural difficulties for state programs, and measures that EPA might adopt to try to mitigate these effects.

Two additional substantive concerns with regulation of CCRs under subtitle C have been raised by commenters: the effect of listing CCRs as hazardous waste under RCRA on beneficial uses, and the availability of existing subtitle C landfill capacity to manage CCRs. As explained previously, EPA shares the concern that beneficial uses not be inadvertently adversely affected by the regulation of CCRs destined for disposal. EPA continues to believe that certain beneficial use, when performed properly, is the environmentally preferable destination for these materials and, therefore, wants to address any potential stigma that might arise from designating CCRs as hazardous wastes. Thus, EPA is seeking data and information, including detailed analyses, of why the subtitle C regulation outlined in today's proposal will have the impact that some commenters have identified. As explained at length in section VI of this preamble, EPA believes it can generally address the concerns that have been raised regarding the effect of subtitle C regulation on legitimate beneficial uses in today's proposal through several of the actions outlined in today's proposal. The most important of these is that EPA is not proposing to revise its May 2000 Regulatory Determination that beneficial uses retain the Bevill exemption and do not warrant federal regulation. Nevertheless, EPA agrees that "stigma" is an important consideration in the Agency's decision, and solicits information and data that will help the Agency quantify the potential effects of any stigma arising from association with CCR disposal regulated under subtitle C.

On the question of hazardous waste disposal capacity, EPA believes that management patterns of CCRs will continue: That landfills and surface impoundments currently receiving CCRs will obtain interim status and convert to RCRA subtitle C status, and that the proposal will not shift disposal patterns in a way that substantially increases the disposal of CCRs off-site from generating utilities to commercial hazardous waste landfills. Therefore, EPA's regulatory analysis assumes disposal patterns will remain generally the same. As commenters have pointed out, CCRs do, in theory, have the potential to overwhelm the current hazardous waste capacity in the United States. EPA's Biennial Report indicates that approximately two million tons of hazardous waste are disposed of annually in hazardous waste landfills, and EPA estimates that the current total national commercial hazardous waste landfill disposal capacity is between 23.5 and 30.3 million tons, while the annual amount of CCRs currently going to land disposal is 46 million tons (with an additional 29.4 million tons going to surface impoundments).[64] These figures illustrate the very large volume of CCR material involved, and how it could overwhelm existing subtitle C disposal capacity. While a DOE survey reports that 70% of disposal involves "company on-site" disposal units and 30% involves "off-site" disposal units, DOE indicated that off-site disposal capacity can be company owned or commercial disposal units. In communications with USWAG, they indicated, in some cases smaller facilities may send ash to a commercial operation, but believed that is in no way representative of the industry as a whole. In some cases, the disposal facility may be operated by a contractor for the utility, and the landfill is a captive facility that does not receive other industrial wastes. At the same time, EPA points out that, to the extent that new capacity is needed, the implementation of today's rule, if the subtitle C alternative is selected, will take place over a number of years, providing time for industry and state permitting authorities to address the issue. However, this is an issue on which EPA would find further information to be helpful. Therefore, EPA solicits detailed information on this topic, to aid in further quantifying the extent to which existing capacity may be insufficient. For example, EPA is interested in detailed information on the volume of CCRs now going off-site for disposal; the nature of off-site disposal sites (*e.g.,* commercial subtitle D landfills versus dedicated CCR landfills owned by the utility); and the amount of available land on utility sites for added disposal capacity.

Finally, the states have expressed concern that the RCRA subtitle C requirements will be considerably more expensive for them to implement than a RCRA subtitle D regulation, without providing commensurate benefits. For example, the states have reported that regulation under RCRA subtitle C, versus subtitle D, would cost them an additional $17 million per year to implement. EPA acknowledges the concern that the RCRA subtitle C requirements can be costly to implement, and could put more pressure on diminishing state budgets. However, were states to utilize the subtitle D requirements of today's proposal, the cost of implementing a RCRA subtitle D program will also be expensive. Thus, EPA is aware of the pressures on state budgets and will consider potential impacts when making a final determination for this rulemaking. Nevertheless, in the event that EPA determines that RCRA subtitle C regulation is warranted, it will be because EPA has determined that there are serious environmental and human health risks that can only be remedied by regulation under subtitle C. Further, under the subtitle C scenario, we believe that most states should be able to address any shortfalls through hazardous waste generator or disposal fees. EPA specifically solicits comments from states as to the extent to which such fees would be able to offset the costs of administering permit, inspection, and enforcement programs.

EPA notes that its estimates of costs of compliance with the subtitle C requirements have increased since its estimates in the 1999 Report to Congress; as explained later in this preamble, EPA believes these costs are commensurate with the benefits to be derived from the controls, and that the costs of regulation under RCRA subtitle D are substantial as well. For example,

[64] These figures reflect the total current capacity, not annual capacity. The annual capacity is significantly less: modifications to annual capacity would require modifications to existing permits.

one of the major potential costs under either the subtitle C or subtitle D option is associated with the required closure of all existing surface impoundments that do not meet the rule's technical requirements, which EPA is proposing under both the subtitle C and subtitle D co-proposals. Further, the technical unit design and groundwater monitoring requirements that will effectively protect human health and the environment under either option are quite similar. Finally, EPA is proposing to modify certain aspects of the RCRA subtitle C framework to address some of the practical implementation challenges associated with applying the existing regulatory framework to these wastes. However, commenters have suggested that EPA has underestimated the costs of compliance under the subtitle C requirements upstream of surface impoundments and landfills (*e.g.,* for storage). Commenters, however, have not provided specific cost estimates associated with storage of CCRs. EPA specifically solicits substantiating detail from commenters.

One disadvantage of a RCRA subtitle C approach, compared to a RCRA subtitle D approach, is that the subtitle C approach, in most states, will not go into effect as quickly as subtitle D. That is, the subtitle C regulations require an administrative process before they become effective and federally enforceable (except in the two states that are not authorized to manage the RCRA program). The RCRA hazardous waste implementation and authorization process is described in detail in sections VII and VIII of this preamble. But to summarize, federal regulations under subtitle C would not go into effect and become federally enforceable until RCRA-authorized states [65] have adopted the requirements under their own state laws, and EPA has authorized the state revisions. Under the RCRA subtitle C regulations, when EPA promulgates more stringent regulations, states are required to adopt those rules within one year, if they can do so by regulation, and two years if required by legislative action. If a state does not adopt new regulations promptly, EPA's only recourse is to withdraw the entire state hazardous waste program. If EPA determines that a subtitle C rule is warranted, the Agency will place a high priority on ensuring that states promptly pick up the new rules and become authorized, and EPA will work aggressively toward this end. Three decades of history in the RCRA program, however, suggest that this process will take two to five years (if not longer) for rules to become federally enforceable.[66]

At the same time, EPA believes there may be benefits in a RCRA subtitle D approach that establishes specific self-implementing requirements that utilities and others managing regulated CCRs would have to comply with, even in the absence of permitting or direct regulatory oversight. EPA recognizes that many of the states have regulatory programs in place, albeit with varying requirements, for the disposal of CCRs, and that industry practices have been improving. The RCRA subtitle D approach would complement existing state programs and practices by filling in gaps, and set forth criteria for disposing of CCRs to meet the national minimum standards that are designed to address key risks identified in damage cases and the risk assessment—including the risk of surface impoundment failure, which has been identified as a concern appropriate for control.

The co-proposed RCRA subtitle D option is less costly than the co-proposed RCRA subtitle C option, according to EPA's Regulatory Impact Assessment. The main differences in the costs are based on the assumption that there will be less compliance, or slower compliance, under a RCRA subtitle D option. In addition, the industry and state commenters suggested that a RCRA subtitle D approach would eliminate two of their concerns: (1) That a RCRA subtitle C approach would inappropriately stigmatize uses of CCRs that provide significant environmental or economic benefits, or that (according to those commenters) hold significant potential promise, and (2) that the volume of CCR wastes generated—particularly if requirements of a RCRA subtitle C regulation led to more off-site disposal—would overwhelm existing subtitle C capacity based on the large volumes of CCRs that are generated and would need to be disposed of. It would also reduce or eliminate expressed industry concerns about the effect of RCRA subtitle C requirements on plant operations, and state concerns related to the burden of the RCRA subtitle C permitting process. Related to the capacity issue, these same commenters have also suggested that, under the RCRA subtitle C regulations, future cleanup of poorly sited or leaking disposal sites (including historical or legacy sites) would be considerably more expensive, especially where off-site disposal was chosen as the option. (EPA's RIA does not quantify this last issue, but the RIA does discuss two recent cases as examples; EPA solicits more detailed comment on this issue, preferably with specific examples.) As stated earlier, EPA does not have sufficient information to conclude that regulation under RCRA subtitle C will stigmatize CCRs destined for beneficial use, for the reasons discussed elsewhere in today's preamble, and the Agency does not at this point have reason to assume that use of off-site commercial disposal of CCRs will increase significantly.

EPA also notes that many of the requirements discussed above would go into effect more quickly under RCRA subtitle D. Under subtitle D of RCRA, EPA would set a specific nationwide compliance date and industry would be subject to the requirements on that date, although as discussed elsewhere in today's preamble, EPA's ability to enforce those requirements is limited. (Of course, certain requirements, such as closure of existing surface impoundments, would have a delayed compliance date set to reflect practical compliance realities, but other requirements, for example, groundwater monitoring or the requirement that new surface impoundments be constructed with composite liners could be imposed substantially sooner than under a RCRA subtitle C rule.) The possible exception would be if EPA decided to establish financial assurance requirements through a regulatory process currently underway that would establish financial assurance requirements for several industries pursuant to CERCLA 108(b), including the Electric Power Generation, Transmission and Distribution Industry. For a more detailed discussion of these issues *see* section IX.

However, there are also disadvantages to any approach under RCRA subtitle D. Subtitle D provides no Federal oversight of state programs as it relates to CCRs. It establishes a framework for Federal, state, and local government cooperation in controlling the management of nonhazardous solid waste. The Federal role in this arrangement is to establish the overall regulatory direction, by providing minimum nationwide standards for protecting human health and the environment, and to provide technical assistance to states for planning and developing their own environmentally sound waste management practices. The co-proposed subtitle D alternative in this proposal would establish national minimum

[65] Currently, all but two states are authorized for the base RCRA program.

[66] In addition, existing facilities would generally operate under self-implementing interim status provisions until the state issued a RCRA permit, which is a several year process, although presumably the facility might remain under state solid waste permits, depending on state law.

standards specifically for CCRs for the first time. The actual planning and direct implementation of solid waste programs under RCRA subtitle D, however, remain state and local functions, and the act authorizes states to devise programs to deal with state-specific conditions and needs.

In further contrast to subtitle C, RCRA subtitle D requirements would regulate only the disposal of solid waste, and EPA does not have the authority to establish requirements governing the transportation, storage, or treatment of such wastes prior to disposal. Under RCRA sections 4004 and 4005(a), EPA cannot require that facilities obtain a permit for these units. EPA also does not have the authority to determine whether any state permitting program for CCR facilities is adequate. This complicates the Agency's ability to develop regulations that can be effectively implemented and tailored to individual site conditions. Moreover, EPA does not have the authority to enforce the regulations, although, the "open dumping" prohibition may be enforced by states and citizens under section 7002 of RCRA.

D. EPA Is Not Reconsidering the Regulatory Determination Regarding Beneficial Use

As noted previously, in the May 2000 Regulatory Determination, EPA concluded that federal regulation was not warranted for the beneficial uses identified in the notice, because: "(a) We have not identified any other beneficial uses that are likely to present significant risks to human health or the environment; and (b) no documented cases of damage to human health or the environment have been identified. Additionally, we do not want to place any unnecessary barriers on the beneficial uses of coal combustion wastes so they can be used in applications that conserve natural resources and reduce disposal costs." (*See* 65 FR 32221) EPA did not conduct specific risk assessments for the beneficial use of these materials, except as noted below and elsewhere in this preamble. Instead, it generally described the uses and benefits of CCRs, and cited the importance of beneficially using secondary materials and of resource conservation, as an alternative to disposal. However, EPA did conduct a detailed risk assessment of certain agricultural uses of CCRs,[67] since the use of CCRs in this manner is most likely to raise concerns from an environmental point of view. Overall, EPA concluded at the time that the identified uses of CCRs provided significant benefits (environmental and economic), that we did not want to impose an unnecessary stigma on these uses and therefore, we did not see a justification for regulating these uses at the federal level.

Since EPA's Regulatory Determination in May 2000, the Agency has gathered additional information. In addition to the evolving character/composition of CCRs due to electric utility upgrades and retrofits needed to comply with the emerging CAA requirements, which could present new or otherwise unforeseen contaminant issues (*e.g.,* hexavalent chromium from post-NO_X controls), changes include: (1) A significant increase in the use of CCRs, and the development of established commercial sectors that utilize and depend on the beneficial use of CCRs, (2) the recognition that the beneficial use of CCRs (and, in particular, specific beneficial uses of CCRs, such as using fly ash as a substitute for Portland cement in the production of concrete) provide significant environmental benefits, including the reduction of GHG emissions, (3) the development of new applications of CCRs, which may hold even greater GHG benefits (for example, fly ash bricks and a process to use CO_2 emissions to produce cement), (4) new research by EPA and others indicating that the standard leach tests—*e.g.,* the Toxicity Characteristic Leaching Procedure (TCLP) that have generally been used may not accurately represent the performance of varying types of CCRs under variable field conditions, (5) new studies and research by academia and federal agencies on the use of CCRs, including studies on the performance of CCR-derived materials in concrete, road construction,[68] and agriculture,[69] and studies of the risks that may or may not be associated with the different uses of CCRs, including uses of unencapsulated CCRs, and (6) the continuing development of state "beneficial use" regulatory programs under state solid waste authorities.

Some of these changes confirm or strengthen EPA's Regulatory Determination in May 2000 (*e.g.,* the growth and maturation of state beneficial use programs and the growing recognition that the beneficial use of CCRs is a critical component in strategies to reduce GHG emissions); other developments raise critical questions regarding this determination (*e.g.,* the potentially changing composition of CCRs as a result of improved air pollution control and the new science on metals leaching). EPA solicits information and data on these developments and how the beneficial use of CCRs will be affected (*e.g.,* increased use of fly ash in cement and concrete).

However, on balance, after considering all of these issues and the information available to us at this time, EPA believes that the most appropriate approach toward beneficial use is to leave the May 2000 Regulatory Determination in place, as the Agency, other federal agencies, academia, and society more broadly investigate these critical questions and clarify the appropriate beneficial use of these materials. This section provides EPA's basis for leaving the Bevill exemption in place for these beneficial uses, although as discussed throughout this section, EPA is also soliciting comment on unencapsulated uses of CCRs and whether they should continue to be exempted as a beneficial use under the Bevill exemption.

EPA is proposing this approach in recognition that some uses of CCRs, such as encapsulated uses in concrete, and use as an ingredient in the manufacture of wallboard, provide benefits and raise minimal health or environmental concerns. That is, from information available to date, EPA believes that encapsulated uses of CCR, as is common in many consumer products, does not merit regulation. On the other hand, unencapsulated uses have raised concerns and merit closer attention. For example, the placement of unencapsulated CCRs on the land, such as in road embankments or in agricultural uses, presents a set of issues, which may pose similar concerns as those that are causing the Agency to propose to regulate CCRs destined for disposal. Still, the amounts and, in some cases, the manner in which they are used—*i.e.,* subject to engineering specifications and material requirements rather than landfilling techniques—are very different from land disposal. EPA also notes that stakeholders, such as Earthjustice have petitioned EPA to ban particular uses of CCR; for example, the placement of CCRs in direct contact with water bodies.

Due to such issues as the changing characteristics of CCRs, as a result of more widespread use of air pollution control technologies and the new information becoming available on the

[67] Draft Final Report; Non-groundwater Pathways, Human Health and Ecological Risk Analysis for Fossil Fuel Combustion Phase 2 (FFC2) and its appendices (A through J); available at *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/fsltech.htm.*

[68] *See http://www.epa.gov/osw/partnerships/c2p2/cases/index.htm.*

[69] *See http://www.epa.gov/osw/partnerships/c2p2/pubs/fgd-fs.pdf.*

leaching of metals from CCRs, we are considering approaches such as, better defining beneficial use or developing detailed guidance on the beneficial use of CCRs to supplement the regulations. The Agency solicits information and data on these and other approaches that EPA could take in identifying when uses of CCRs constitute a "beneficial use," and consequently will remain exempt.

Other alternative approaches—for example, to regulate the beneficial use of CCRs under the regulations that apply to "use constituting disposal," to prohibit unencapsulated uses outright, including CCRs used in direct contact with water matrices, including the seasonal high groundwater table, or to require front-end CCR and site characterization through the use of leach tests adapted for specific uses of CCR, prior to CCR management decisions—could address concerns that have been expressed over the land placement of CCRs. However, EPA is trying to balance concerns that proposing one or more of these alternatives might have the effect of stifling economic activities and innovation in areas that have potential for environmental benefits, while also providing adequate protection of human health and the environment.

At the same time, EPA recognizes that seven proven damage cases involving the large-scale placement, akin to disposal, of CCRs has occurred under the guise of "beneficial use"—the "beneficial" use being the filling up of old quarries or gravel pits, or the regrading of landscape with large quantities of CCRs. EPA did not consider this type of use as a "beneficial" use in its May 2000 Regulatory Determination, and does not consider this type of use to be covered by the exclusion. Therefore, today's proposed rule explicitly removes these types of uses from the category of beneficial use, such that they would be subject to the management standards that EPA finally promulgates. EPA also seeks information and data on whether it should take a similar approach in today's proposal to unencapsulated uses of CCRs, such as the placement of unencapsulated CCRs on the land—*e.g.,* agricultural uses. Alternatively, EPA is also soliciting comment on whether the Agency should promulgate standards allowing such uses, on a site-specific basis, based on a site specific risk assessment, taking into consideration, inter alia, the CCRs character and composition, their leaching potential under the range of conditions under which CCRs will be managed, and the context in which the CCRs will be applied, such as location, volume, rate of application, and proximity to water.

Before getting into a detailed discussion of the materials in question, EPA would reiterate that CCRs, when beneficially used will conserve resources, provide improved material properties, reduce GHG emissions, lessen the need for waste disposal units, and provide significant domestic economic benefits (as noted above in section XII). At the same time, EPA recognizes that there are important issues and uncertainties associated with specific uses of specific CCRs, that there has been considerable recent and ongoing research on these uses, and that the composition of CCRs are likely changing as a result of more aggressive air pollution controls. EPA is particularly concerned that we avoid the possibility of cross-media transfers stemming from CAA regulations requiring the removal of hazardous air pollutants (*e.g.,* arsenic, mercury, selenium) from utility stacks being released back into the soil and groundwater media through inappropriate "beneficial" uses.

EPA has received numerous comments on specific uses of CCRs, and we have been working with states to help them develop effective beneficial use programs (which apply to a wide range of secondary materials, not just CCRs). EPA, other federal agencies, and academia have conducted research on specific uses, and have provided guidance and best management practices on using CCRs in an environmentally sound manner in a range of applications. For example, EPA, working with the Federal Highway Administration (FHWA), DOE, the American Coal Ash Association (ACAA), and USWAG issued guidance in April 2005 on the appropriate use of coal ash in highway construction. EPA understands that the composition of CCRs, the nature of different CCR uses, and the specific environment in which CCRs are used, can affect the effectiveness and the environmentally sound use of particular projects. In today's proposal, EPA is suggesting that an appropriate balance can be met by (1) determining that the placement of CCRs in sand and gravel pits, as well as the use of large volumes of CCRs in restructuring landscapes to constitute disposal, rather than the beneficial use of CCRs, and at the same time (2) leaving in place its determination that the beneficial uses of CCRs—*e.g.,* those identified in the May 2000 Regulatory Determination as clarified in this notice—should not be prohibited from continuing. As described later in this section of today's notice, EPA solicits comment on whether an alternative approach is appropriate, particularly for unencapsulated uses of CCRs on the land.

1. Why is EPA not proposing to change the determination that CCRs that are beneficially used do not warrant federal regulation?

As an initial matter, we would note that for some of the beneficial uses, CCRs are a raw material used as an ingredient in a manufacturing process that have never been "discarded,[70]" and thus, would not be solid wastes under the existing hazardous waste rules. For example, synthetic gypsum is a product of the FGD process at coal-fired power plants. In this case, the utility designs and operates its air pollution control devices to produce an optimal product, including the oxidation of the FGD to produce synthetic gypsum. In this example, after its production, the utility treats FGD as a valuable input into a production process, *i.e.,* as a product, rather than as something that is intended to be discarded. Wallboard plants are sited in close proximity to power plants for access to raw material, with a considerable investment involved. Thus, FGD gypsum used for wallboard manufacture is a product rather than a waste or discarded material. This use and similar uses of CCRs that meet product specifications would not be affected by today's proposed rule in any case, regardless of the option taken.

With that said, today's proposed action would leave in place EPA's May 2000 Regulatory Determination that beneficially used CCRs do not warrant federal regulation under subtitle C or D of RCRA. As EPA stated in the May 2000 Regulatory Determination, "In the [Report to Congress], we were not able to identify damage cases associated with these types of beneficial uses, nor do we now believe that these uses of coal combustion wastes present a significant risk to human health and the environment. While some commenters disagreed with our findings, no data or other support for the commenters' position was provided, nor was any information provided to show risk or damage associated with agricultural use. Therefore, we conclude that none of the beneficial uses of coal combustion wastes listed above pose risks of concern." (*See* 65 FR 32230.) Since that time, EPA is not aware of data or other information to indicate that existing

[70] In order for EPA to regulate a material under RCRA, the material must be a solid waste, which the statute defines as materials that have been discarded. *See* Section 1004(27) of RCRA for definition of solid waste.

efforts of states, EPA and other federal agencies are not adequate to address environmental issues associated with the beneficial uses of CCRs, that were originally identified in the Regulatory Determination. Therefore, at this time, EPA is not proposing to reverse that determination. Specifically: (1) EPA believes today's proposal will ensure that inappropriate beneficial use situations, like the Gambrills, MD site, will be regulated as disposal; (2) many states are developing effective beneficial use programs which, in many cases, allow the use of CCRs as long as they are demonstrated to be non-hazardous materials, and (3) EPA does not wish to inhibit or eliminate the significant and measurable environmental and economic benefits derived from the use of this valuable material without a demonstration of an environmental or health threat.

EPA also wants to make clear that wastes that consist of or contain these Bevill-exempt beneficially used materials, including demolition debris from beneficially used CCRs in wallboard or concrete that were generated because the products have reached the end of their useful lives—would also not be listed as a special waste subject to subtitle C of RCRA, from the point of their generation to their ultimate disposal.

In summary, EPA continues to believe that the beneficial use of CCRs, when performed properly and in an environmentally sound manner, is the environmentally preferable outcome for CCRs and, therefore, is concerned about regulatory decisions that would limit beneficial uses, including research on beneficial uses. Thus, EPA is not proposing to modify the existing Bevill exemption for CCRs (sometimes referred to as CCPs when beneficially used), and instead is proposing to leave the current determination in place. However, EPA recognizes that there is a disparity in the quality of state programs dealing with beneficial uses, uncertainty relative to the future characteristics of CCRs and, therefore, uncertainty concerning the risks associated with some beneficial uses. At the same time, EPA recognizes the potential environmental benefits with regard to the uses of CCRs. For these reasons, EPA is requesting information and data on the appropriate means of characterizing beneficial uses that are both protective of human health and the environment and provide benefits. EPA is also requesting information and data demonstrating where the federal and state programs are or have been inadequate in being environmentally protective and, conversely, where states have, or are developing, increasingly effective beneficial use programs.

As previously discussed, and discussed in section VI, some stakeholders have commented that EPA should not regulate CCRs when disposed of in landfills or surface impoundments as a hazardous waste, because such an approach would stigmatize the beneficial use of CCRs, and these uses would disappear. Although it remains unclear whether any stigmatic effect from regulating CCRs destined for disposal as hazardous waste would decrease the beneficial use of CCRs, and irrespective of whether EPA ultimately concludes to promulgate regulations under RCRA subtitles C or D, EPA is convinced that regulating the beneficial use of CCRs under RCRA subtitle C as hazardous waste would be unnecessary, in light of the potential risks associated with these uses. For example, use of fly ash as a replacement for Portland cement is one of the most environmentally beneficial uses of CCRs (as discussed below), yet regulating this beneficial use under RCRA subtitle C requirements would substantially increase the cost and regulatory difficulties of using this material, without providing any corresponding risk reduction. Regulating the use of coal ash as a cement ingredient under RCRA subtitle C would subject the coal ash to full hazardous waste requirements up to the point that it is made into concrete, including requirements for generators, manifesting for transportation, and permits for storage. In addition, ready-mix operators would be subject to the land disposal restrictions and other requirements, as use of the concrete would constitute disposal if placed on the land. EPA instead is proposing an approach that would allow beneficial uses to continue, under state controls, EPA guidance, and current industrial standards and practices. Where specific problems are identified, EPA believes they can be safely addressed, but we do not believe that an approach that eliminates a wide range of uses that would add considerably to the costs of the rule, and that would disrupt and potentially close ongoing businesses legitimately using CCRs is justified, on the strength of the existing evidence.

EPA's May 2000 Regulatory Determination not to regulate various beneficial uses under the hazardous waste requirements, and today's proposal to leave that determination in place, does not conflict with EPA's view that certain beneficial uses, *e.g.,* use in road construction or agriculture, should be conducted with care, according to appropriate management practices, and with appropriate characterization of the material and the site where the materials would be placed. In this respect, CCRs are similar to other materials used in this manner—including raw materials derived from quarried aggregates, secondary materials from other industrial processes, and materials derived from natural ores. Rather, EPA concludes that, based on our knowledge of how CCRs are used, that potential risks of these uses do not warrant federal regulation, but can be addressed, if necessary, in other ways, as discussed previously, such as the State of Wisconsin has an extensive beneficial use program that supports the use of CCRs in a variety of circumstances, including in road base construction and agriculture uses, provided certain criteria are met. Similarly, EPA is working with the U.S. Department of Agriculture to develop guidance on the use of FGD gypsum in agriculture.

2. What constitutes beneficial use?

As discussed previously, EPA is not proposing to change the regulatory status of those CCRs that are beneficially used. However, because EPA is proposing to draw a distinction between CCRs that are destined for disposal and those that are beneficially used, we believe it is necessary and appropriate to distinguish between beneficial use and operations that would constitute disposal operations—such as large volumes of CCRs that are used in sand and gravel pits or for restructuring the landscape. EPA believes the following criteria can be used to define legitimate beneficial uses appropriately, and are consistent with EPA's approach in the May 2000 Regulatory Determination, although such criteria were not specifically identified at that time:

◦ The material used must provide a functional benefit. For example, CCRs in concrete increase the durability of concrete—and are more effective in combating degradation from salt water; synthetic gypsum serves exactly the same function in wallboard as gypsum from ore, and meets all commercial specifications; CCRs as a soil amendment adjusts the pH of soil to promote plant growth.

◦ The material substitutes for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices, such as extraction. For example, the use of FGD gypsum in the manufacture of wallboard (drywall) decreases the need to mine natural gypsum, thereby conserving the natural resource and conserving energy that otherwise would be needed to mine natural gypsum; the use of fly ash in lieu of portland cement reduces the need for cement. CCRs used in road bed replace quarried aggregate or other industrial materials. These CCRs substitute for another ingredient in an industrial or commercial product.

○ Where relevant product specifications or regulatory standards are available, the materials meet those specifications, and where such specifications or standards have not been established, they are not being used in excess quantities. Typically, when CCRs are used as a commercial product, the amount of CCRs used is controlled by product specifications, or the demands of the user. Fly ash used as a stabilized base course in highway construction is part of many engineering considerations, such as the ASTM C 593 test for compaction, the ASTM D 560 freezing and thawing test, and a seven day compressive strength above 2760 (400 psi). If excessive volumes of CCRs are used—*i.e.,* greater than were necessary for a specific project,—that could be grounds for a determination that the use was subject to regulations for disposal.

○ In the case of agricultural uses, CCRs would be expected to meet appropriate standards, constituent levels, prescribed total loads, application rates, etc. EPA has developed specific standards governing agricultural application of biosolids. While the management scenarios differ between biosludge application and the use of CCRs as soil amendments, EPA would consider application of CCRs for agriculture uses not to be a legitimate beneficial use if they occurred at constituent levels or loading rates greater than EPA's biosolids regulations allow.[71] EPA also recognizes that the characteristics of CCRs are such that total concentrations of metals, as biosolids are assessed, may not be the most appropriate standard, as CCRs have been shown to leach metals with significant variability.

EPA is proposing that these criteria be included in the regulations as part of the definition of beneficial use. EPA requests comment on these criteria, as well as suggestions for other criteria that may need to be included to ensure that legitimate beneficial uses can be identified and enforcement action can be taken against inappropriate uses.

Each of the uses identified in the May 2000 Regulatory Determination, CCRs can and have been utilized in a manner that is beneficial. The discussion that follows provides a brief summary of how certain of the beneficial uses meet the various criteria. EPA solicits comment on the need to provide a formal listing of all beneficial uses. To this end, EPA solicits comment on whether additional uses of CCRs have been established since the May 2000 Regulatory Determination that have not been discussed elsewhere in today's preamble should be regarded as beneficial. Of particular concern in this regard are reports that CCRs are being used in producing counter tops, bowling balls, and in the production of makeup. The Agency solicits comment on whether use of CCRs in consumer products of this kind can be safely undertaken. The Agency further solicits comments for any new uses of CCR, as well as the information and data that supports that it is beneficially used in an environmentally sound manner. The concern with such an alternative is that new and innovative uses that are not on the list would be subject to disposal regulations, until EPA revised its rule.

In the uses where the CCR is encapsulated in the product, such as cement, concrete, brick and concrete products, wallboard, and roofing materials—the CCRs provide a functional benefit—that is, the CCRs provide a cementitious or structural function, the CCRs substitute for cement, gypsum, and aggregate and thus save resources that would otherwise need to be mined and processed, and the CCRs are subject to product specifications, such as ASTM standards. Some of the uses, such as CCRs in paints and plastics not only provide benefits, but EPA generally does not consider materials used in these ways to be waste—that is, they have not been discarded. Use of CCRs in highway projects is a significant practice covering road bed and embankments. CCRs used according to FHA/DOT standards provide an important function in road building, replacing material that would otherwise need to be obtained, such as aggregate or clay. In many cases, the CCRs can lead to better road performance. For snow and ice controls, the beneficial use is limited to boiler slag and bottom ash, which replaces fine aggregate that would otherwise need to be used to prevent skidding, and amounts used are in line with the materials they replace.[72]

3. Disposal of CCRs in Sand and Gravel Pits and Large Scale Fill Operations Is Not Considered a Beneficial Use

As indicated earlier, EPA has identified several proven damage cases associated with the placement of CCRs in sand and gravel pits. There has also been significant community concern with large-scale fill operations. Because of the damage cases and the concern that sand and gravel pits and large scale fill operations are essentially landfills under a different name, EPA is clarifying and, thus, proposing to define the placement of CCRs in sand and gravel pits and large scale fill projects as land disposal that would be subject to either the proposed RCRA subtitle C or D regulations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills.

However, EPA recognizes that we need to define or provide guidance on the meaning of "a large scale fill operation." EPA solicits comments on appropriate criteria to distinguish between legitimate beneficial uses and inappropriate operations, such as, for example, a comparison to features associated with relatively small landfills used by the utility industry, and whether characteristics of the materials would allow their safe use for a particular application in a particular setting (*i.e.,* characterize both the materials for the presence of leachable metals and the area where the materials will be placed).

4. Issues Associated With Unencapsulated Beneficial Uses

Since the May 2000 Regulatory Determination, the major issues associated with the placement of CCRs on the land for beneficial use has involved the Gambrills, MD site which involves a sand and gravel pit and the Battlefield golf course, which was a large scale fill operation. These are the types of operations that EPA is proposing would be subject to any disposal regulations proposed in today's rule. However, because the Gambrills and Battlefield sites involved the unencapsulated placement of CCRs on the land, it raises questions regarding the beneficial use of unencapsulated uses of CCRs; accordingly, in this section, the Agency presents information on the issues on which it is specifically soliciting comment.

First, we identify the array of environmental issues associated with unencapsulated uses. CCRs can leach toxic metals at levels of concern, so depending on the characteristics of the CCR, the amount of material placed, how it is placed, and the site conditions, there is a potential for environmental concern.

• The importance of characterizing CCRs prior to their utilization is that CCRs from certain facilities may be acceptable under particular beneficial

[71] *See* 40 CFR part 503.

[72] According to the ACAA survey, 80% of boiler slag—a vitreous material often used as an abrasive—is reused, although industry has reported that the demand for boiler slag products is high, and virtually all of the slag is currently used.

use scenarios, while the same material type from a different facility or from the same facility, but generated under different operating conditions (*e.g.,* different air pollution controls or configurations) may not be acceptable for the same management scenario. Changes in air pollution controls will result in fly ash and other CCRs presenting new contaminant issues (*e.g.,* hexavalent chromium from post-NOx controls). Additionally, as described in section I. F. 2, there is significant variability in total metals content and leach characteristics.

- The amount of material placed can significantly impact whether placement of unencapsulated CCRs causes environmental risks. There are great differences between the amount of material disposed of in a landfill and in beneficial use settings. For example, a stabilized fly ash base course for roadway construction may be on the order of 6 to 12 inches thick under the road where it is used—these features differ considerably from the landfill and sand and gravel pit situations where hundreds of thousands to millions of tons of CCRs are disposed of and for which damage cases are documented.
- Unencapsulated fly ash used for structural fill is moistened and compacted in layers, and placed on a drainage layer. By moistening and compacting the fly ash in layers, the hydraulic conductivity can be greatly reduced, sometimes achieving levels similar to liner systems. This limits the transport of water through the ash and thus acts to protect groundwater. The drainage layer prevents capillary effects and thus also limits the amount of water that remains in contact with the fly ash. Although EPA is not aware of the use of organosilanes for beneficial use operations in the U.S., if mixed with fly ash, it is reported to be able to essentially render the fly ash impermeable to water, and thus there may be emerging placement techniques that can also greatly influence the environmental assessment.
- Site conditions are important factors. Hydraulic conductivity of the subsurface, the rainfall in the area, the depth to groundwater, and other factors (*e.g.,* changes in characteristics due to the addition of advanced air pollution controls) are important considerations in whether a specific beneficial use will remain protective of the environment.

Second, EPA notes the work and research being done by states, federal agencies, and academics to assess, provide guidance on, or regulate to address the environmental issues that may be associated with beneficial use. In addition to the recent EPA research on constituent leaching from CCRs described earlier in the preamble, a few highlights include:

- Many states have beneficial use programs. The ASTSWMO 2006 Beneficial Use Survey Report states: "A total of 34 of the 40 reporting States, or 85 percent, indicated they had either formal or informal decision-making processes or beneficial use programs relating to the use of solid wastes." [73] (*http://www.astswmo.org/files/publications/solidwaste/2007BUSurveyReport11–30–07.pdf*) For example, Wisconsin's Department of Natural Resources has developed a regulation (NR 538 Wis. Adm. Code), which includes a five-category system to allow for the beneficial use of industrial by-products, including coal ash. The state has approved CCRs in a full range of uses, including road construction and agricultural uses.
- EPA and USDA are conducting a multi-year study on the use of FGD gypsum in agriculture. The results of that study should be available in late 2012.
- EPA developed an easy to use risk model for assessing the use of recycled industrial materials in highways. This model is shared with states to facilitate assessments to determine if such beneficial use projects will be environmentally protective.[74]
- There is also considerable study and research by states and academic institutions, which EPA views as valuable in not only guiding the parties to appropriate uses, but also in informing EPA. A few examples are:
  - Li L, Benson CH, Edil TB, Hatipoglu B. Groundwater impacts from coal ash in highways. Waste and Management Resources 2006;159(WR4):151–63.
  - Friend M, Bloom P, Halbach T, Grosenheider K, Johnson M. Screening tool for using waste materials in paving projects (STUWMPP). Office of Research Services, Minnesota Dept. of Transportation, Minnesota; 2004. Report nr MN/RC–2005–03.
  - Sauer JJ, Benson CH, Edil TB. Metals leaching from highway test sections constructed with industrial byproducts. University of Wisconsin—Madison, Madison, WI: Geo Engineering, Department of Civil and Environmental Engineering; 2005 December 27, Geo Engineering Report No. 05–21.

Overall, federal agencies, states, and others are doing a great amount of work to promote environmentally sound beneficial use practices, to advance our understanding, and to consider emerging science and practices. Furthermore, the beneficial use of CCRs is a world wide activity, so there is also considerable work and effort from around the globe. In Europe, nearly all CCRs are beneficially used, and when used are considered to be products rather than wastes. Sweden, for example, actively supports the use of CCRs in road construction, and has conducted long-term tests of its use in this manner.

While recognizing the many beneficial use opportunities for CCRs, EPA believes it is imperative to gather a full range of views on the issue of unencapsulated uses in order to ensure the protection of human health and the environment. EPA is fully prepared to reconsider our proposed approach for these uses if comments provide information and data to demonstrate that it is inappropriate. For example, previous risk analyses do not address many of the use applications currently being implemented, and have not addressed the changes to CCR composition with more advanced air pollution control methods and improved leachate characterization. In addition, some scientific literature indicates that the uncontrolled (*i.e.,* excessive) application of CCRs can lead to the potentially toxic accumulation of metals (*e.g.,* in agricultural applications [75] and as fill material [76]). Thus, while EPA does not want to negatively impact the legitimate beneficial use of CCRs unnecessarily, we are also aware of the need to fully consider the risks, management practices, state controls, research, and any other pertinent information. Thus, to help EPA determine whether to revise

[73] Part of EPA's efforts with the states is to support the development of a national database on state beneficial use determinations. Information on the beneficial use determination database can be found on the Northeast Waste Management Officials' Association (NEWMOA) Web site at *http://www.newmoa.org/solidwaste/bud.cfm.* This database helps states share information on beneficial use decisions providing for more consistent and informed decisions.

[74] *See* a Final Report titled, "Use of EPA's Industrial Waste Management Evaluation Model (IWEM) to Support Beneficial Use Determinations" at *http://www.epa.gov/partnerships/c2p2/pubs/iwem-report.pdf* and the Industrial Waste Management Evaluation Model (IWEM) at *http://www.epa.gov/osw/nonhaz/industrial/tools/iwem.*

[75] *See,* for example, "Effects of coal fly ash amended soils on trace element uptake in plant," S.S. Brake, R.R. Jensen, and J. M. Mattox, Environmental Geology, November 7, 2003 *available at http://www.springerlink.com/content/3c5gaq2qrkr5unvp/fulltext.pdf.*

[76] *See* information regarding the Town of Pines Groundwater Plume at *http://www.epa.gov/region5superfund/npl/sas_sites/INN000508071.htm. Also see* additional information for this site at *http://www.epa.gov/region5/sites/pines/#updates.*

its approach and regulate, for example, unencapsulated uses of CCRs on the land, we solicit comments on whether to regulate, and if so, the most appropriate regulatory approach to be taken. For example, EPA might consider a prohibition on these uses, except where, as part of a case-by-case, or material-by-material petition process where appropriate characterization of the material is used (including taking into account the pH to which the material will be exposed) and a risk assessment, approved by a regulatory Agency, shows that the risks were within acceptable ranges.[77] Moreover, if regulating these uses under the RCRA hazardous waste authority is deemed warranted, the risk assessment would have to be approved, through a notice-and-comment process, by EPA or an authorized state. EPA expects that the risk assessment would be based on actual leach data from the material. (*See* request for comment below on material characterization.)

In reaching its decision on whether to regulate unencapsulated uses, EPA would be interested in comments and data on the following:

- We would like comment on whether persons should be required to use a leaching assessment tool in combination with the Draft SW–846 leaching test methods described in Section I. F. 2 and other tools (*e.g.,* USEPA's *Industrial Waste Management Evaluation Model* (IWEM)) to aid prospective beneficial users in calculating potential release rates over a specified period of time for a range of management scenarios, including use in engineering and commercial applications using probabilistic assessment modeling.
- As discussed previously, EPA is working with USDA to study agricultural use of FGD gypsum to provide further knowledge in this area. The Agency is interested in comments relating to the focus of these assessments, the use of historical data, the impact of pH on leaching potential of metals, the scope of management scenarios, the variable and changing nature of CCRs, and variable site conditions. Commenters interested in the EPA/USDA effort should consider the characteristics of FGD gypsum (*see http://www.epa.gov/epawaste/partnerships/c2p2/pubs/fgdgyp.pdf*) and information on the current study (*see http://www.epa.gov/epawaste/partnerships/c2p2/pubs/fgd-fs.pdf*).
- If EPA determines that regulations are needed, should EPA consider removing the Bevill exemption for such unencapsulated uses and regulate these under RCRA subtitle C or should EPA develop regulations under RCRA subtitle D?
- If materials characterization is required, what type of characterization is most appropriate? If the CCRs exceed the toxicity characteristic at pH levels different from the TCLP, should they be excluded from beneficial use? When are total levels relevant? EPA solicits information and data on the extent to which states request and evaluate CCR characterization data prior to the use of unencapsulated CCRs (keeping in mind that EPA ORD studies generally show that measurement of total concentrations for metals do not correlate well with metal leachate concentrations).
- If regulations are developed, should they cover specific practices, for example, restricting fill operations to those that moisten and compact fly ash in layers to attain 95% of the standard Proctor maximum dry density value and provide a drainage layer? Are such construction practices largely followed now?
- Historically, EPA has proposed or imposed conditions on other types of hazardous wastes destined for land placement (*e.g.,* maximum application rates and risk-based concentration limits for cement kiln dust used as a liming agent in agricultural applications (*see* 64 FR 45639; August 20, 1999); maximum allowable total concentrations for non-nutritive and toxic metals in zinc fertilizers produced from recycled hazardous secondary materials (*see* 67 FR 48393; July 24, 2002). Comments are solicited as to whether EPA should establish standards or rely on implementing states to impose CCR-/site-specific limits based on front-end characterization that ensures individual beneficial uses remain protective.
- Whether to exclude from beneficial use unencapsulated uses in direct contact with water bodies (including the seasonal high groundwater table)?

E. Placement of CCRs in Minefilling Operations

In today's proposal, EPA is not addressing its Regulatory Determination on minefilling, and instead will work with the OSM to develop effective federal regulations to ensure that the placement of coal combustion residuals in minefill operations is adequately controlled. In doing so, EPA and OSM will consider the recommendations of the National Research Council (NRC), which, at the direction of Congress, studied the health, safety, and environmental risks associated with the placement of CCRs in active and abandoned coal mines in all major U.S. coal basins. The NRC published its findings on March 1, 2006, in a report entitled "Managing Coal Combustion Residues (CCRs) in Mines," which is available at *http://books.nap.edu/openbook.php?isbn=0309100496.*

The report concluded that the "placement of CCRs in mines as part of coal mine reclamation may be an appropriate option for the disposal of this material. In such situations, however, an integrated process of CCR characterization, site characterization, management and engineering design of placement activities, and design and implementation of monitoring is required to reduce the risk of contamination moving from the mine site to the ambient environment." The NRC report recommended that enforceable federal standards be established for the disposal of CCRs in minefills to ensure that states have specific authority and that states implement adequate safeguards. The NRC Committee on Mine Placement of Coal Combustion Wastes also stated that OSM and its SMCRA state partners should take the lead in developing new national standards for CCR use in mines because the framework is in place to deal with mine-related issues. Consistent with the recommendations of the National Academy of Sciences, EPA anticipates that the U.S. Department of the Interior (DOI) will take the lead in developing these regulations. EPA will work closely with DOI throughout that process. Therefore, the Agency is not addressing minefilling operations in this proposed rule.

F. EPA Is Not Proposing To Revise the Bevill Determination for CCRs Generated by Non-Utilities

In this notice, EPA is not proposing to revise the Bevill exclusion for CCRs generated at facilities that are not part of the electric power sector and which use coal as the fuel in non-utility boilers, such as manufacturing facilities, universities, and hospitals. The Agency lacks sufficient information at this time to determine an appropriate course of action for the wastes from these facilities.

Industries that primarily burn coal to generate power for their own purposes (*i.e.,* non-utilities), also known as combined heat and power (CHP) plants, are primarily engaged in business activities, such as agriculture, mining, manufacturing, transportation, and education. The electricity that they generate is mainly for their own use, but

[77] As part of the petition application, the petitioner would also need to demonstrate that the CCRs are being beneficially used.

any excess may be sold in the wholesale market.[78] According to the Energy Information Administration (EIA), CHPs produced 2.7% of the total electricity generated from coal combustion in 2007 [79] and burned 2.3% of the total coal consumed for electricity generation (24 million tons) [80] at 2,967 facilities.[81] EPA estimates that CHPs generate approximately 3 million tons of CCRs annually or an average of just over 1,000 tons per facility. This is in comparison to electric utilities, which generated 136 million tons of CCRs in 2008, or an average of approximately 275,000 tons per facility. In addition, these manufacturing facilities generate other types of waste, many of which are generated in much larger quantities than CCRs, and thus, they are likely to be mixed or co-managed together. As a result, the composition of any co-managed waste might be fundamentally different from the CCRs that are generated by electric utilities. Presently, EPA lacks critical data from these facilities sufficient to address key Bevill criteria such as current management practices, damage cases, risks, and waste characterization. Thus, EPA solicits information and data on CCRs that are generated by these other industries, such as volumes generated, characteristics of the CCRs, whether they are co-managed with other wastes generated by the industry, as well as other such information. In addition, EPA does not currently have enough information on non-utilities to determine whether a regulatory flexibility analysis would be required under the Regulatory Flexibility Act, nor to conduct one if it is necessary. Therefore, the Agency has decided not to assess these operations in today's proposal, and will instead focus on the nearly 98% of CCRs that are generated at electric utilities.

V. Co-Proposed Listing of CCRs as a Special Waste Under RCRA Subtitle C and Special Requirements for Disposal of CCRs Generated by Electric Utilities

One of the alternatives in today's co-proposal is to add a new category of wastes that would be subject to regulation under subtitle C of RCRA, by adding to 40 CFR part 261, Subpart F—Special Wastes Subject to Subtitle C Regulations for CCRs destined for disposal. Under this alternative, the Agency further proposes to list CCRs destined for disposal as a special waste and CCRs would then be subject to regulation under 40 CFR parts 260 through 268 and 270 to 279 and 124, and subject to the notification requirements of section 3010 of RCRA. This listing would apply to all CCRs destined for disposal. This section provides EPA's basis for regulating CCRs under subtitle C of RCRA when disposed. As described in this preamble, the proposed listing would not apply to CCRs that are beneficially used (*see* section IV), CCRs that are part of a state or federally required cleanup that commenced prior to the effective date of the final rule (*see* section VI), or CCRs generated by facilities outside the electric power sector (*see* section IV).

A. What is the basis for listing CCRs as a special waste?

Many of the underlying facts on which EPA would rely on to support its proposed special waste listing have been discussed in the previous sections, which lay out reasons why the Agency may decide to reverse the Bevill Regulatory Determination and exemption. Rather than repeat that discussion here, EPA simply references the discussion in the earlier sections. In addition, EPA would be relying on the various risk assessments conducted on CCRs to provide significant support for a listing determination. EPA's risk assessment work includes four analyses: (1) U.S. EPA 1998, "Draft Final Report: Non-groundwater Pathways, Human Health and Ecological Risk Analysis for Fossil Fuel Combustion Phase 2 (FFC2)" (June 5, 1998) referred to hereafter as the 1998 Non-groundwater risk assessment (available in docket # F–1999–FF2P–FFFFF in the RCRA Information Center, and on the EPA Web site at *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ngwrsk1.pdf*); (2) preliminary groundwater and ecological risk screening of selected constituents in U.S. EPA 2002, "Constituent Screening for Coal Combustion Wastes," (contractor deliverable dated October 2002, available in docket EPA–HQ–RCRA–2006–0796 as Document # EPA–HQ–RCRA–2006–0796–0470); referred to hereafter as the 2002 screening analysis; (3) U.S. EPA 2010a, "Human and Ecological Risk Assessment of Coal Combustion Wastes" (April 2010) available in the docket for this proposed rule, and referred to hereafter as the 2010 risk assessment; and (4) U.S. EPA 2010b, "Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills—DRAFT" available in the docket for this proposed rule. As explained below, the 2010 risk assessment correlates closely with the listing criteria in EPA's regulations.

1. Criteria for Listing CCRs as a Special Waste and Background on 2010 Risk Assessment

In making listing determinations under subtitle C of RCRA, the Agency considers the listing criteria set out in 40 CFR 261.11. EPA considered these same criteria in making the proposed special waste listing decision.

The criteria provided in 40 CFR 261.11(a)(3) include eleven factors that EPA must consider in determining whether the waste poses a "substantial present or potential hazard to human health and the environment when improperly treated, stored, transported or disposed of or otherwise managed." Nine of these factors, as described generally below, are incorporated or are considered in EPA's risk assessment for the waste streams of concern:

◦ Toxicity (Sec. 261.11(a)(3)(i)) is considered in developing the health benchmarks used in the risk assessment modeling.

◦ Constituent concentrations (Sec. 261.11(a)(3)(ii)) and the quantities of waste generated (Sec. 261.11(a)(3)(viii)) are combined in the calculation of the levels of the CCR constituents that pose a hazard.

◦ Potential of the hazardous constituents and any degradation products to migrate, persist, degrade, and bioaccumulate (sections 261(a)(3)(iii), 261.11(a)(3)(iv), 261.11(a)(3)(v), and 261.11(a)(3)(vi)) are all considered in the design of the fate and transport models used to determine the concentration of the contaminants to which individuals are exposed.

◦ Two of the factors, plausible mismanagement and the regulatory actions taken by other governmental entities based on the damage caused by the constituents ((§§ 261.11(a)(3)(vii) and 261.11(a)(3)(x)), were used in establishing the waste management scenario(s) modeled in the risk assessment.

One of the remaining factors of the eleven listed in 261.11(a)(3) is consideration of damage cases (§ 261.11(a)(3)(ix)); these are discussed in section II. C. The final factor allows EPA to consider other factors as appropriate (§ 261.11(a)(3)(xi)).

As discussed earlier, EPA conducted analyses of the risks posed by CCRs and determined (subject to consideration of public comment) that it would meet the criteria for listing set forth in 40 CFR 261.11(a)(3). The criteria for listing determinations found at 40 CFR part

[78] Energy Information Administration (*http://www.eia.doe.gov/cneaf/electricity/page/prim2/toc2.html#non*).

[79] *http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfile1_1.pdf.*

[80] *http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfile4_1.pdf.*

[81] *http://www.eia.doe.gov/cneaf/electricity/epa/epaxlfile2_3.pdf.*

261.11 require the Administrator to list a solid waste as a hazardous waste (and thus subject to subtitle C regulation) upon determining that the solid waste meets one of three criteria in 40 CFR 261.11(a)(1)-(3). As just noted, the criteria considered by EPA in determining that listing is warranted pursuant to 40 CFR 261.11(a)(3) are:

- Whether the waste contains any of the toxic constituents listed in Appendix VIII of 40 CFR part 261 (Hazardous Waste Constituents) and, after considering the following factors, the Administrator concludes that the waste is capable of posing a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of, or otherwise managed:

(i) The nature of the toxicity presented by the constituent.

(ii) The concentration of the constituent in the waste.

(iii) The potential of the constituent or any toxic degradation product of the constituent to migrate from the waste into the environment under the types of improper management considered in paragraph (vii).

(iv) The persistence of the constituent or any toxic degradation product of the constituent.

(v) The potential for the constituent or any toxic degradation product of the constituent to degrade into non-harmful constituents and the rate of degradation.

(vi) The degree to which the constituent or any degradation product of the constituent bioaccumulates in ecosystems.

(vii) The plausible types of improper management to which the waste could be subjected.

(viii) The quantities of the waste generated at individual generation sites or on a regional or national basis.

(ix) The nature and severity of the human health and environmental damage that has occurred as a result of the improper management of wastes containing the constituent.

(x) Action taken by other governmental agencies or regulatory programs based on the health or environmental hazard posed by the waste or waste constituent.

(xi) Such other factors as may be appropriate.

In 1994, EPA published a policy statement regarding how the Agency uses human health and environmental risk estimates in making listing decisions, given the uncertainty that can co-exist with risk estimates. Specifically:

"* * * the Agency's listing determination policy utilizes a "weight of evidence" approach in which risk is a key factor * * * however, risk levels themselves do not necessarily represent the sole basis for a listing. There can be uncertainty in calculated risk values and so other factors are used in conjunction with risk in making a listing decision. * * *. EPA's current listing determination procedure * * * uses as an initial cancer risk "level of concern" a calculated risk level of 1×10^{-5} (one in one hundred thousand) * * * (1) Waste streams for which the calculated high-end individual cancer-risk level is 1×10^{-5} or higher generally are considered candidates for a list decision * * * (2) Waste streams for which these risks are calculated to be 1×10^{-4} or higher * * * generally will be considered to pose a substantial present or potential hazard to human health and the environment and generally will be listed as hazardous waste. Such waste streams fall into a category presumptively assumed to present sufficient risk to require their listing as hazardous waste. However, even for these waste streams there can in some cases be factors which could mitigate the high hazard presumption. These additional factors * * * will also be considered by the Agency in making a final determination. (3) Waste streams for which the calculated high-end individual cancer-risk level is lower than 1×10^{-5} generally are considered initial candidates for a no-list decision. (4) Waste streams for which these risks are calculated to be 1×10^{-6} or lower, and lower than 1.0 HQs or EQs for any non-carcinogens, generally will be considered not to pose a substantial present or potential hazard to human health and the environment and generally will not be listed as hazardous waste. Such waste streams fall into a category presumptively assumed not to pose sufficient risk as to require their listing as hazardous waste. However, even for these waste streams, in some cases, there can be factors that could mitigate the low hazard presumption. These also will be considered by the Agency in making a final determination. (5) Waste streams where the calculated high-end individual cancer-risk level is between 1×10^{-4} and 1×10^{-6} fall in the category for which there is a presumption of candidacy for either listing (risk $> 10^{-5}$) or no listing (risk $< 10^{-5}$). However, this presumption is not as strong as when risks are outside this range. Therefore, listing determinations for waste streams would always involve assessment of the additional factors discussed below. * * * Additional factors. b. The following factors will be considered in making listing determinations, particularly for wastes falling into the risk range between 1×10^{-4} and 1×10^{-6}. (1) Certainty of waste characterization; (2) Certainty in risk assessment methodology; (3) Coverage by other regulatory programs; (4) Waste volume; (5) Evidence of co-occurrence; (6) Damage cases showing actual impact to human health or the environment; (7) Presence of toxicant(s) of unknown or unquantifiable risk." *See* 59 FR 66075–66077, December 22, 1994.

B. Background on EPA's 2010 Risk Assessment

1. Human Health Risks

Individuals can be exposed to the constituents of concern found in CCRs through a number of exposure routes. Potential contaminant releases from landfills and surface impoundments include: leaching to ground water; overland transport from erosion and runoff; and air emissions. The potential of human exposure from any one of these exposure pathways for a particular chemical is dependent on the physical and chemical characteristics of the chemical, the properties of the waste stream, and the environmental setting. EPA has conducted a peer-reviewed risk assessment of potential human health risks from CCR constituents leaching to groundwater that subsequently migrate either to a nearby drinking water well, or to nearby surface water, and is ingested as drinking water or through fish consumption (U.S. EPA 2010a). EPA has also performed preliminary analyses of human health effects from CCR constituents that have eroded or have run off from CCR waste management units (U.S. EPA 2002), and of human health effects from breathing windblown particulate matter from CCR landfill disposal operations (the 1998 risk assessment and U.S. EPA 2010b).

Longstanding EPA policy is for EPA risk assessments to include a characterization of the risks at two points on a distribution (*i.e.,* range) of risk estimates: a central tendency estimate that represents conditions likely to be encountered in a typical exposure situation, and a high end estimate that represents conditions likely to be encountered by individuals with higher exposures (U.S. EPA 1995).[82] Examples of factors that would influence a nearby resident's exposure are the residence's distance from a CCR waste management unit, and an individual's behavior or activity patterns. In the 2010 risk assessment, the high end risk estimates are the 90th percentile estimates from a probabilistic analysis.

The comparisons that EPA used in this rule to judge whether either a high end or central tendency estimated risk

[82] *Guidance for Risk Characterization,* U.S. Environmental Protection Agency, 1995; accessible at *http://www.epa.gov/OSA/spc/pdfs/rcguide.pdf,* which states that "For the Agency's purposes, high end risk descriptors are plausible estimates of the individual risk for those persons at the upper end of the risk distribution," or conceptually, individuals with "exposure above about the 90th percentile of the population distribution". As suggested in the *Guidance,* we also provide 50th percentile results as the central tendency estimate of that risk distribution.

is of concern are the risk criteria discussed in the 1995 policy. As noted under that policy, for an individual's cancer risk, the risk criteria are in the range of 1×10^{-6}, or one in one million "excess" (above and beyond pre-existing risk) probability of developing cancer during a lifetime, to 1×10^{-4} (one in ten thousand),[83] with 1×10^{-5} (one in one hundred thousand) being the "point of departure" for listing a waste and subjecting it to regulation under subtitle C of RCRA.[84] For human non-cancer hazard, the risk criterion is an estimated exposure above the level at which no adverse health effects would be expected to occur (expressed as a ratio of the estimated exposure to the exposure at which it is likely that there would be no adverse health effects; this ratio is also called a hazard quotient (HQ), and a risk of concern equates to a HQ greater than one, or, in certain cases of drinking water exposure, water concentrations above the MCL established under the Safe Drinking Water Act.

The exposure pathways for humans that EPA has evaluated for CCR landfills and surface impoundments are nearby residents' groundwater ingestion and air inhalation, and fish consumption by recreational fishers.

2. Ecological Risks

For ecological non-cancer hazards that are modeled, the risk criterion is a hazard quotient that represents impacts on individual organisms, with a risk of concern being an estimated HQ greater than one. In some instances, EPA also considered documented evidence of ecological harm, such as field studies published in peer-reviewed scientific literature. Such evidence is often sufficient to determine adverse ecological effects in lieu of or in addition to modeling potential ecological risks.

Two types of exposures can occur for ecological receptors: exposures in which ecological receptors inhabit a waste management unit directly, and exposures in which CCRs or its chemical constituents migrate, or move, out of the waste management unit and contaminate nearby soil, surface water, or sediment.

C. Consideration of Individual Listing Criteria

CCRs contain the following Appendix VIII toxic constituents: antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and thallium. These Appendix VIII constituents are frequently found in CCRs, as has been reported by the U.S. EPA (1988, 1999, 2002, 2006, 2008, and 2010).[85] These are discussed below with respect to the factors outlined in § 261.11(a)(3)(i)–(xi), and the Agency's findings. In the following discussion of the eleven listing factors, we combined factors iii (Migration), iv (Persistence), v (Degradation) and vi (Bioaccumulation); and factors vii (Plausible Types of Mismanagement), viii (Quantities of the Waste Generated), and ix (Nature and Severity of Effects from Mismanagement) for a more lucid presentation of our arguments.

1. Toxicity—Factor (i)

Toxicity is considered in developing the health benchmarks used in risk assessment modeling. The Agency for Toxic Substances and Disease Registry (ATSDR) ToxFAQs,[86] the EPA Integrated Risk Information System (IRIS),[87] and the Toxicology Data Network (TOXNET) of the National Institutes of Health[88] are all sources of toxicological data on the Appendix VIII hazardous constituents found in CCRs. (The information from these data sources on the toxicity of the metals identified is included in the docket to today's proposed rule.) Two types of ingestion benchmarks are developed. For carcinogens, a cancer slope factor (CSF) is developed. A CSF is the slope of the curve representing the relationship between dose and cancer risk. It is used to calculate the probability that the toxic nature of a constituent ingested at a specific daily dose will cause cancer. For non-carcinogens, a reference dose (RfD) is developed. The RfD (expressed in units of mg of substance/kg body weight-day) is defined as an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. The constituents of concern associated with CCRs include antimony, arsenic, barium, beryllium, cadmium, hexavalent chromium, lead, mercury, nickel, selenium, silver, and thallium. Based on the information in ASTDR's Tox FAQs, EPA's IRIS system and TOXNET, the Agency believes that the metals identified are sufficiently toxic that they are capable of posing a substantial present or potential hazard to human health and the environment when improperly treated, stored, transported disposed of, or otherwise managed. A brief summary of the toxic effects associated with these constituents is presented below, including for the four Appendix VIII hazardous constituents that were estimated in the draft groundwater risk assessment to pose high-end (90th percentile) risks at or above the risk criteria in one or more situations, and that were also found to present risk to human health in one or more damage cases (arsenic, cadmium, lead, and selenium):

Arsenic. Ingestion of arsenic has been shown to cause skin cancer and cancer in the liver, bladder and lungs.[89]

Antimony. Antimony is associated with altered glucose and cholesterol levels, myocardial effects, and spontaneous abortions. EPA has set a limit of 145 ppb in lakes and streams to protect human health from the harmful effects of antimony taken in through water and contaminated fish and shellfish.[90]

Barium. Barium has been found to potentially cause gastrointestinal disturbances and muscular weaknesses when people are exposed to it at levels above the EPA drinking water standards for relatively short periods of time.[91]

[83] *See* 40 CFR 300.430.

[84] As noted previously, EPA's hazardous waste listing determination policy is described in the notice of proposed rulemaking for wastes from the dye and pigment industries at 59 FR 66075–66077.

[85] Full references: U.S. EPA (Environmental Protection Agency). 1988. *Wastes from the Combustion of Coal by Electric Utility Power Plants—Report to Congress.* EPA–530–SW–88–002. U.S. EPA Office of Solid Waste and Emergency Response. Washington, DC. November.

U.S. EPA (Environmental Protection Agency). 1999. *Report to Congress: Wastes from the Combustion of Fossil Fuels—Volume II,* EPA 530–S–99–010. Office of Solid Waste. March.

U.S. EPA (Environmental Protection Agency). 2002. *Constituent Screening for Coal Combustion Wastes.* Draft Report prepared by Research Triangle Institute for Office of Solid Waste, Washington, DC. September.

U.S. EPA (Environmental Protection Agency). 2006. *Characterization of Mercury-Enriched Coal Combustion Residuals from Electric Utilities Using Enhanced Sorbents for Mercury Control.* EPA 600/R–06/008. Office of Research and Development. Research Triangle Park, NC. January.

U.S. EPA (Environmental Protection Agency). 2008. *Characterization of Coal Combustion Residuals from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control.* EPA/600/R–08/077. Report to U.S. EPA Office of Research and Development, Air Pollution Control Division. Research Triangle Park, NC. July.

U.S. EPA (Environmental Protection Agency). 2010. *Human and Ecological Risk Assessment of Coal Combustion Wastes.* Office of Resource Conservation and Recovery, Washington, DC. April.

[86] *http://www.atsdr.cdc.gov/toxfaq.html.*

[87] *http://cfpub.epa.gov/ncea/iris/index.cfm?fuseaction=iris.showSubstanceList&list_type=alpha&view=B.*

[88] *http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB.*

[89] ATSDR ToxFAQs. *Available at: http://www.atsdr.cdc.gov/toxfaq.html.*

[90] *Ibid.*

[91] *Ibid.*

Beryllium. Beryllium can be harmful if you breathe it. If beryllium air levels are high enough (greater than 1,000 ug/m^3), an acute condition can result. This condition resembles pneumonia and is called acute beryllium disease.[92]

Cadmium and Lead. Cadmium and lead have the following effects: kidney disease, lung disease, fragile bone, decreased nervous system function, high blood pressure, and anemia.[93]

Hexavalent Chromium. Hexavalent chromium has been shown to cause lung cancer when inhaled.[94]

Mercury. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus.[95]

Nickel. The most common harmful health effect of nickel in humans is an allergic reaction. Approximately 10–20% of the population is sensitive to nickel. The most common reaction is a skin rash at the site of contact. Less frequently, some people who are sensitive to nickel have asthma attacks following exposure to nickel. Some sensitized people react when they consume food or water containing nickel or breathe dust containing it.[96]

Selenium. Selenium is associated with selenosis.[97]

Silver. Exposure to high levels of silver for a long period of time may result in a condition called arygria, a blue-gray discoloration of the skin and other body tissues.[98]

Thallium. Thallium exposure is associated with hair loss, as well as nervous and reproductive system damage.[99]

2. Concentration of Constituents in Waste—Factor (ii)

A CCR constituent database was developed for the Regulatory Determination in May 2000 and in followup work leading to today's co-proposal. This database contained data on the total CCR constituents listed above, as well as many others, with the Appendix VIII constituents found in varying concentrations (*see* Table 6).[100]

TABLE 6—TOTAL METALS CONCENTRATIONS FOUND IN CCRS

[ppm]

Constituent	Mean	Minimum	Maximum
Antimony	6.32	0.00125	3100
Arsenic	24.7	0.00394	773
Barium	246.75	0.002	7230
Beryllium	2.8	0.025	31
Cadmium	1.05	0.000115	760.25
Chromium	27.8	0.005	5970
Lead	25	0.0074	1453
Mercury	0.18	0.000035	384.2
Nickel	32	0.0025	54055
Selenium	2.4075	0.0002	673
Silver	0.6965	0	3800
Thallium	1.75	0.09	100

The data in Table 6 show that many of these metals are contained in CCRs at relatively high concentrations, such that if CCRs were improperly managed, they could leach out and pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of or otherwise managed. The risk assessment that was conducted confirms this finding, as do the many damage cases that have been documented and presented in today's co-proposal, including documents contained in the docket to today's proposed rule.

3. Migration, Persistence, Degradation, and Bioaccumulation—Factors (iii), (iv), (v), and (vi)

The potential of the hazardous constituents and any degradation products to migrate, persist, degrade and/or bioaccumulate in the environment are all factors that EPA considered and evaluated in the design of the fate and transport models that were used in assessing the concentrations of the toxic constituents to which humans and ecological receptors may be exposed. However, before discussing the hazardous constituents in the fate and transport models, the Agency would note that the toxic constituents for CCRs are all toxic metals—antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver and thallium, which do not decompose or degrade with the passage of time. Thus, these toxic metals will persist in the environment for very long periods of time, and if they escape from the disposal site, will continue to provide a potential source of long-term contamination.

The purpose of the risk assessment was to use the fate and transport models to assess likely migration of the CCR toxic constituents from different waste types through different exposure pathways, to receptors and to predict whether CCRs under different management scenarios may produce risks to human health and the environment. To estimate the risks posed by the management of CCRs in landfills and surface impoundments, the risk assessment estimated the release of the CCR toxic constituents from landfills and surface impoundments, the concentrations of these constituents in environmental media surrounding coal-fired utility power plants, and the risks that these concentrations pose to human and ecological receptors. The risk estimates were based on a groundwater fate and transport model in which constituents leached to groundwater consumed as drinking water, migrated to surface water and bioaccumulated in recreationally caught and consumed fish, and on direct ecological exposure. The specific 50th and 90th percentile risk assessment results for relevant Appendix VIII constituents are discussed below. While these results are based on a subset of CCR disposal units, they are likely representative of the risks posed by other similar disposal units. As discussed previously, the risk

[92] *Ibid.*

[93] *Ibid.*

[94] *Ibid.*

[95] *Ibid.*

[96] *Ibid.*

[97] *Ibid.*

[98] *Ibid.*

[99] *Ibid.*

[100] Additional data on the waste characteristics of fly ash and FGD are presented in section I.F.2.

assessment demonstrates that if CCRs are improperly managed, they have the potential to present a hazard to human health and the environment above a 1×10^{-4} to 1×10^{-6} cancer range or an HQ of 1. A detailed discussion of the modeling and risks from this pathway can be found in U.S. EPA 2009a (available in the docket for this proposal). This report presents the methodology, results, and uncertainties of EPA's assessment of human health risks resulting from groundwater contamination from coal-fired electric utilities.

Ingestion of Groundwater: The risk assessment predicted that CCRs pose an estimated trivalent arsenic cancer risk of 4 in 10,000 for unlined landfills and 2 in 10,000 for clay-lined landfills at the 90th percentile. No cancer risks above 1 in 100,000 were found at the 50th percentile. The 90th percentile results also estimated that thallium is ingested at three times the reference dose and antimony at twice the reference dose for unlined landfills. For clay-lined landfills, only thallium is estimated to exceed the reference dose, with a 90th percentile ingestion of twice the reference dose.

CCRs co-managed with coal refuse in landfills are estimated to pose arsenic cancer risks of 5 in 10,000 for an unlined landfill and 2 in 10,000 for a clay-lined landfill at the 90th percentile. EPA estimates that arsenic poses a 2 in 100,000 risk of cancer at the 50th percentile for unlined landfills, but poses cancer risks of less than 1 in 100,000 for clay or composite-lined landfills. For CCRs co-managed with coal refule, thallium is estimated at two times the reference dose in unlined landfills at the 90th percentile, but did not exceed the reference dose at the 0th percentile for any liner type.

For unlined landfills managing FBC waste, arsenic is estimated to have a cancer risk of three in one hundred thousand at the 90th percentile. For clay-lined landfills managing FBC waste, arsenic is estimated to have a cancer risk of six in one hundred thousand at the 90th percentile, while thallium is estimated to have an HQ of 4, and antimony is estimated to have an HQ of 3.

The Appendix VIII constituents in CCRs managed in landfills are not all estimated to arrive at the drinking water well at the same time. For unlined landfills, the median number of years until peak well water concentrations are estimated to occur is approximately 2,800 to 9,700 years for arsenic, 2,600 to 10,000 years for selenium, and 2,300 years for thallium. For clay-lined landfills, the median estimated time until peak well concentrations is approximately 4,000 to 10,000 years for arsenic, 5,100 to more than 10,000 years for selenium, and 4,300 years for thallium. Of the contaminated groundwater plumes that are estimated to reach the receptor wells from composite-lined units, the median time to peak well concentration as not estimated to sour in the 10,000 year time period that was modeled.[101]

For surface impoundments, the risk estimates differ. CCRs managed alone, that is, without coal refuse in the same impoundment, are found to pose an arsenic cancer risk of 2 in 1,000 for unlined surface impoundments and 9 in 10,000 for clay-lined surface impoundments at the 90th percentile. For unlined surface impoundments at the 90th percentile, selenium's HQ is two and lead's is three. At the 50th percentile, none of the constituents assessed for non-cancer effects exceed their reference dose in any scenario, but arsenic did pose estimated cancer risks of 1 in 10,000 and 6 in 100,000 for unlined and clay-lined units, respectively. For the surface impoundments with composite liners, arsenic did not exceed cancer risks of 1 in 100,000, nor did selenium exceed its reference dose.

Co-disposed CCRs and coal refuse managed in surface impoundments resulted in the highest risks. For the 90th percentile, arsenic's estimated cancer risk is 2 in 100 and 7 in 1,000 for unlined and clay-lined surface impoundments, respectively.[102] At the 50th percentile, these units still resulted in estimated arsenic cancer risks of 6 in 10,000 for the unlined surface impoundment and 2 in 10,000 for the clay-lined surface impoundment. Cadmium and lead both are estimated to exceed the reference dose by nine times at the 90th percentile for unlined surface impoundments. In clay-lined surface impoundments, cadmium has an estimated cadmium HQ of 3. When managed in surface impoundments with composite liners, these constituents' estimated cancer risks did not exceed 1 in 100,000, nor are they estimated to exceed their reference doses.

As with landfills, the modeling shows differing arrival times of various constituents at the modeled well locations. Due to differences in behaviors when interacting in soil, some chemical constituents move more quickly than others through the subsurface environment. For unlined surface impoundments, the median number of years until peak well water concentrations would occur is estimated to be 74 years for hexavalent selenium and 78 years for arsenic. For clay-lined surface impoundments, the median number of years was estimated to be 90 years for hexavalent selenium and 110 years for trivalent arsenic. Of the plumes that did reach the receptor wells from composite-lined units,[103] the median number of years was estimated to be 4,600 years for hexavalent selenium and 8,600 years for trivalent arsenic.

While hexavalent chromium, and nickel were not modeled using the fate and transport models, they did show the potential for excess risk at the screening stage.[104] Risk attenuation factors were developed for each of these constituents at the 50th and 10th percentiles. Here, attenuation refers to the dilution of the concentration of a constituent. Thus, the 10th percentile (not the 90th percentile) was developed to represent the high-end risks. These risk attenuation factors were calculated by dividing the screening risk results by the full-scale risk results, across all unit types combined, for the constituents modeled in the full-scale assessment. Using the risk attenuation factors, none of the constituents were estimated to exceed an HQ of 1 at either the 50th or 10th percentile for landfills. For surface impoundments, hexavalent chromium was estimated to exceed an HQ of 1 at the 50th percentile, while hexavalent chromium was estimated to exceed an HQ of 1 at the 10th percentile. The HQ for nickel under the surface

[101] The risk model used by EPA evaluates conditions over a 10,000 year period, and considers constituent concentrations during that period. In some cases, peak concentrations do not occur during the 10,000 year period.

[102] Including data with very high leach levels in surface impoundments where pyritic wastes were managed. As mentioned earlier, management of CCRs with coal refuse may have changed, and some pore water data from the coal refuse may not represent the management of these materials today. EPA has solicited comments on these issues.

[103] In other words, based on the results from this subset of the total number of Monte Carlo realizations.

[104] Previous risk assessment results for CCR (U.S. EPA, 1998) indicated concern for the groundwater pathway and limited concern for aboveground pathways for human and ecological receptors. The primary purpose of subsequent risk analyses was to update those results by incorporating new waste characterization data received since 1998 and by applying current data and methodologies to the risk analyses. The initial step in this process is screening and constituent selection for a more detailed analysis. The goal of screening is to identify CCR constituents, waste types, receptors, and exposure pathways with risks below the level of concern and eliminate those combinations from further analysis. The screening analysis (U.S. EPA, 2002) compared the 90th percentile leachate values directly to the human health benchmarks identified above. In other words, it was assumed that a human receptor was drinking leachate directly from a CCR landfill or surface impoundment with no attenuation or variation in exposure.

impoundment scenario was less than 1 using the 50th and 10th percentile values. However, the use of risk attenuation factors in place of probabilistic fate and transport modeling increases the uncertainty associated with these results. This analysis was conducted only for the drinking water exposure pathway.

Consumption of Recreationally Caught Fish: For the unlined, clay-lined, or composite-lined landfills, none of the modeled Appendix VIII hazardous constituents posed a cancer risk greater than 1 in 100,000, nor did they exceed their reference doses. However, for surface impoundments co-disposing of CCRs with coal refuse, trivalent arsenic's 90th percentile estimates are 3 in 100,000 and 2 in 100,000 excess cancer risk for unlined and clay-lined units, respectively. Pentavalent arsenic's 90th percentile estimate is 2 in 100,000 excess cancer risk for unlined impoundments. For all other liner and management unit scenarios at the 90th percentile, and all scenarios at the 50th percentile, there were no arsenic cancer risks above 1 in 100,000. Hexavalent selenium is estimated to result in exposures at three times the reference dose and twice the reference dose in the unlined and clay-lined surface impoundment scenarios, respectively, at the 90th percentile. However, selenium is not estimated to exceed the reference dose in the composite lined scenario at the 90th percentile, or any scenario at the 50th percentile.

Particulate Matter Inhalation: Air emissions from CCR disposal and storage sites can originate from waste unloading operations, spreading and compacting operations, the re-suspension of particulates from vehicular traffic, and from wind erosion. Air inhalation exposures may cause adverse human health effects, either due to inhalation of small-diameter (less than 10 microns) "respirable" particulate matter that causes adverse effects (PM_{10} and smaller particles which penetrate to and potentially deposit in the thoracic regions of the respiratory tract), which particles are associated with a host of cardio and pulmonary mortality and morbidity effects. *See e.g.* 71 FR at 61151–62 and 61178–85 (Oct. 6, 2006); *see* also 40 CFR 50.6 and 50.13 (National Ambient Air Quality Standards for thoracic coarse particles and fine particles).

To evaluate the potential exposure of residents to particulate matter that live near landfills that have disposed of CCRs, EPA has performed a screening-level analysis using the SCREEN3 model. This analysis, in *Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills—DRAFT* (U.S. EPA 2010b, copy of which is in the docket for this proposed rule), indicates that, without fugitive dust controls, there could be exceedances of the National Ambient Air Quality Standards (NAAQS) for fine particulate matter in the air at residences near CCR landfills. EPA requests comment and data on the screening analysis, on the results of any ambient air monitoring for particulate matter that has been conducted, where air monitoring stations are located near CCR landfills, along with information on any techniques, such as wetting, compaction, or daily cover that may be employed to reduce such exposures.

A description of the modeling and risks from this pathway for disposal of CCRs in landfills and surface impoundments can be found in the Draft Final Report: Non-ground Water Pathways, Human Health and Ecological Risk Analysis for Fossil Fuel Combustion Phase 2 (FFC2); June 5, 1998.[105] This analysis did not address the issue of enrichment of toxic constituents present in the finer, inhalable fraction of the overall particulate matter size distribution,[106] but used the total constituent concentrations to represent the concentrations of constituents present on the inhaled particulate matter. Based on the analysis, at landfills, the highest estimated risk value was an individual excess lifetime risk of 4 in one million for the farmer, due to inhalation of chromium (all chromium present in the particulate matter was assumed to be in the more toxic, hexavalent form). For surface impoundments, the highest risk value was 2 in one million for the farmer (again assuming all chromium present was hexavalent). The Agency requests comment on the analysis, as presented in the draft final report, as well as any data, including air monitoring data that may be available regarding the potential for residents to be exposed to toxic constituents by this exposure pathway.

Ecological Exposure: Where species were directly exposed to surface impoundments, the risk assessment found ecological risks due to selenium, silver, nickel, chromium, arsenic, cadmium, barium, lead, and mercury. For scenarios where species were exposed to constituents that had migrated from the groundwater to surface water and sediment, ecological risk exceedances were found for lead, selenium, arsenic, barium, antimony, and cadmium at the 90th percentile, but not at the 50th percentile. EPA's risk assessment, confirmed by the existing damage cases and field studies published in the peer-reviewed scientific literature, show elevated selenium levels in migratory birds, and elevated contaminant levels in mammals as a result of environmental uptake, fish deformities, and inhibited fish reproductive capacity. Because of the large size of these management units, many being 100's of acres to one that is about 2,600 acres, receptors can often inhabit these waste management units. There are a number of recent references in the peer-reviewed scientific literature specific to CCRs managed in surface impoundments that confirm the 1998 risk assessment results and provide additional pertinent information of potential ecological damage. Hopkins, et al. (2006)[107] observed deformities and reproductive effects in amphibians living on or near CCR disposal sites in Georgia. Rowe, et al. (2002)[108] provided a thorough review of laboratory and field studies that relate to the impact of CCR surface impoundment management practices' on aquatic organisms and communities. Examples of studies cited in Rowe, et al. (2002) that illustrates the impact of CCRs on aquatic organisms in direct contact with surface impoundment waters and/or sediments include Benson and Birge (1985),[109] Coutant, et al. (1978)[110] and Rowe, et al. (2001),[111] while examples of studies cited in Rowe, et al. 2002 that illustrates the impact of CCRs on aquatic organisms in water bodies near CCR surface

[105] *http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/ngwrsk1.pdf.*

[106] *See,* for example, Vouk, V. and Piver, W. "Metallic Elements in Fossil Fuel Combustion Products: Amounts and Form of Emissions and Evaluation of Carcinogenicity and Mutagenicity." Env Health Perspec 1983:47(201–225).

[107] Hopkins, W.A., S.E. DuRant, B.P. Staub, C.L. Rowe, and B.P. Jackson. 2006. Reproduction, embryonic development, and maternal transfer of contaminants in the amphibian Gastrophryne carolinensis. *Environmental Health Perspectives.* 114(5):661–666.

[108] Rowe, C., Hopkins, W., Congdon, G. "Ecotoxicological Implications of Aquatic Disposal of Coal Combustion Residuals in the United States: A Review." Env Monit Assess 2002: 80(270–276).

[109] Benson, W. and Birge, W. "Heavy metal tolerance and metallothionein induction in fathead minnows: results from field and laboratory investigations." Environ Toxicol Chem 1985:4(209–217).

[110] Coutant, C., Wasserman, C., Chung, M., Rubin, D., Manning, M. "Chemistry and biological hazard of a coal-ash seepage stream." J. Water Poll. Control Fed. 1978:50(757–743).

[111] Rowe C., Hopkins, W., and Coffman, V. "Failed recruitment of southern toads (Bufo terrestris) in a trace-element contaminated breeding habitat: direct and indirect effects that may lead to a local population sink." Arch. Environ. Contam. Toxicol. 2001:40(399–405).

impoundments include Lemly (1993),[112] Sorensen, et al. (1982)[113] and (1988).[114] This latter category may reflect CCR impacts attributable to three constituent migration mechanisms: (1) NPDES-permitted discharges from impoundments; (2) overtopping of impoundments; and (3) groundwater-to-surface-water discharges (modeled in US EPA 2010a), as well as other, non-CCR-related, sources of pollutants.

Although chromium, beryllium, and silver were not modeled, they were analyzed using dilution attenuation factors developed for the 50th and 10th percentiles in the same manner as described above. The only exceedance of the HQ of 1 was for silver at the 10th percentile under the landfill scenario. The only exceedances of the ecological criteria for surface impoundments of the 40 CFR part 261 Appendix VIII constituents was for chromium at the 10th percentile. Since full-scale modeling was not conducted, the results for these constituents are uncertain.

4. Plausible Types of Mismanagement, Quantities of the Waste Generated, Nature and Severity of Effects From Mismanagement—Factors (vii), (viii) and (ix)

As discussed earlier, approximately 46 million tons of CCRs were managed in calendar year 2008 in landfills (34%) and nearly 29.4 million tons were managed in surface impoundments (22%).[115] EPA has estimated that in 2004, 69% of the CCR landfills and 38% of the CCR surface impoundments had liners. As shown in the risk assessment and damage cases, the disposal of CCRs into unlined landfills and surface impoundments is likely to pose significant risks to human health and the environment. Additionally, documented damage cases have helped to confirm the actuality and magnitude of risks posed by these unlined disposal units.

The CCR waste stream is generated in very large volumes and is increasing. The ACAA estimates that the production of CCRs has increased steadily from approximately 30 million tons in the 1960s to over 120 million tons in the 2000s.[116] A recent ACAA survey estimates a total CCR production of just over 136 million tons in 2008.[117] This is a substantially large waste stream when compared to the 6.9 million tons of non-wastewater hazardous wastes disposed by all other sectors in 2007, and the 2 million tons of hazardous waste being reported as disposed of in landfills and surface impoundments in 2005.[118]

EPA currently has documented evidence of proven damages to groundwater and surface water from 27 disposal sites and potential damages at 40 sites which are discussed in detail above and in the Appendix to this proposal. The damage cases resulting from CCR constituents migrating into groundwater were generally the same with those predicted in the risk assessment with respect to constituents which migrated, the concentrations reaching receptors, and the consequent magnitude of risk to those receptors. Of the constituents in Appendix VIII of Part 261, four were found at levels of concern in both the risk assessment and the damage cases (arsenic, cadmium, lead, and selenium). Two additional Appendix VIII (Part 261) constituents (chromium and nickel) were found in damage cases, and showed the potential for risk in the risk assessment, but were not modeled through fate and transport modeling. Finally, there were two Appendix VIII (Part 261) constituents (antimony and thallium) that were projected to be capable of migrating and reaching receptors at levels of concern in the risk assessment, but have yet to be identified in any of our groundwater damage cases.[119]

The damages to surface water from Appendix VIII (Part 261) constituents do not reflect a ground water to surface water pathway, but rather reflect surface water discharges. Five damage cases resulted in selenium fish consumption advisories consistent with the risk assessment's prediction that selenium consumption from fish in water bodies affected by CCR disposal units would result in excess ecologic and human health risk. We are aware that at least three of the fish advisories were subsequently rescinded when the criteria was reassessed and revised. The risk assessment also predicts that arsenic would pose such risks. However, while no arsenic fish advisories have been linked to CCR disposal at this time, the risk assessment predicts that selenium will migrate faster than arsenic.

In addition to the impacts on human health from groundwater and surface water contaminated by CCR released from disposal units, the damage cases have also shown the following adverse effects to plants and wildlife: Elevated selenium levels in migratory birds, wetland vegetative damage, fish kills, amphibian deformities, snake metabolic effects, plant toxicity, mammal uptake, fish deformities, and inhibited fish reproductive capacity. Although these effects cannot easily be linked to the results of the risk assessment as was done for groundwater and surface water above, the risk assessment generally agreed with the damage cases because it sometimes showed very high risks to ecological receptors. For additional information on ecological damages, *see* the document titled "What Are the Environmental and Health Effects Associated with Disposing of CCRs in Landfills and Surface Impoundments?" in the docket to this proposal.

Furthermore, four of the 27 proven damage case disposal sites have been listed on the EPA's National Priorities List (NPL). The NPL is the list of national priority sites with known releases or threatened releases of hazardous substances, pollutants, or contaminants throughout the United States and its territories. The Hazard Ranking System (HRS), the scoring system EPA uses to assess the relative threat associated with a release from a site, is the primary method used to determine whether a site should be placed on the NPL.[120] The HRS takes into account the three elements of environmental and human health risk: (1) Probability of release; (2) exposure; and (3) toxicity. EPA generally will list sites with scores of 28.5 or above. The HRS is a proven tool for evaluating and prioritizing the releases that may pose threats to human health and the environment throughout the nation.

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[112] Lemly A., "Guidelines for evaluating selenium data from aquatic monitoring and assessment studies." Environ. Monit. Assess. 1993:28(83–100).

[113] Sorensen, E., Bauer, T., Bell, J., Harlan, C. "Selenium accumulation and cytotoxicity in teleosts following chronic, environmental exposure." Bull. Environ. Contam. Toxicol. 1982:29(688–696).

[114] Sorenson, E. "Selenium accumulation, reproductive status, and histopathological changes in environmentally exposed redear sunfish." Arch Toxicol 1988:61(324–329).

[115] Estimated from the 2009 ACAA survey and Energy Information Administration 2005 F767 Power Plant database.

[116] ACAA (American Coal Ash Association). 2008. Production & Use Chart (1966–2007). *http://www.acaa-usa.org/associations/8003/files/Revised_1966_2007_CCP_Prod_v_Use_Chart.pdf.*

[117] ACAA (American Coal Ash Association). 2009. *2008 Coal Combustion Product (CCP) Production & Use Survey Results. http://www.acaa-usa.org/associations/8003/files/2007_ACAA_CCP_Survey_Report_Form%2809-15-08%29.pdf.*

[118] The National Biennial RCRA Hazardous Waste Report (2007) available at *http://www.epa.gov/epawaste/inforesources/data/br07/national07.pdf.*

[119] While this could indicate a potential conservatism in the model with respect to these two constituents, it is more likely to result from a failure to sample for these constituents as frequently. This is consistent with the data reported in Table 4–29 of the revised risk assessment (only 11 samples taken for antimony and thallium in surface impoundments versus hundreds for various other constituents).

[120] U.S. EPA 2007. "Introduction to the Hazard Ranking System (HRS)." Accessed at: *http://www.epa.gov/superfund/programs/npl_hrs/hrsint.htm.*

Whereas each of those 4 NPL sites also contains waste other than CCRs, CCRs are one of the prevalent waste types in each case.[121]

In addition, the Kingston, Tennessee damage case (*see* the Appendix) helps to illustrate the additional threats to human health and the environment that can be caused by the failure of a CCR waste management unit. At TVA's Kingston facility, there were four failure conditions: The presence of an unusually weak fly ash ("Slimes") foundation; the fill geometry and setbacks; increased loads due to higher fill; and hydraulically placed loose wet ash. If owners or operators do not maintain due diligence regarding the structural integrity of surface impoundments, significant damage to human health and the environment could be a likely outcome. In summary, while the preponderance of documented damage cases were the result of releases from unlined landfills and surface impoundments, EPA believes that the above data identify situations (*e.g.,* adverse impacts on migratory birds) illustrative of potential problems occurring from the management of CCRs in any type of surface impoundment.

5. Action Taken by Other Governmental Agencies or Regulatory Programs Based on the Health or Environmental Hazard Posed by the Waste or Waste Constituent—Factor (x)

As a result of the mismanagement of CCRs, EPA and states have taken steps to compel cleanup in several situations. Specifically, in addition to EPA placing sites on the NPL due to the disposal or indiscriminant placement of CCRs, at least 12 states have issued administrative orders for corrective actions at CCR disposal sites. Corrective action measures at these CCR management units vary depending on the site specific circumstances and include formal closure of the unit, capping, re-grading of ash and the installation of liners over the ash, ground water treatment, groundwater monitoring, and combinations of these measures.

6. Other Factors—Factor (xi)

The damage cases and the risk assessment also found excess risks for human and ecological receptors that resulted from non-Appendix VIII (Part 261) constituents.[122] While not currently identified under RCRA as hazardous or toxic constituents, several of these constituents have the same toxic endpoints as the Appendix VIII (Part 261) constituents found in CCRs, while nitrate is associated with pregnancy complications and methemoglobinemia (blue baby syndrome).[123] Although these non-Appendix VIII (Part 261) constituents do not provide an independent basis for listing CCRs, EPA finds their presence in the damage cases and risk assessment results to be relevant to the listing decision because of the potential to cause additive or synergistic effects to the Appendix VIII constituents. For instance, exposure to high levels of cobalt (cobalt has an HQ of 500 when rounded to 1 significant digit) can result in lung and heart effects, the same endpoints as exposure to high levels of antimony. Thus, these two constituents could act additively or synergistically on both the heart and lungs. The risk assessment showed 90th percentile cobalt drinking water ingestion to be 500 times the reference dose. Thus, cobalt could exacerbate the heart and lung effects due to CCR antimony exposures.

Therefore, based on our examination of CCRs against the criteria for listing, a listing determination for CCRs destined for disposal can be based on such factors as (1) The continued evidence that CCRs in landfills and surface impoundments may not be properly managed—*e.g.,* the lack of groundwater monitoring for many existing units; (2) the continued gaps in some state regulations; (3) the damage cases we have documented to date, including the damage done by the recent catastrophic release of CCRs from the impoundment failure in Kingston, Tennessee; and (4) the results of the risk assessment, which indicates high-end risks associated with disposal of CCRs in unlined and clay-lined CCR landfills and surface impoundments far exceeding acceptable levels (*e.g.,* exceeding a cancer risk threshold of 1×10^{-5})[124] and the non-cancer risk threshold (HQ greater than 1).

VI. Summary of the Co-Proposed Subtitle C Regulations

Under the subtitle C alternative, EPA would list CCRs from electric utilities and independent power producers intended for disposal in landfills and surface impoundments as a special waste, which would make them subject to the existing subtitle C regulations at 40 CFR parts 260 through 268, as well as the permitting requirements in 40 CFR part 270, and the state authorization process in 40 CFR parts 271–272.[125] These regulations establish, among other things, location restrictions; standards for liners, leachate collection and removal systems, and groundwater monitoring for land disposal units; fugitive dust control; closure and post-closure care requirements; storage requirements; corrective action; financial assurance; waste characterization; and permitting requirements. These regulations also impose requirements on generators and transporters of CCRs destined for disposal, including manifesting (if the CCRs destined for disposal are sent off site). As discussed in detail in section IV. E of today's preamble, EPA is proposing to leave the Bevill determination in place for CCRs used beneficially. Thus, CCRs beneficially used would not be subject to regulation from the point of generation or from the point they are recovered from landfills or surface impoundments, to the point where they are used beneficially. In addition, when beneficially used (*e.g.,* in wallboard and concrete), the CCRs become part of a new product; these products do not carry the special waste listing. When these products reach the end of their useful life and are to be disposed of, this represents a new point of generation. This new waste would be subject to RCRA subtitle C if the waste exhibits a characteristic of hazardous waste (*i.e.,* ignitability, corrosivity, reactivity, or toxicity).

In the majority of cases, EPA is proposing that CCRs be subject to the existing subtitle C requirements without modification. Accordingly, for those regulatory requirements that we propose not to modify or for which EPA does not specifically solicit comment, EPA is not proposing to reopen any aspect of those requirements, and will not respond to any unsolicited comments submitted during this rulemaking. However, where EPA has determined that special

[121] For specifics, please *see http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=EPA-HQ-RCRA-2006-0796-0015.*

[122] Aluminum, boron, chloride, cobalt, copper, fluoride, iron, lithium, manganese, molybdenum, nitrate/nitrite, strontium, sulfate, vanadium, and zinc.

[123] ATSDR CSEM. Available at: *http://www.atsdr.cdc.gov/csem/nitrate/no3physiologic_effects.html.*

[124] This risk level is consistent with those discussed in EPA's hazardous waste listing determination policy (see the discussion in a proposed listing for wastes from the dye and pigment industries, December 22, 1994; 59 FR 66072).

[125] As discussed in section VI. D of the preamble, as part of the proposal to list CCRs as a special waste, as is done routinely with listed wastes, EPA is also proposing to subject CCRs that are disposed of to the notification requirements under CERCLA at 40 CFR part 302.

characteristics of these wastes warrant changes; *e.g.,* where implementation of existing requirements would present practical difficulties, or where additional requirements are necessary due to the special characteristics of these wastes, EPA is proposing to revise the requirements to account for these considerations. For example, EPA is proposing tailored design criteria for new CCR disposal units, pursuant to its authority under section 3004(x) of RCRA.[126] Similarly, under the authority of section 3004(x) of RCRA, EPA is proposing to modify the CCR landfill and surface impoundment liner and leak detection system requirements and the effective dates for the land disposal restrictions, and the surface impoundment retrofit requirements. EPA is also proposing to establish new land disposal prohibitions and treatment standards for both wastewater and non-wastewater CCRs. In addition, to address dam safety and stability issues, EPA is proposing design and inspection requirements for surface impoundments, similar to those of the Mine Safety and Health Administration (MSHA) design requirements for slurry impoundments at 30 CFR part 77.216 for surface impoundments. Further, EPA is proposing that all existing surface impoundments that have not closed in accordance with the rule's requirements by the effective date of this rule would be subject to all of the requirements of this rule, including the need to obtain a permit, irrespective of whether the unit continues to receive CCRs or the facility otherwise engages in the active management of those units.

Finally, we would note that if the Agency concludes to reverse the Bevill determinations and list CCRs as a special waste, EPA would make in any final rule conforming changes to 40 CFR parts 260 through 268 and 270 through 272 so that it is clear that these requirements apply to all facilities regulated under the authority of RCRA subtitle C that generate, transport, treat, store, or dispose of special wastes as well as to those facilities that generate, treat, store, or dispose of special wastes.

The following paragraphs set out the details of this subtitle C proposal, with the modified or new requirement discussed in Section B. and the existing subtitle C requirements discussed in Section C.

A. Special Waste Listing

Under this regulatory option, EPA is proposing to list CCRs generated by electric utilities and independent power producers destined for disposal as a special waste subject to the requirements of RCRA subtitle C by amending 40 CFR part 261 and to add Subpart F—Special Wastes Subject to Subtitle C Regulations. The Agency believes this would be the appropriate manner for listing these wastes, and, as discussed in detail later in this section, the Agency believes that listing CCRs destined for disposal as a special waste, rather than a hazardous waste could, in large measure, address potential issues of stigma.

B. Proposed Special Requirements for CCRs

The following paragraphs discuss the special requirements the Agency is proposing for CCRs. These requirements modify or are in addition to the general subtitle C requirements found at 40 CFR parts 264–268 and 270–272.

1. Modification of Technical Standards Under 3004(x)

Section 3004(x) of RCRA authorizes the Administrator to modify the statutory requirements of sections 3004(c), (d), (e), (f), (g), (o), (u), and 3005(j) of RCRA in the case of landfills or surface impoundments receiving Bevill wastes, including CCRs that EPA determines to regulate under subtitle C, to take into account the special characteristics of the wastes, the practical difficulties associated with implementation of such requirements, and site-specific characteristics, including, but not limited to the climate, geology, hydrology and soil chemistry at the site, so long as such modified requirements assure protection of human health and the environment. The Agency is proposing to modify, through its authority under RCRA 3004(x), the CCR landfill and surface impoundment liner and leak detection system requirements, the effective dates for the land disposal restrictions, and the surface impoundment retrofit requirements.

i. Modification of CCR Landfills and Surface Impoundments From the Section 3004(o) Liner and Leak Detection Requirements

The minimum technological requirements set out in RCRA Section 3004(o)(1)(A)(i) requires that new hazardous waste landfills and surface impoundments, replacements of existing landfills and impoundments, and lateral expansions of existing landfills and impoundments,[127] to install two or more liners and a leachate collection and removal system above (in the case of a landfill) and between such liners. Section 3004(o)(4)(A) also requires these units to install a leak detection system. Landfills and surface impoundments covered under the regulations at 40 CFR part 264 are required to have a double liner system, and a leachate collection and removal system that can also serve as a leak detection system as described in 40 CFR sections 264.221 and 264.301. Under section 3005 (j)(1) (and, as explained below, effectively under section 3005 (j)(11) as well), existing surface impoundments are required to meet all of these requirements as well.

EPA is proposing to modify the double liner and leachate collection and removal system requirement by substituting a requirement to install a composite liner and leachate collection and removal system. As modeled in EPA's risk assessment, composite liners effectively reduce risks from all constituents to below the risk criteria for both landfills and surface impoundments. Therefore, the Agency believes a composite liner system would be adequately protective of human health and the environment and a double liner system would be unnecessarily burdensome. The modified standards specify a composite liner system that consists of two components: the upper component must consist of a minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component. The leachate collection system must be designed and constructed to maintain less than a 30-cm depth of leachate over the liner.

[126] Section 3004(x) of RCRA provides EPA the authority to modify certain statutory provision (i.e., 3004(c), (d), (e), (f), (g), (o), and (u) and 3005(j) taking into account the special characteristics of such wastes, the practical difficulties associated with implementation of such requirements, and site-specific characteristics, including, but not limited to, climate, geology, hydrology, and soil chemistry at the site, so long as such modified requirements are protective of human health and the environment.

[127] Replacement unit means a landfill, surface impoundment, or waste pile unit (1) from which all or substantially all of the waste is removed, and (2) that is subsequently reused to treat, store, or dispose of such waste. "Replacement unit" does not apply to a unit from which waste is removed during closure, if the subsequent reuse solely involves the disposal of waste from that unit and other closing units or corrective action areas at the facility, in accordance with an approved closure plan or EPA or State approved corrective action. Lateral expansion means a horizontal expansion of the waste boundaries of an existing landfill or surface impoundment.

EPA has concluded that these liner and leachate collection requirements will be protective of human health and the environment from the release of contaminants to groundwater from CCRs in landfills and surface impoundments. Specifically, the risk assessment indicates that risks from disposal units with composite liners will be less than the 1×10^{-5} for carcinogens and less than an HQ of one for other hazardous constituents—levels that EPA has considered protective for the management of hazardous wastes. (The results of EPA's risk analyses are discussed in section II.B, and in the full risk assessment document, which is in the docket for today's proposed rulemaking.) Further support is provided by the damage cases, as none of the proven damage cases involved lined landfills or surface impoundments (with the possible exception of one unit, which in any case did not have a composite liner). In addition, the proposed modified requirements are the design standards for composite liners specified for municipal solid waste landfills at 40 CFR part 258; based on EPA's experience, such liner design would be expected to be effective in mitigating the risks of leaching to groundwater for a waste, such as CCRs. For example, CCRs do not contain volatile organics, such as ethylbenzene, which has recently been shown to be problematic for synthetic liners.

Although EPA has not confirmed damage cases involving the failure of clay liners, it is not proposing to allow new disposal units to be built solely with clay liners. EPA's modeling in its risk assessment indicated that clay liners could be of concern; EPA also believes that composite liners reflect today's best practices for new units, and, as such, can therefore be feasibly implemented.[128] Nevertheless, EPA solicits comments on whether clay liners should also be allowed under EPA's regulations. To assist EPA in its review, we request that commenters provide data on the hydraulic conductivity of clay liners associated with coal ash disposal units, and information on the protectiveness of clay liner designs based on site-specific analyses.

Thus, we are proposing to amend the current requirements of 40 CFR 264.220, and 264.300 to require that CCR surface impoundments and landfills install a composite liner and leachate collection and removal system. EPA would codify these requirements, as well as other special requirements for CCR wastes in a new subpart FF of 40 CFR part 264.

EPA also notes that section 3004(o)(2) allows the Agency to approve alternate liner designs, based on site-specific demonstrations that the alternate design and operating practices, together with location characteristics, will prevent the migration of any hazardous constituents into ground or surface water at least as effectively as the double-liner system (42 U.S.C. 6924(o)(2)). EPA solicits comment on whether, in addition to the flexibility provided by section 3004(o)(2), EPA's regulations should also provide for alternative liner designs based on, for example, a specific performance standard, such as the subtitle D performance standard in 40 CFR 258.40(a)(1), or a site specific risk assessment, or a standard that the alternative liner, such as a clay liner, was at least as effective as the composite liner. Such an approach might be appropriate, for example, in situations where groundwater is particularly deep and/or infiltration rates are low, or where alternative liner systems provide an equivalent level of protection.

Subtitle C of RCRA requires only new hazardous waste landfills (or new portions of existing landfills) to meet the minimum technology requirements for liners and leachate collection and removal systems. RCRA section 3004 (o)(1)(A). The statute thus does not require existing landfills that are brought into the subtitle C system because they are receiving newly listed hazardous wastes, or the new category of listed special wastes proposed in this notice, to be retrofitted with a new minimum-technology liner/leachate collection and removal system (or to close). They can continue to receive hazardous or special waste, and continue to operate as compliant hazardous or special waste landfills. Following from these provisions, EPA has not typically required existing landfills to be retrofitted to meet the new requirements. Congress specifically established this approach under subtitle C, and EPA sees no reason or special argument to adopt more stringent requirements for CCR landfills, particularly given the volume of the material and the disruption that would be involved with any other approach. However, under the proposal, existing units would have to meet the groundwater monitoring, corrective action, and other requirements of the subtitle C regulations to assure that any groundwater releases from the unit were identified and promptly remediated. This is consistent with the manner in which EPA has historically implemented the hazardous waste requirements. EPA believes that maintaining this approach in this context will be protective, in part, because, unless facilities ship all of their wastes off-site (which EPA believes is highly unlikely), they will need a permit for on-site management of CCRs, which will provide regulatory oversight that could, as necessary, address the risks from the existing (unpermitted) landfills.

By contrast, Congress was significantly more concerned about the risks associated with unlined surface impoundments managing newly listed hazardous wastes (*see* 42 U.S.C. Section 6924, October 21, 1976). This is addressed in more detail in section (iv) below titled "Wet-Handling of CCRs, Closure, and Interim Status for Surface Impoundments."

ii. Fugitive Dust Controls

The proposed subtitle C approach would require that surface impoundments and landfills be managed in a manner that controls fugitive dust consistent with any applicable requirements developed under a State Implementation Plan (SIP) or issued by EPA under section 110 of the Clean Air Act (CAA). Specifically, EPA is proposing to adopt as a standard the 35 $\mu g/m^3$ level established as the level of the 24-hour NAAQS for fine particulate matter (PM–2.5). In addition, CCR facilities would be required to control fugitive dust by either covering or otherwise managing CCRs to control wind dispersal of dust, emplacement as wet conditioned CCRs to control wind dispersal, when stored in piles, or storage in tanks or buildings. For purposes of the proposal, wet conditioning means wetting CCRs with water to a moisture content that prevents wind dispersal, facilitates compaction, but does not result in free liquids. Trucks or other vehicles transporting CCRs are to be covered or otherwise managed to control wind dispersal of dust. EPA is proposing this requirement based on the results of a screening level analysis of the risks posed by fugitive dusts from CCR landfills, which showed that, without fugitive dust controls, levels at nearby locations could exceed the 35 $\mu g/m^3$ level established as the level of the 24-hour PM 2.5 NAAQS for fine particulate.

iii. Special Requirements for Stability of CCR Surface Impoundments

To detect and prevent potential catastrophic releases, EPA is proposing requirements for periodic inspections of surface impoundments. The Agency

[128] EPA notes that the state of Maryland, in developing new standards for CCR disposal units under its subtitle D authorities, prescribes composite liners.

believes that such a requirement is critical to ensure that the owner and operator of the surface impoundment becomes aware of any problems that may arise with the structural stability of the unit before they occur and, thus, prevent the past types of catastrophic releases, such as at Martins Creek, Pennsylvania and TVA's Kingston, Tennessee facility. Therefore, EPA is proposing that inspections be conducted every seven days by a person qualified to recognize specific signs of structural instability and other hazardous conditions by visual observation and, if applicable, to monitor instrumentation. If a potentially hazardous condition develops, the owner or operator shall immediately take action to eliminate the potentially hazardous condition; notify the Regional Administrator or the authorized State Director; and notify and prepare to evacuate, if necessary, all personnel from the property which may be affected by the potentially hazardous condition(s). Additionally, the owner or operator must notify state and local emergency response personnel if conditions warrant so that people living in the area down gradient from the surface impoundment can be evacuated. Reports of inspections are to be maintained in the facility operating record.

To address surface impoundment (or impoundment) integrity (dam safety), EPA considered two options. One option, which is the option proposed in this notice, is to establish standards under RCRA for CCR surface impoundments similar to those promulgated for coal slurry impoundments regulated by the Mine Safety and Health Administration (MSHA) at 30 CFR 77.216. Facilities relying on CCR impoundments would need to (1) submit to EPA or the authorized state plans for the design, construction, and maintenance of existing impoundments, (2) submit to EPA or the authorized state plans for closure, (3) conduct periodic inspections by trained personnel who are knowledgeable in impoundment design and safety, and (4) provide an annual certification by an independent registered professional engineer that all construction, operation, and maintenance of impoundments is in accordance with the approved plan. When problematic stability and safety issues are identified, owners and operators would be required to address these issues in a timely manner.

In developing these proposed regulations for structural integrity of CCR impoundments, EPA sought advice from the federal agencies charged with managing the safety of dams in the United States. Many agencies in the federal government are charged with dam safety, including the U.S. Department of Agriculture (USDA), the Department of Defense (DOD), the Department of Energy (DOE), the Nuclear Regulatory Commission (NRC), the Department of Interior (DOI), and the Department of Labor (DOL), MSHA. EPA looked particularly to MSHA, whose charge and jurisdiction appeared to EPA to be the most similar to our task. MSHA's jurisdiction extends to all dams used as part of an active mining operation and their regulations cover "water, sediment or slurry impoundments" so they include dams for waste disposal, freshwater supply, water treatment, and sediment control. In fact, MSHA's current impoundment regulations were created as a result of the dam failure at Buffalo Creek, West Virginia on February 26, 1972. (This failure released 138 million gallons of stormwater run-off and fine coal refuse, and resulted in 125 persons being killed, another 1,000 were injured, over 500 homes were completely demolished, and nearly 1,000 others were damaged.)

MSHA has nearly 40 years of experience writing regulations and inspecting dams associated with coal mining, which is directly relevant to the issues presented by CCRs in this rule. In our review of the MSHA regulations, we found them to be comprehensive and directly applicable to the dams used in surface impoundments at coal-fired utilities to manage CCRs. We also believe that, based on the record compiled by MSHA for its rulemaking, and on MSHA's 40 years of experience implementing these regulations, these requirements will prevent the catastrophic release of CCRs from surface impoundments, as occurred at TVA's facility in Kingston, Tennessee, and will generally meet RCRA's mandate to ensure the protection of humans and the environment. Thus, we have modeled our proposal on the MSHA regulations in 30 CFR Part 77 and we have placed the text of the salient portions of the MSHA regulations in the docket for this rulemaking. The Agency requests comment on EPA's proposal to adopt the MSHA standards (with limited modifications to deal with issues specific to CCR impoundments) to address surface impoundment integrity under RCRA.

MSHA's regulations cover impoundments which can present a hazard and which impound water, sediment or slurry to an elevation of more than five (5) feet and have a storage volume of 20 acre-feet or more and those that impound water, sediment, or slurry to an elevation of 20 feet or more. EPA seeks comment on whether to cover all CCR impoundments for stability, regardless of height and storage volume, whether to use the cut-offs in the MSHA regulations, or whether other regulations, approaches, or size cut-offs should be used. If commenters believe that other regulations or size cut-offs should be adopted (and not the size-cut offs established in the MSHA regulations), we request that commenters provide the basis and technical support for their position.

The second option that EPA considered, but is not being proposed today, is to establish impoundment integrity requirements under the Clean Water Act's NPDES permit system. Existing regulations at 40 CFR 122.41(e) require that permittees properly operate and maintain all facilities of treatment and control used to achieve compliance with their permits. In addition, regulations at 40 CFR 122.44(k) allow the use of best management practices for the control and abatement of the discharge of toxic pollutants. Guidance could be developed to use best management practices to address impoundment construction, operation, and maintenance, consistent with the requirements of 40 CFR 122.41(e) and 122.44(k). Associated permit conditions could require that surface impoundments be designed and constructed in accordance with relevant state and federal regulations. The Agency requests comments regarding the alternate use of NPDES permits rather than the development of RCRA regulations to address dam safety and structural integrity.

iv. Wet-Handling of CCRs, Closure, and Interim Status for Surface Impoundments

Where a nonhazardous waste surface impoundment is storing a waste that becomes newly subject to the RCRA hazardous waste requirements, RCRA subtitle C and the implementing regulations require these surface impoundments either to be closed or upgraded to meet the minimum technology requirements within four years. RCRA section 3005 (j)(6), is implemented by 40 CFR 268.14.[129] In order to be eligible for this four year grace period, the impoundment must be in compliance with the applicable

[129] 40 CFR 268.14 allows owners and operators of newly regulated surface impoundments to continue managing hazardous waste without complying with the minimum technology requirements for a period up to four years before upgrading or closing the unit.

groundwater monitoring provision under Part 40 CFR 265, Subpart F within 12 months of the promulgation of the new hazardous listing or characteristic.

RCRA section 3005 (j)(11) allows the placement of untreated hazardous waste (*i.e.* hazardous waste otherwise prohibited from land disposal which has not been treated to meet EPA-established treatment standards before land disposal) in surface impoundments under limited circumstances. Such hazardous wastes may be placed in impoundments for purposes of treatment provided the impoundments meet the minimum technology requirements and provided that any treatment residues which either do not meet the treatment standards or which remain classified as hazardous wastes are removed from the impoundment annually. *See* the implementing rules in 40 CFR section 268.4. EPA has interpreted this provision so as not to nullify the provisions of section 3005(j)(6), the upshot being that impoundments receiving newly identified or listed wastes would have four years to close or retrofit under all circumstances. *See* 56 FR 37194. If the surface impoundment continues to treat hazardous wastes after the four year period, it must then be in compliance with 40 CFR 268.4 (Treatment Surface Impoundment Exemption).

Section 3005(j) of RCRA generally requires that existing surface impoundments cannot obtain interim status and continue to receive or store newly regulated hazardous waste for more than four years after the promulgation of the listing—unless the facility owner retrofits the unit by installing a liner that meets the requirements of section 3004(o)(1)(A), or meets the conditions specified in section 3005(j)(2). Under section 3005(j)(2), a surface impoundment may obtain interim status and continue to receive or store hazardous waste after the four-year deadline if (1) The unit has at least one liner, and there is no evidence it is leaking, (2) is located more than one-quarter mile from an underground source of drinking water; and (3) complies with the groundwater monitoring requirements applicable to permitted facilities. In this case, under section 3005(j)(9), the facility owner, at the closure of the unit, would have to remove or decontaminate all waste residues, all contaminated liner material, and contaminated soil to the extent practicable.

As part of the requirement to assure that surface impoundments will be safely phased out, EPA also proposes to regulate surface impoundments that have not completed closure prior to the effective date of the rule. Under that scenario, these units would be subject to the interim status closure requirements of 40 CFR 265.111 and 265.228(a)(2). For surface impoundments that have not met the interim status requirements by the effective date of the rule, they would be subject to the full RCRA subtitle C closure requirements (*e.g.,* obtain a Part A permit and comply with the interim status regulations).

EPA recognizes that for regulatory purposes, it has historically not required disposal units that cease receiving new listed or characteristic wastes before the effective date of RCRA subtitle C to comply with the requirements. However, EPA believes that a revised approach is necessary to protect human health and the environment, in this particular case, given the size of the CCR surface impoundments in question; the enormous volumes of CCRs they typically contain (which typically represent overwhelming mass of the material in place); the fact that the CCRs are typically destined for permanent entombment when the unit is eventually closed (typically with limited removal); the presence of very large hydraulic head leading to continued release—even where the impoundment has been drained—that is, improperly closed CCR impoundments remain open to precipitation and infiltration; and the continuing threat to human health and the environment through catastrophic failure, if the impoundments are not properly closed.

EPA's authority under subtitle C of RCRA extends to wastes that are treated, stored, or disposed of; the statutory definition of disposal has been broadly interpreted to include passive leaking. But historically, EPA has construed the definition of disposal for regulatory purposes to be narrower than the statutory definition of disposal. Although in some situations, post-placement management has been considered disposal, triggering RCRA subtitle C regulatory requirements *e.g.,* multiple dredging of impoundments or management of leachate, EPA has generally interpreted the statute to require a permit only if a facility treats, stores, or disposes of the waste, after the effective date of its designation as a hazardous waste. *See, e.g.,* 43 FR 58984 (Dec. 18, 1978; 45 FR 33074 (May 1980).

The consequence of this interpretation is that, for example, no permit would be required if, after the rule's effective date, a facility neither continued to accept the listed wastes for disposal, nor continued to "manage the wastes" in the existing unit. In other words, under this interpretation, facility owners could abandon the unit before the effective date of the rule without incurring any regulatory obligations under RCRA subtitle C (presuming no other regulated unit is present on-site).

Given the particularly significant risk associated with CCR impoundments described above, as well as the fact that these risks are primarily driven by the existing disposal units, EPA believes a broader interpretation of disposal is appropriate in this case. This is reinforced by the fact that the continued release of constituents to surrounding soil and groundwater through the continued infiltration of precipitation through inappropriately closed CCR impoundments (or failure to remove the impoundment waters, which provides a hydraulic head) properly constitute regulatory disposal in this specific situation.

As a practical matter, EPA believes that owners of facilities where CCRs are managed in existing surface impoundments being brought under RCRA subtitle C by today's proposal would choose not to, or would not be able to, comply with either of these alternatives (*i.e.,* retrofit or clean closure), given the size of the units and the volume of CCRs involved. Therefore, EPA believes that the section 3005(j) requirements, for all practical purposes, will have the effect of requiring the closure of existing surface impoundments receiving CCRs within four years of the effective date of today's proposed rule (unless they already meet the liner requirements).[130]

Section 3004(x), however, gives EPA the authority to modify section 3005(j) requirements, if the specific criteria listed in that section are met. In today's notice, EPA is proposing to modify the time required for retrofitting surface impoundments under section 3005(j), because of the special characteristics (*i.e.,* extremely large volumes) of CCRs and the practical difficulties associated with requiring facilities to cease to store CCRs within four years of the effective date of today's rule.

Therefore, EPA is proposing to modify the section 3005(j) requirements by extending the time limit for unit closure. The modified standard in today's proposal would require facilities operating surface impoundments that do not meet minimum technology

[130] The HSWA surface impoundment retrofit requirements, as they applied to impoundments in existence at the time RCRA was amended in 1984, went into effect in 1988. EPA is not aware of any facility owner/operator managing an existing surface impoundment at the time who chose to retrofit its impoundment, rather than to close it. EPA believes facilities managing surface impoundments today, will similarly choose to close the surface impoundment rather than retrofit.

requirements and are receiving CCRs to stop receiving those CCRs no later than five years after the effective date of the final regulation and to close the unit within two years after that date. In other words, the time required for closure would be up to seven years rather than four years.

EPA believes that the four-year deadline in RCRA section 3005(j) receiving CCRs will be extraordinarily difficult if not impossible for many facilities to meet, given the size of the units and limitations in available alternative subtitle C disposal capacity. Facility owners choosing to close surface impoundments may have to make significant engineering and process changes, *e.g.,* to convert from wet- to dry-handling of wastes, which cannot necessarily be accomplished within four years. For example, USWAG has raised concerns that there is limited manufacturing capacity for key conversion equipment, which could reasonably be expected to complicate the utilities' ability to collectively make the necessary engineering changes within a four-year timeframe. An additional consideration is that EPA expects that many facilities would need to obtain permits for new units or find alternative subtitle C capacity to receive the wastes diverted from surface impoundments. Also, facilities that use surface impoundments receiving CCRs to manage stormwater and nonhazardous wastewater will have to site and get permits for new stormwater management units before facility owners can cease utilizing existing units. The amount of time to achieve either of these alternatives relies, to some extent, on events beyond the facility's control; for example, the timeframes to obtain a permit for a new unit can vary substantially and, in large measure, are ultimately dictated by the permitting authority, rather than the applicant. This may be further complicated by the fact that location standards or on-site space limitations can restrict the opportunity for siting new units at the generating facility, requiring utilities to find off-site disposal facilities able to receive the special waste in the volumes in question.

In the 1984 amendments, Congress only allowed surface impoundments four years to cease receiving hazardous waste (or comply with minimum technological design requirements, etc.). Given the enormously greater volume of waste involved with CCR surface impoundments and the process changes that the facilities will need to implement to convert to dry handling, EPA believes it not practicable to require surface impoundments to cease receiving CCR waste or comply with the minimum technological requirements four years and that additional time is appropriate. (As noted below, facilities in most states will have significantly more time for planning, because the rules will not become effective in states authorized for the RCRA program before those states have amended their requirements consistent with today's rule; the state regulatory process will likely take several years.) On the other hand, as the risks predicted in the risk assessment are extraordinarily high (up to 2×10^{-2}), EPA believes that closure within the shortest practicable time is important.

Any modifications of section 3005(j) must meet the section 3004(x) stricture that the modification must still "assure protection of human health and the environment (42 U.S.C. 6924(x)." EPA believes that allowing three additional years for closure, under today's proposal, would be protective because surface impoundments subject to the closure requirements would be required (during this interim period) to have groundwater monitoring systems sufficient to detect releases of hazardous constituents into the groundwater, and take corrective action where releases were detected above drinking water levels.[131] Additionally, the median number of years until peak well water concentrations are reached for selenium and arsenic are estimated at 74 and 78 years, respectively, for unlined surface impoundments and 90 and 110 years, respectively, for clay-lined surface impoundments, reducing the likely risks posed over this five-year period.

In addition, although not directly relevant to leaching from these surface impoundments, we would also note (as described previously in this section) that the facility would be required to have an independent registered professional engineer certify that design of the impoundment is in accordance with recognized and generally accepted good engineering practices (RAGAGEP)[132] for the maximum volume of CCR slurry and wastewater that will be impounded therein, and that the design and management features ensure dam stability. Finally, the facilities will be required to conduct weekly inspections to ensure that any potentially hazardous condition or structural weakness will be quickly identified. Therefore, the additional timeframe that EPA is proposing to allow—needed to address practical realities—will "assure protection of human health and the environment. While groundwater monitoring, corrective action, and close oversight of these units is not, we believe, the most appropriate long-term solution, we do believe that these steps will protect public health and the environment in the short term while the permanent solutions are being implemented.

EPA recognizes that the costs of these requirements will be significant, especially for existing surface impoundments and similar units that handle wet CCRs. EPA also acknowledges that the date by which impoundments have to close is an important issue, affecting the costs of phase-out of wet handling and the ability of industry to comply. USWAG has argued strenuously against a closure requirement in the first place, and has asserted that, if such a requirement were imposed, industry would require ten years to comply.[133]

EPA is not persuaded by these comments. We appreciate the cost considerations but also believe it is important that these surface impoundments cease receiving wet-handled CCRs and proceed to closure as soon as practicable. The Agency believes that the time period proposed today is sufficient to provide industry the time necessary to convert from wet handling to dry handling of these wastes, close out existing units, and find or put in place new disposal capacity for these wastes. In addition, the Agency notes that TVA and other utilities have already decided, or are being required by states, to close existing impoundments, regardless of the requirements of today's proposed rule. As a result, EPA believes today's proposal would have less effect than industry commenters suggest because some facilities may be making these changes anyway and they reflect best management practices in today's environment. However, EPA solicits comments on whether seven years (5 years to cease receiving waste and 2 years to close) from the effective date to implement these provisions is an achievable time for facilities to comply.

[131] The Agency is also modifying the requirement that surface impoundments be dredged annually, based on RCRA section 3004(x). This is discussed in detail in section v (Proposed Land Disposal Restrictions) below.

[132] Recognized and generally accepted good engineering practices (RAGAGEPs) are engineering, operation, or maintenance activities based on established codes, standards, published technical reports or recommended practices (RP) or a similar document. RAGAGEPs detail generally approved ways to perform specific engineering, inspection or mechanical integrity activities. *See http://www.osha.gov/OshDoc/Directive_pdf/CPL_03-00-010.pdf.*

[133] In developing cost estimates for closing its surface impoundments, TVA also assumed that the process would take place over ten years.

EPA is interested in comments on procedural, as well as technical, issues (*e.g.,* time to allow permit modifications for new capacity or EPA or state approval of closure plans). As stated earlier, EPA does note that, in the 1984 amendments to RCRA, Congress required existing hazardous waste surface impoundments without liners to retrofit within four years if they are to continue operating. Congress also required impoundments which place hazardous wastes into impoundments to either treat the wastes first, or to use minimum technology impoundments, including a requirement to dredge the impoundment annually. *See* discussion of section 3005(j)(11) and implementing regulations above. As a practical matter, this meant that all but a very few surface impoundments ceased receiving hazardous wastes within this time period. Thus, a requirement that surface impoundments cease receiving liquid wastes in five years and close in seven years is consistent with Congressional direction on appropriate time periods to phase out the management of CCRs in surface impoundments. Further, as noted previously, these specific requirements will not go into effect in most cases until a state is authorized for this aspect of the RCRA program, which normally takes from two to five years after the regulations become federally effective (with some estimates as long as eight years), giving facilities substantial advance notice. (*See* discussion on when the rules become effective in section VII of this preamble.) For commenters who suggest a longer time period is needed, EPA solicits comment on how a longer time period would meet the section 3004(x) risk standard.

Whatever time period EPA selects, the Agency solicits comment on whether it should include a provision that would allow the regulatory Agency to provide additional time on a case-by-case basis because of site-specific issues (*e.g.,* particular technical difficulties or equipment availability outside the utility's control, as well as permitting delays). This provision might be modeled after the provision of 40 CFR 264.112 and 265.112 (Amendment of Plans), allowing facilities to delay closure of hazardous waste management units.

Commenters have also stated that, while it may be appropriate to require closure of most existing impoundments, some may be clearly safe. For example, existing impoundments theoretically may already have a composite liner, and present minimal threat of release (*e.g.,* because they are below grade or not far above grade). EPA solicits comment on whether a variance process would be appropriate allowing some impoundments or similar units that manage wet-handled CCRs to remain in operation because they present minimal risk to groundwater (*e.g.,* because they have a composite liner) and minimal risk of a catastrophic release (*e.g.,* as indicated by a low potential hazard rating under the Federal Guidelines for Dam Safety established by the Federal Emergency Management Agency). It should be noted that the statute already provides such a mechanism in section 3005 (j)(4) and (5) (based on making a so-called 'no-migration' demonstration—evidently Congress' view of what level of control is considered protective for hazardous waste impoundments not utilizing minimum technology controls [134]) and commenters should address whether this existing case-by-case mechanism should be utilized here. In such cases, the wastes might also meet current LDR treatment standards.

v. Proposed Land Disposal Restrictions

Through RCRA sections 3004 (d), (e), (f), and (g), Congress has prohibited the land disposal of hazardous waste unless the waste meets treatment standards established by EPA before the waste is disposed of, or is disposed of in units from which there will be no migration of hazardous constituents for as long as the waste remains hazardous. The treatment standards may be either a treatment level or a specified treatment method, and the treatment must substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized (RCRA section 3004(m)). If the hazardous waste has been treated to the level or by a method specified in the regulations (or if the waste as generated meets the treatment standard), the waste is not subject to any land disposal prohibition and may be disposed of in a land disposal unit which meets the requirements of 40 CFR parts 264 or 265 (the exception being for surface impoundments discussed in the preceding subsection and further below). For hazardous wastes identified or listed under RCRA section 3001 after the date of the 1984 amendments to RCRA subtitle C (the situation here), EPA is required to determine whether the waste shall be prohibited from one or more methods of land disposal within six months after the date of such identification or listing, and if EPA determines that one or more methods are prohibited, the Agency is also required to specify treatment levels or methods of treatment for the waste (RCRA section 3004(g)(4)).

In an effort to make treatment standards as uniform as possible, while adhering to the fundamental requirement that the standards must minimize threats to human health and the environment before hazardous wastes can be land disposed, EPA developed the Universal Treatment Standards (UTS) (codified at 40 CFR 268.48). Under the UTS, whenever technically and legally possible, the Agency adopts the same technology-based numerical limit for a hazardous constituent regardless of the type of hazardous waste in which the constituent is present. *See* 63 FR 28560 (May 26, 1998); 59 FR 47982 (September 19, 1994). The UTS, in turn, reflect the performance of Best Demonstrated Available Technologies (BDAT) of the constituents in question. These treatment standards can be met by any type of treatment, other than impermissible dilution, and wastes can satisfy the treatment standards as generated (*i.e.,* without being treated).

As explained above, section 3004(x) of RCRA authorizes the EPA Administrator to modify the requirements of sections (d), (e), (f), and (g) of section 3004 for Bevill wastes, including CCRs that EPA determines to regulate as hazardous, to take into account the special characteristics of the wastes, the practical difficulties associated with implementation of the requirements, and site-specific characteristics, so long as such modified requirements assure protection of human health and the environment.

In conjunction with a proposed listing, EPA is proposing to prohibit the land disposal of CCRs, unless they meet the applicable treatment standards. In addition, although CCRs could be disposed of without treatment in landfills and impoundments from which there will be no migration of hazardous constituents for as long as the waste remains hazardous, EPA doubts that such a unit exists, given the volumes of CCRs and their many (documented) release pathways discussed above. In any case, no-migration determinations are necessarily made on a case-by-case basis, and the burden is on petitioners to show that individual land disposal units satisfy the exacting standard. *See* 40 CFR section 268.6.

[134] See RCRA section 3004 (d), (e), (f), and (g) all of which define a land disposal unit as protective of human health and the environment if "it has been demonstrated to a reasonable degree of certainty that there will be no migration of hazardous constituents from the disposal unit * * * for as long as the wastes remain hazardous".

2. Proposed Treatment Standards for Non-Wastewaters (Dry CCRs)

For non-wastewaters (*i.e.,* dry CCRs), EPA is proposing that CCRs be subject to the UTS. As EPA has found repeatedly, this standard reflects the performance of Best Demonstrated Available Technology and so satisfies the requirements of section 3004 (m) (*see Hazardous Waste Treatment Council* v. *EPA,* 886 F. 2d 355, 363 (D.C. Cir. 1989)), and also does not force treatment past the point at which threats to human health and the environment are minimized (*see* 55 FR 6640, 6641–42 (Feb. 26, 1990)). These standards should be achievable by application of various available technologies, although data [135] indicate that a great portion (if not virtually all) dry CCRs meet these standards as generated.

3. Proposed Treatment Standards for Wastewaters (Wet-Handled CCRs)

EPA is also proposing standards for wastewater CCRs. As an initial matter, EPA is proposing to adopt a specific and different definition of wastewater for CCRs. Under the existing RCRA subtitle C rules, a wastewater is defined as one that contains less than 1% by weight total organic carbon (TOC) and less than 1% by weight total suspended solids (*i.e.,* the current wastewater definition for purposes of LDRs; *see* 40 CFR part 268.2 (f)). Functionally, the current definition of wastewaters would not include slurried fly ash or slurried FGD from wet air pollution control systems. EPA believes it important to distinguish between nonwastewaters which involve dry coal ash and surface impoundment systems which are commonly viewed as involving wastewaters. EPA, therefore, is proposing to create the distinction between wastewater and nonwastewater CCRs by classifying CCRs as wastewaters if the moisture content of the waste exceeds 50%. Thus, if CCRs contain more water than solids, the CCR would be classified as a wastewater, and would be subject to the LDR treatment standard for wastewaters. By proposing the criteria at 50% moisture, EPA believes new methods for pumping and disposal of high solids material without free liquids are still viable. EPA is proposing this definition to appropriately address risks associated with CCRs surface impoundments, which contain free liquids. However, the Agency requests comment on this alternative definition of wastewaters for purposes of determining which treatment standards the CCRs would be subject to.

As part of the proposed treatment standard, EPA is proposing that these wastewaters undergo solids removal so that the wastewaters contain no greater than 100 mg/l total suspended solids (TSS) and meet the UTS for wastewaters. This proposed level is consistent with wastewater treatment requirements based on Best Practicable Control Technology Currently Available for the Electric Power Generating Point Source Category (40 CFR section 423.12).[136] Solids separation is a base level water pollution control technology, which assures that the vast majority of coal ash and associated contaminants are removed and managed in landfills.

EPA is proposing that wastewaters meet the UTS for wastewaters at 40 CFR section 268.48 as the treatment standard for the liquid fraction. (The CCR solids removed from the wastewater stream would be a non-wastewater and would be subject to the UTS for non-wastewaters.) EPA believes dry disposal of the CCR solids will protect human health and the environment. As previously discussed, this is borne out by the results of the Agency's risk assessment and damage case assessments, which show that wet disposal poses the greatest risks of contaminant releases.

The Agency believes the proposed treatment methods will diminish the toxicity of the waste or substantially reduce the likelihood of migration of toxic constituents from the waste so that short-term and long-term threats to human health and the environment are minimized. If finalized, EPA will add new treatment method codes to the table of Technology Codes and Description of Technology-Based Standards at 40 CFR 268.42. EPA seeks comments on the proposed treatment standards.

4. Effective Date of the LDR Prohibitions

Land disposal prohibitions are to be effective immediately unless EPA finds that there is insufficient alternative protective treatment, recovery or disposal capacity for the wastes. RCRA section 3004(h)(2). National capacity variances can be for up to two years from the date of the prohibition. During the duration of a national capacity variance, the wastes do not require treatment in order to be land disposed. If they are disposed of in a landfill or surface impoundment, however, that unit must meet the minimum technology requirements of RCRA section 3004(o). RCRA section 3004 (h) and 40 CFR section 268.5 (h).[137]

In this case, EPA is proposing that the prohibition and treatment standards for nonwastewaters take effect within 6 months from the date of promulgation of the listing of CCRs as a special waste. We are proposing 6 months to allow time for owners and operators to set up analytic capacity and record-keeping mechanisms for dry CCR wastes, as well as for federal and state agencies to assure that implementation mechanisms are in place. We are not allocating additional time for treatment because our expectation is that all or virtually all dry CCRs meet the proposed treatment standards as generated. However, EPA solicits comment on this issue. EPA also notes that the proposed LDR prohibition and treatment standards would not take effect until programs in authorized states are authorized and the state implementing rules take effect, so this proposal effectively is for the prohibition and treatment standard requirement to take effect 6 months following the conclusion of the authorization process and effective date of authorized state rules. This should be ample time to come into compliance.

For wastewaters, however, under the authority of section 3004 (x), we are proposing that the prohibition and treatment standards take effect within five years of the prohibition. In practice, these requirements will have the effect of prohibiting disposal of wet-handled CCRs in surface impoundments after that date. The proposed date for the wastewater treatment standards would thus be the same as the proposed date that impoundments would stop receiving CCRs, and is being proposed for many of the same reasons. Surface impoundments, of course, are the land disposal units in which wastewaters are managed, so the issues are necessarily connected. As discussed in section VI. B. above, the statute allows owners and operators up to four years to retrofit existing surface impoundments to meet

[135] EPA's CCR constituent database which is available from the docket to this proposal.

[136] Although TSS is not a hazardous constituent, it is a reasonable surrogate of effective treatment performance here because TSS necessarily contain the metal hazardous constituents which are the object of treatment, and these metals will necessarily be removed as TSS are removed. See e.g.; *National Lime Ass'n* v. *EPA, 234 F. 3d 625, 639* (D.C. Cir. 2000) (even though particulate matter is not a hazardous air pollutant, it can be used as a permissible surrogate for treatment of hazardous air pollutant metals since those metals are removed by treatment as PM is removed).

[137] EPA is also authorized to grant up to a one-year extension, renewable for another year, of a prohibition effective date on a case-by-case basis. RCRA section 3004 (h)(3). Applicants must demonstrate that adequate alternative treatment, recovery, or disposal capacity for the petitioners waste cannot reasonably be made available by the effective date due to circumstances beyond the applicant's control, and that the petitioner has entered into a binding contractual commitment to construct or otherwise provide such capacity. 40 CFR 268.5.

the minimum technology requirements (or to close such surface impoundments), and EPA has interpreted this provision as applying to treatment surface impoundments receiving hazardous wastes otherwise prohibited from land disposal. *See* RCRA sections 3005 (j)(6) and 3005 (j)(11). As further explained above, EPA believes that an additional three years is needed for owners and operators to close surface impoundments—*i.e.* seven years in all—and is thus proposing a two year national capacity variance (as provided in RCRA section 3004(h)(2)) and a five year period for impoundment retrofitting yielding a seven year extension.

The legal basis for the proposal is 3004 (x) (which specifically authorizes modification of the section 3005 (j) requirements). Section 3005 (j) (11) allows untreated wastewaters to be managed in surface impoundments that do not meet the minimum technology requirements, but requires that residues in the impoundment be dredged at least annually for management elsewhere. Given the enormous volume of CCRs currently managed in surface impoundments, estimated at 29.4 million tons per year (within EPA's estimated range of 23.5 to 30.3 million tons for the total available U.S. hazardous waste disposal capacity), and the absence of alternative disposal capacity in the short-term, EPA believes annual dredging is impractical and would defeat the purpose of providing additional time to convert to the dry handling of CCRs. Moreover, in this short time, the utilities will be working to convert their processes to dry handling and it is not practicable or necessary to impose this additional requirement. Finally, as discussed previously, in the interim period before surface impoundments cease taking waste and are closed, numerous safeguards will be in place to protect public health and the environment, including ground water monitoring and the requirement to act on any releases quickly. Thus, while such measures are not a long-term solution, they will "assure protection of human health and the environment" in the short-term.

As this discussion clarifies, the issue of a national capacity extension for CCR wastewaters is really an issue of how long it will take to convert to dry handling and to find management capacity for solids dredged from impoundments, *i.e.* issues arising under section 3005 (j)(11) of the statute. EPA, therefore, believes it has the authority and that it is appropriate to use section 3004 (x) to extend the national capacity period in order to convert to dry handling.[138]

EPA is further proposing that during the national capacity variance (the initial two years of the proposed two years plus five year extension of otherwise-applicable requirements), CCR wastewaters could continue to be managed in impoundments that do not meet the minimum technology requirements. The reasons are identical to those allowing such impoundments to receive CCRs for the remainder of the proposed extension period.

EPA solicits comment on these proposals, including comment on whether further time extensions are actually needed in light of the already extended time which will be afforded by the state authorization process.

C. Applicability of Subtitle C Regulations

The discussion in this section describes the existing technical standards required in 40 CFR parts 264/265/267. However, persons who generate and transport CCRs, under the subtitle C alternative, would also be subject to the generator (40 CFR part 262) and transporter (40 CFR part 263) requirements. Although EPA presents this to provide the public with background information as noted previously, EPA is not proposing to modify these standards, nor to reopen the requirements.

1. General Facility Requirements, including Location Restrictions. Under the existing regulations, all of the following requirements would apply: the general facility standards of 40 CFR parts 264/265/267 (Subpart B), the preparedness and prevention standards of 40 CFR parts 264/265/267 (Subpart C), the contingency plan and emergency procedures of 40 CFR parts 264/265/267 (Subpart D), and the manifest system, recordkeeping, and reporting requirements of 40 CFR parts 264/265/267 (Subpart E). Consistent with section 264.18, the regulations would include location standards prohibiting the siting of new treatment, storage, or disposal units in a 100-year floodplain (unless the facility made a specific demonstration)[139] and seismic impact areas would be prohibited.[140]

2. Ground water monitoring/corrective action for regulated units. The subtitle C alternative to today's proposed rule would require the current ground water monitoring and corrective action requirements of 40 CFR parts 264/265 for regulated landfills and surface impoundments, without modification. Consistent with 40 CFR 265.90, existing CCR disposal units would be required to install groundwater monitoring systems within one year of the effective date of these regulations. The facility would operate under the self-implementing interim status requirements of 40 CFR part 265 until the regulatory authority imposed the specific requirements of 40 CFR part 264 through the RCRA permitting process. Generally, 40 CFR parts 264/265 require groundwater monitoring systems that consist of enough wells, installed at appropriate locations and depths, to yield ground water samples from the uppermost aquifer that represent the quality of background groundwater that has not been affected by leakage from the disposal unit. A detection monitoring program would be required to detect releases to groundwater of CCR constituents listed in the facility permit (these constituents, we believe, would be the metals typically identified as constituents of concern in CCRs). Monitoring frequency is determined by the EPA Regional Administrator or, more typically the authorized state, and required in the RCRA permit. If any of the constituents listed in the facility permit are detected at levels that constitute statistically significant evidence of contamination, the owner or operator must initiate a compliance monitoring program to determine whether the disposal units are in

[138] EPA notes in addition that it is authorized under section 3004 (x) to modify the requirements of LDR prohibitions under section 3004 (g), and EPA views capacity variances related to such prohibitions as within the scope of that section 3004 (x) authorization.

[139] A 100-year flood means a flood that as a one-percent or greater chance of recurring in any given year or a flood of a magnitude equaled or exceeded once in 100 years on the average over a significantly long period.

[140] A seismic impact area means an area with a two percent or greater probability that the maximum horizontal acceleration in lithified earth material, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10 g in 50 years. Note that in the pre-1997 editions of the NEHRP (National Earthquake Hazards Reduction Program) provisions, seismic hazards around the nation were defined at a uniform 10 percent probability of exceedance in 50 years. Since the 1997 NEHRP Provisions, however, the seismic design maps have been redefined such that for most regions of the nation, the maximum considered earthquake ground motion is defined with uniform probability of exceedance of 2 percent in 50 years. The change in the exceedance probability (from 10% to 2%) was responsive to comments that the use of 10 percent probability of exceedance in 50 years is not sufficiently conservative in the central and eastern United States where earthquakes are expected to occur infrequently.

compliance with the groundwater protection standards established by EPA or the state and specified in the permit. (*See* 40 CFR part 264, subpart F.)

Under 40 CFR part 264, subpart F, if the results of the compliance monitoring program indicate exceedances of any of the constituent levels listed in the permit for the groundwater protection standard, the owner or operator would have to initiate corrective action to achieve compliance with the groundwater protection standards.

3. Storage. EPA is not proposing to modify the existing 40 CFR parts 264/265/267 storage standards. These regulations establish design and operating requirements for containers, tanks, and buildings used to treat or store hazardous wastes. For containers, the regulations establish requirements for the storage of hazardous waste, including a requirement for secondary containment. However, if the wastes do not contain free liquids, they need not require a secondary containment system, provided the storage area is sloped or is otherwise designed and operated to drain and remove liquid resulting from precipitation or the containers are elevated or otherwise protected from contact with accumulated liquid.

For new tanks, owners or operators must submit to EPA or the authorized states an assessment certified by an independent registered professional engineer that the foundation, structural support, seams, connections, and pressure controls (if applicable) are adequately designed and that the tank system has sufficient structural strength, compatibility with the waste(s) to be stored or treated, and corrosion protection to ensure that the tank will not collapse, rupture, or fail. Tank systems are required to have secondary containment under section 264.193, unless they receive a specific variance; however, tanks that contain no free liquids and are in buildings with an impermeable floor do not require secondary containment. New tanks (that are required to have secondary containment) must have secondary containment when constructed; existing tanks (that are required to have secondary containment) must come into compliance within two years of the rule's effective date (or when the tank has reached fifteen years of age). Section 264.193 specifically describes the secondary containment required, and the variance process.

Containment buildings must be completely enclosed with a floor, walls, and a roof to prevent exposure to the elements (*e.g.,* precipitation, wind, run-on), and to assure containment of the managed wastes. Buildings must be designed so that they have sufficient structural strength to prevent collapse or other failure, and all surfaces to be in contact with hazardous wastes must be chemically compatible with those wastes.

Recently, representatives of the utility industry have stated their view that CCRs cannot be practically or cost effectively managed under the existing 40 CFR parts 264/265/267 storage standards, and that these standards impose significant costs without meaningful benefits when applied specifically to CCRs.[141] In particular, they cite the very large volume of wastes that must be handled on a daily basis, and the extensive storage and other infrastructure already in place that might have to be retrofitted if the existing 40 CFR parts 264/265/267 storage requirements applied. For example, they state that some CCRs are stored prior to disposal in silos which are not located within a building and may contain free liquids. As a result, under the subtitle C requirements, the owner or operator would be required to construct a building with an impermeable floor, or construct a secondary containment system around the silo (alternatively, they could go through a variance process with the regulatory Agency).

EPA believes that the variance process allowing alternatives to secondary containment would address the concerns raised by industry. The Agency, however, recognizes that the variance process imposes time and resource burdens not only on industry, but on the regulatory agencies. EPA notes that, in the case of larger volume, higher toxicity mineral processing materials being reclaimed, the Agency developed special storage standards under RCRA subtitle C, and it solicits comments on whether those or similar-type standards would be appropriate for CCRs.[142]

Namely, in 40 CFR 261.4(a)(17), EPA required that tanks, containers, and buildings handling this material must be free standing and not a surface impoundment (as defined in the definitions section of this proposal) and be manufactured of a material suitable for storage of its contents. (While not specifically mentioned in this section, we would also consider a requirement that such materials meet appropriate specifications, such as those established either by the American Society of Testing Materials (ASTM), the American Petroleum Institute (API), or Underwriters Laboratories, Inc. (UL) standards.) Buildings must be man-made structures and have floors constructed from non-earthen materials, have walls, and have a roof suitable for diverting rainwater away from the foundation. A building may also have doors or removable sections to enable trucks or machines access.

EPA solicits comments on the practicality of the proposed subtitle C storage requirements for CCRs, the workability of the existing variance process, and the alternative requirements based, for example, on the mining and mineral processing wastes storage requirements. EPA has not developed cost estimates for managing CCRs in compliance with the 40 CFR parts 264/265/267 storage standards. EPA solicits specific comments on these potential costs.

4. Closure and Post-Closure Care. Under the RCRA subtitle C alternative to this co-proposal, all of the requirements for closure and post-closure care of landfills and surface impoundments would apply to those landfills that continue to receive CCRs, or otherwise actively manage them, and to those surface impoundments that have not completed closure, when the requirements of a final rule become effective. The 40 CFR parts 264/265 landfill and surface impoundment requirements establish cover requirements (*e.g.,* the cover must have a permeability less than or equal to the permeability of any bottom liner system and must minimize the migration of liquids through the closed landfill). These requirements are generally applied through a closure-plan or permit approval process. Also, the regulations require 30 years of post-closure care, including maintenance of the cap and ground-water monitoring, unless an alternative post-closure period is established by EPA or the authorized state.

5. Corrective action. EPA is also not proposing to modify the existing corrective action requirements, including the facility-wide corrective action requirements of RCRA under section 3004(u), section 3008(h), and 40 CFR 264.101. Under these requirements, landfills that continue to receive CCRs or otherwise actively manage them, and surface impoundments that have not

[141] While the utility industry did not specifically mention the 40 CFR part 267 storage standards, we presume that they would make the same technical arguments with respect to those standards.

[142] Land Disposal Restrictions Phase IV: Final Rule Promulgating Treatment Standards for Metal Wastes and Mineral Processing Wastes; Mineral Processing Secondary Materials and Bevill Exclusion Issues; Treatment Standards for Hazardous Soils, and Exclusion of Recycled Wood Preserving Wastewaters; Final Rule (*http://www.epa.gov/EPA-WASTE/1998/May/Day-26/f989.htm*).

completed closure on the date the final rule becomes effective, will be requires to characterize, and as necessary remediate, releases of CCRs or hazardous constituents. Section 3004(x) provides EPA the flexibility to modify corrective action requirements for facilities managing CCRs, including facility-wide corrective action (assuming EPA can reasonably determine that an alternative is protective of human health and the environment). The facility-wide corrective action requirement applies to all solid waste management units from which there have been releases of hazardous wastes or hazardous constituents; however, EPA does not *see* a compelling reason to change the corrective action requirements. Imposing corrective action requirements, including facility-wide corrective action, will assure that closed and inactive units at the facility are properly characterized and, if necessary, remediated, especially since many of these closed or inactive units are unlined. Nevertheless, EPA solicits comment on whether EPA should modify the corrective action requirements under section 3004(x) of RCRA. Commenters should specifically address the issue of how other alternatives could be protective without mandating corrective action as needed for all solid waste management units from which there have been releases of hazardous waste or hazardous constituents at the facility.

6. Financial assurance. EPA is also not proposing to modify the existing financial assurance requirements at 40 CFR parts 264/265/267, subpart H. Financial assurance must be adequate to cover the estimated costs of closure and post-closure care (including facility-wide corrective action, as needed), and specific levels of financial assurance are required to cover liability for bodily injury and property damage to third parties caused by sudden accidental occurrences arising from operations of the facility. Allowable financial assurance mechanisms are trust funds, surety bonds, letters of credit, insurance policies, corporate guarantees, and demonstrations and documentation that owners or operators of the facility have sufficient assets to cover closure, post-closure care, and liability. The regulations also require financial assurance for corrective action under section 264.101.

As we have estimated that 53 local governments own and operate coal-fired electric utilities, EPA seeks comment on whether a financial test similar to that in 40 CFR 258.74(f) in the Criteria for Municipal Solid Waste Landfills should be established for local governments that own and operate coal-fired power plants.

7. Permitting requirements. Under the RCRA subtitle C alternative, facilities that manage CCRs (in this case, facilities with landfills and surface impoundments, and other possible management units used to store or dispose of CCRs, or generating facilities that store CCRs destined for off-site disposal) must obtain a permit from EPA or from the authorized state. The effect of EPA's proposed listing would extend these permitting requirements to those facilities managing special wastes regulated under subtitle C of RCRA. Parts 124, 267 and 270 detail the specific procedures for the issuance and modification of permits, including public participation, and through the permit process regulatory agencies impose technical design and management standards of 40 CFR parts 264/267. Facilities with landfills that are in existence on the effective date of the regulation (which in this case would generally be the effective date of the state regulations establishing the federal CCR requirements)—which receive CCRs or actively manage CCRs—are eligible for "interim status" under federal regulations, providing they comply with the requirements of 40 CFR section 270.70. By contrast, facilities with surface impoundments that have not completed closure as outlined in this proposal would be subject to the existing permitting requirements, irrespective of whether they continue to receive CCRs into the unit or to actively manage CCRs. While facilities are in interim status, they are subject to the largely self-implementing requirements of 40 CFR part 265. As noted previously, in a final regulation, EPA would make conforming changes to these parts of the CFR to make it clear that the requirements apply to facilities that manage either hazardous wastes or special wastes regulated under subtitle C.

8. EPA is Not Proposing to Apply the Subtitle C Requirements to CCRs from Certain On-Going State or Federally Required Cleanups. Under the subtitle C alternative, the Agency is proposing to allow state or federally-required cleanups commenced prior to the effective date of the final rule to be completed in accordance with the requirements determined to be appropriate for the specific cleanup. EPA's rationale for this decision is two-fold. First, for state or federally required cleanups that already commenced and are continuing, the state or federal government has entered into an administrative agreement with the facility owner or operator which specifies remedies, clean-up goals, and timelines that were determined to be protective of human health and the environment, based on the conditions at the site. The overseeing Agency will also be able to ensure that the cleanup waste, if sent off-site (which may sometimes be necessary) will go to appropriately designed and permitted facilities. Second, altering the requirements for cleanups currently underway would be disruptive and could cause significant delays in achieving clean-up goals. Once the rule becomes final, EPA or the state will be able to avail themselves of regulations under RCRA designed specifically for cleanup. However, the Agency takes comment on this proposed provision.

D. CERCLA Designation and Reportable Quantities

Under current law and regulations, all hazardous wastes listed under RCRA and codified in 40 CFR 261.31 through 261.33, and special wastes under 261.50 if the proposed special waste listing is finalized, as well as any solid waste that is not excluded from regulation as a hazardous waste under 40 CFR 261.4(b) and that exhibits one or more of the characteristics of a RCRA hazardous waste (as defined in §§ 261.21 through 261.24), are hazardous substances under CERCLA, as amended (*see* CERCLA section 101(14)(C)). CERCLA hazardous substances are listed in Table 302.4 at 40 CFR 302.4 along with their reportable quantities (RQs). If a hazardous substance is released in an amount that equals or exceeds its RQ within a 24-hour period, the release must be reported immediately to the National Response Center (NRC) pursuant to CERCLA section 103.

Thus, under this subtitle C alternative, and as EPA does with any other listed waste, the Agency is proposing to also list CCRs as a CERCLA hazardous substance in Table 302.4 of 40 CFR 302.4. The key constituents of concern in CCRs are already listed as hazardous substances under CERCLA (*i.e.,* arsenic, cadmium, mercury, selenium), and therefore persons who spill or release CCRs already have reporting obligations, depending on the volume of the spill. Typically, under current CERCLA requirements, a person releasing CCRs, for example, would report depending on his estimate of the amount of arsenic or other constituents contained in the release.

Typically, when EPA lists a new waste subject to RCRA subtitle C, the statutory one-pound RQ is applied to the waste. However, EPA is proposing two alternative methods to adjust the one-pound statutory RQ. The first method, one traditionally utilized by the Agency, adjusts the RQ based on the lowest RQ of the most toxic substance present in the waste. The second method, as part of the Agency's effort to review and re-evaluate its methods for CERCLA designation and RQ adjustment, adjusts the one-pound statutory RQ based upon the Agency's characterization and physical properties of the complex mixtures which comprise the waste to be designated as S001. The Agency invites comment on both methods, and may, based upon these comments and further information, decide to go forward with either method or both methods.

1. Reporting Requirements

Under CERCLA section 103(a), the person in charge of a vessel or facility from which a CERCLA hazardous substance has been released in a quantity that is equal to or exceeds its RQ within a 24-hour period must immediately notify the NRC as soon as that person has knowledge of the release. The toll-free telephone number of the NRC is 1–800–424–8802; in the Washington, DC, metropolitan area, the number is (202) 267–2675. In addition to the reporting requirement under CERCLA, section 304 of the Emergency Planning and Community Right-to-Know Act (EPCRA) requires owners or operators of certain facilities to report releases of extremely hazardous substances and CERCLA hazardous substances to state and local authorities. The EPCRA section 304 notification must be given immediately after the release of an RQ (or more) within a 24-hour period to the community emergency coordinator of the local emergency planning committee (LEPC) for any area likely to be affected by the release and to the state emergency response commission (SERC) of any state likely to be affected by the release.

Under section 102(b) of CERCLA, all hazardous substances (as defined by CERCLA section 101(14)) have a statutory RQ of one pound, unless and until the RQ is adjusted by regulation. In this rule, EPA is proposing to list CCRs that are generated by electric utility and independent power producers that are intended for disposal (and not beneficially used), as special wastes subject to regulation under subtitle C of RCRA. In order to coordinate the RCRA and CERCLA rulemakings with respect to the new special waste listing, the Agency is also proposing adjustments to the one-pound statutory RQs for this special waste stream.

2. Basis for RQs and Adjustments

EPA's methodology for adjusting the RQs of individual hazardous substances begins with an evaluation of the intrinsic physical, chemical, and toxicological properties of each hazardous substance. The intrinsic properties examined, called "primary criteria," are aquatic toxicity, mammalian toxicity (oral, dermal, and inhalation), ignitability, reactivity, chronic toxicity, and potential carcinogenicity.

Generally, for each intrinsic property, EPA ranks the hazardous substance on a five-tier scale, associating a specific range of values on each scale with an RQ value of 1, 10, 100, 1,000, or 5,000 pounds. The data for each hazardous substance are evaluated using the various primary criteria; each hazardous substance may receive several tentative RQ values based on its particular intrinsic properties. The lowest of the tentative RQs becomes the "primary criteria RQ" for that substance.

After the primary criteria RQ are assigned, the substances are further evaluated for their susceptibility to certain degradative processes, which are used as secondary adjustment criteria. These natural degradative processes are biodegradation, hydrolysis, and photolysis (BHP). If a hazardous substance, when released into the environment, degrades relatively rapidly to a less hazardous form by one or more of the BHP processes, its RQ (as determined by the primary RQ adjustment criteria) is generally raised by one level. Conversely, if a hazardous substance degrades to a more hazardous product after its release, the original substance is assigned an RQ equal to the RQ for the more hazardous substance, which may be one or more levels lower than the RQ for the original substance. Table 7 presents the RQ for each of the constituents of concern in CCRs taken from Table 302.4—List of Hazardous Substances and Reportable Quantities at 40 CFR 302.4.

TABLE 7—REPORTABLE QUANTITIES OF CONSTITUENTS OF CONCERN

Hazardous waste No.	Constituent of concern	RQ Pounds (Kg)
S001	Antimony	5000 (2270)
	Arsenic	1 (0.454)
	Barium	No RQ
	Beryllium	10 (4.54)
	Cadmium	10 (4.54)
	Chromium	5000 (2270)
	Lead	10 (4.54)
	Mercury	1 (0.454)
	Nickel	100 (45.4)
	Selenium	100 (45.4)
	Silver	1000 (454)
	Thallium	1000 (454)

The standard methodology used to adjust the RQs for RCRA wastes is based on an analysis of the hazardous constituents of the waste streams. EPA determines an RQ for each hazardous constituent within the waste stream and establishes the lowest RQ value of these constituents as the adjusted RQ for the waste stream. EPA is proposing to use the same methodology to adjust RQs for listed special wastes. In this notice, EPA is proposing a one-pound RQ for listed CCRs based on the one pound RQs for arsenic and mercury (*i.e.,* the two constituents within CCRs with the lowest RQ). In this same rule, however, EPA is also proposing that an alternative method for adjusting the RQ of the CCR wastes also can be used in lieu of the one pound RQ.

3. Application of the CERCLA Mixture Rule to Listed CCR

Although EPA is proposing a one-pound RQ for CCRs listed as a special waste, we are also proposing to allow the owner or operator to use the maximum observed concentrations of the constituents within the listed CCR wastes in determining when to report releases of the waste.

For listed CCR wastes, where the actual concentrations of the hazardous constituents in the CCRs are not known and the waste meets the S001 listing description, EPA is proposing that persons managing CCR waste have the option of reporting on the basis of the maximum observed concentrations that have been identified by EPA (*see* Table 8 below). Thus, although actual knowledge of constituent concentrations may not be known, assumptions can be made of the concentrations based on the EPA identified maximum concentrations. These assumptions are based on actual sampling data, specifically the maximum observed concentrations of hazardous constituents in CCRs.[143] Table 7 identifies the hazardous constituents for CCRs, their maximum observed concentrations in parts per million (ppm), the constituents' RQs, and the number of pounds of CCRs needed to contain an RQ of each constituent for the CCR to be reported.

TABLE 8—POUNDS REQUIRED TO CONTAIN RQ FOR EACH CONSTITUENT OF LISTED CCR

Waste stream constituent	Maximum ppm	RQ (lbs)	Pounds required to contain RQ
CCR	....	1	
Antimony	3,100	5,000	1,612,903
Arsenic	773	1	1,294
Barium	7,230	No RQ	No RQ
Beryllium	31	10	322,581
Cadmium	760	10	13,158
Chromium	5,970	5,000	837,521
Lead	1,453	10	6,883
Mercury	384	1	2,604
Nickel	6,301	100	15,871
Selenium	673	100	148,588
Silver	338	1,000	2,958,580
Thallium	100	1,000	10,000,000

For example, if listed CCR wastes are released from a facility, and the actual concentrations of the waste's constituents are not known, it may be assumed that the concentrations will not exceed those listed above in Table 8. Thus, applying the mixture rule, the RQ threshold for arsenic in this waste is 1,294 pounds—that is, 1,294 pounds of listed CCR waste would need to be released to reach the RQ for arsenic. Reporting would be required only when an RQ or more of any hazardous constituent is released.

Where the concentration levels of all hazardous constituents are known, the traditional mixture rule would apply. Under this scenario, if the actual concentration of arsenic is 100 ppm, 10,000 pounds of the listed CCR waste would need to be released to reach the RQ for arsenic. As applied to listed CCR waste, EPA's proposed approach reduces the burden of notification requirements for the regulated community and adequately protects human health and the environment.

The modified interpretation of the mixture rule (40 CFR 302.6) as it applies to listed CCR wastes in this proposal is consistent with EPA's approach in a final rule listing four petroleum refining wastes (K169, K170, K171, and K172) as RCRA hazardous wastes and CERCLA hazardous substances (*see* 63 FR 42110, Aug. 6, 1998). In that rule, the Agency promulgated a change to the regulations and its interpretation of the mixture rule to allow facilities to consider the maximum observed concentrations for the constituents of the petroleum refining wastes in determining when to report releases of the four wastes. EPA codified this change to its mixture rule interpretation in 40 CFR 302.6(b)(1) as a new subparagraph (iii). In another rule, EPA also followed this approach in the final rule listing two chlorinated aliphatic production wastes (K174 and K175) as RCRA hazardous wastes and CERCLA hazardous substances (*see* 65 FR 67068, Nov. 8, 2000). If the proposed subtitle C alternative becomes final, EPA may modify 40 CFR section 302.6(b)(1) to extend the modified interpretation of the mixture rule to include listed CCR wastes.

4. Correction of Table of Maximum Observed Constituent Concentrations Identified by EPA

When the final rule that listed Chlorinated Aliphatics Production Wastes was published in the Code of Federal Regulations (CFR), the existing table that provided the maximum observed constituent concentrations for petroleum refining wastes (K169, K170, K171, and K172) was inadvertently replaced instead of amended to add the maximum observed constituent concentrations for the chlorinated aliphatic production wastes (K174 and K175). Therefore, the Agency is at this time proposing to correct that inadvertent removal of the petroleum refining wastes by publishing a complete table that includes, the petroleum refining wastes, the chlorinated aliphatic production wastes, and now the CCR wastes (*e.g.,* K169, K170, K171, K172, K174, K175, and S001).

E. Listing of CCR as Special Wastes To Address Perceived Stigma Issue

Commenters suggested that the listing of CCRs as a hazardous waste will impose a stigma on their beneficial use, and significantly curtail these uses. EPA questions this assertion, in fact, our experience suggests that the increased costs of disposal of CCRs as a result of regulation of CCRs under RCRA subtitle C would create a strong economic incentive for increased beneficial uses of CCRs. We also believe that the increased costs of disposal of CCRs, as a result of regulation of CCR disposal, but not beneficial uses, should achieve increased usage in non-regulated beneficial uses, simply as a result of the economics of supply and demand. The economic driver—availability of a low-cost, functionally equivalent or often

[143] EPA's CCR constituent concentrations database is available in the docket to this notice.

superior substitute for other raw materials—will continue to make CCRs an increasingly desirable product. Furthermore, it has been EPA's experience in developing and implementing RCRA regulation and elsewhere that material inevitably flows to less regulated applications.

However, with that said, the electric utility industry, the states, and those companies that beneficially use CCRs have nevertheless commented that listing of CCRs as a RCRA subtitle C waste will impose a stigma on their beneficial use and significantly curtail these uses. In their view, even an action that regulates only CCRs destined for disposal as RCRA subtitle C waste, but retains the Bevill exemption for beneficial uses, would have this adverse effect. Finally, the states particularly have commented that, by operation of state law, the beneficial use of CCRs would be prohibited under many states' beneficial use programs, if EPA were to designate CCRs destined for disposal as a RCRA subtitle C waste. Unlike the incentive effect introduced by increased disposal costs in which firms rationally try to avoid higher costs or seek lower cost of raw materials, the idea that there will be a stigma effect rests on an assumption that stigma would alter consumer preferences thereby decreasing end-users' willingness to pay for products that include CCPs. This would have the practical effect of shifting the aggregate CCP demand curve downward.

Some of the other comments that have been made include: (1) Beneficially used CCRs are the same material as that which would be considered hazardous; this asymmetry increases confusion and the probability of lawsuits, however, unwarranted, (2) while the supply of CCRs to be beneficially used may increase given the additional incentives to avoid disposal costs, the consumer demand may decrease as negative perceptions are not always based on reason, (3) any negative impact on beneficial use will require more reliance on virgin materials with higher GHG and environmental footprints, (4) state support may be weakened or eliminated, even in states that are friendly to beneficial use, (5) competitors who use virgin or other materials are taking advantage of the hazardous waste designation by using scare tactics and threats of litigation to get customers to stop using products containing CCRs, (6) customers are already raising questions about the safety of products that contain CCRs, and (7) uncertainty is already hurting business as customers are switching to products where there is less regulatory risk and potential for environmental liabilities. For example, one commenter stated that they have received requests to stop selling boiler slag for ice control due to potential liability.

EPA is concerned about potential stigma and, as we have stated previously, we do not wish to discourage environmentally sound beneficial uses of CCRs. In looking to evaluate this issue, we believe it is first important to understand that the proposed rule (if the subtitle C alternative is finalized) would regulate CCRs under subtitle C of RCRA only if they are destined for disposal in landfills and surface impoundments, and would leave the Bevill determination in effect for the beneficial use of CCRs. That is, the legal status of CCRs that are beneficially used would remain entirely unchanged (*i.e.,* they would not be regulated under subtitle C of RCRA as a hazardous waste, nor subject to any federal non-hazardous waste requirements). EPA is proposing to regulate the disposal of CCRs under subtitle C of RCRA because of the specific nature of disposal practices and the specific risks these practices involve—that is, the disposal of CCRs in (often unlined) landfills or surface impoundments, with millions of tons placed in a concentrated location. The beneficial uses that EPA identifies as excluded under the Bevill amendment, for the most part, present a significantly different picture, and a significantly different risk profile. As a result, EPA is explicitly not proposing to change their Bevill status (although we do take comment on whether "unconsolidated uses" of CCRs need to be subject to federal regulation). (For further discussion of the beneficial use of CCRs, *see* section IV. D in this preamble.)

Furthermore, in today's preamble, we make it clear that certain uses of CCRs—*e.g.,* FGD gypsum in wallboard—do not involve "waste" management at all; rather, the material is a legitimate co-product that, under most configurations, has not been discarded in the first place and, therefore, would not be considered a "solid waste" under RCRA. Moreover, EPA's experience suggests that it is unlikely that a material that is not a waste in the first place would be stigmatized, particularly when used in a consolidated form and while continuing to meet long established product specifications.

In fact, EPA's experience with past waste regulation, and with how hazardous waste and other hazardous materials subject to regulation under subtitle C are used and recycled, suggests that a hazardous waste "label" does not impose a significant barrier to its beneficial use and that non-regulated uses will increase as the costs of disposal increase. There are a number of examples that illustrate these points, although admittedly many of these products are not used in residential settings:

- Electric arc furnace dust is a listed hazardous waste (K061), and yet it is a highly recycled material. Specifically, between 2001 and 2007, approximately 42% to 51% of K061 was recycled (according to Biennial Reporting System (BRS) data). Both currently and historically, it has been used as an ingredient in fertilizer and in making steel, and in the production of zinc products, including pharmaceutical materials. Slag from the smelting of K061 is in high demand for use in road construction.[144] In fact, there is little doubt that without its regulation as a hazardous waste, a significantly greater amount of electric arc further dust would be diverted from recycling to disposal in non-hazardous waste landfills.
- Electroplating wastewater sludge is a listed hazardous waste (F006) that is recycled for its copper, zinc, and nickel content for use in the commercial market. In 2007, approximately 35% of F006 material was recycled (according to BRS data). These materials do not appear to be stigmatized in the marketplace.
- Chat, a Superfund mining cleanup waste with lead, cadmium and zinc contamination, is used in road construction in Oklahoma and the surrounding states.[145] In this case, the very waste that has triggered an expensive Superfund cleanup is successfully offered in the marketplace as a raw material in road building. The alternative costs of disposal in this case are a significant driver in the beneficial use of this material, and the Superfund origin of the material has not served as a barrier to its use.
- Used oil is regulated under RCRA subtitle C standards. While used oil that is recycled is subject to a separate set of standards under subtitle C (and is not identified as a hazardous waste), "stigma" does not prevent home do-it-yourselfers from collecting used oil, or automotive shops from accepting it and sending it on for recovery. Collected used oil may be re-refined, reused, or used as fuel in boilers, often at the site

[144] According to the most recently available data, in 2008 *Horsehead* produced about 300,000 tons per year of an Iron-Rich Material (IRM) as a by-product of its dust recycling process, and in 2009 *Inmetco* produced close to 20,000 tons per year. PADEP asserts that these plants cannot meet the demands for use of the slag by PennDOT.

[145] 40 CFR part 260, 39331–39353.

where it is collected. Safety Kleen reported that in 2008, the company recycled 200 million gallons of used oil. (This example is almost directly analogous to the situation with respect to CCRs, although for CCRs, we are not proposing to subject them to any management standards when used or recycled, but, as in the case of used oil, this alternative would avoid labeling CCR's as "hazardous waste," even while relying on subtitle C authority.)

- Spent etchants are directly used as ingredients in the production of a copper micronutrient for livestock; and
- Spent solvents that are generated from metals parts washing and are generally hazardous wastes before reclamation are directly used in the production of roofing shingles.

Furthermore, common products and product ingredients routinely used at home (*e.g.,* motor oil; gasoline; many common drain cleaners and household cleaners; and cathode ray tube monitors for TVs and computers) are hazardous wastes in other contexts. This includes fluorescent lamps (and CFLs) which are potentially hazardous because of mercury. Consumers are generally comfortable with these products, and their regulatory status does not discourage their use. Given this level of acceptance, EPA questions whether CCR-based materials that might be used in the home, like concrete or wallboard, would be likely to raise concerns where they are safely incorporated into a product.

Certain commenters have also expressed the concern that standards-setting organizations might prohibit the use of CCRs in specific products or materials in their voluntary standards. Recently, chairpersons of the American Standards and Testing Materials (ASTM) International Committee C09, and its subcommittee, C09.24, in a December 23, 2009 letter indicated that ASTM would remove fly ash from the project specifications in its concrete standard if EPA determined that CCRs were a hazardous waste when disposed. However, it remains unclear whether ASTM would ultimately adopt this position, in light of EPA's decision not to revise the regulatory status of CCRs destined for beneficial use. Further ASTM standards are developed through an open consensus process, and they currently apply to the use of numerous hazardous materials in construction and other activities. For example, ASTM provides specifications for the reuse of solvents and, thus, by implication, does not appear to take issue with the use of these recycled secondary materials, despite their classification as hazardous wastes.[146]

Others take a different view on how standard-setting organizations will react. Most notably, a U.S. Green Building Council representative was referenced in the New York Times as saying that LEED incentives for using fly ash in concrete would remain in place, even under an EPA hazardous waste determination.[147] If the Green Building Council (along with EPA) continues to recognize fly ash as an environmentally beneficial substitute for Portland cement, the use of this material is unlikely to decrease solely because of "stigma" concerns. Additionally, we believe it is unlikely that ASTM will prohibit the use of fly ash in concrete under its standards solely because of a determination that fly ash is regulated under subtitle C of RCRA when it is discarded, especially given that this use of fly ash is widely accepted throughout the world as a practice that improves the performance of concrete, it is one of the most cost-effective near-term strategies to reduce GHG emissions, and there is no evidence of meaningful risk, nor any reason to think there might be, involved with its use in cement or concrete.

Finally, many states commented that their statutes or regulations prohibit the use of hazardous wastes in their state beneficial use programs and, therefore, that if EPA lists CCRs as hazardous wastes (even if only when intended for disposal), their use would be precluded in those states. EPA reviewed the regulations of ten states with the highest consumption of fly ash and concluded that, while these states do not generally allow the use of hazardous waste in their beneficial use programs, this general prohibition would not necessarily prohibit the beneficial use of CCRs under the proposal that EPA outlines in this rule. Beneficially used CCRs would remain Bevill-exempt solid wastes, or in some cases, would not be considered wastes at all and thus, the legal status of such CCRs may not be affected by EPA's proposed RCRA subtitle C rule. As an example, the use of slag derived from electric furnace dust (K061) is regulated under Pennsylvania's beneficial use program, despite the fact that it is derived from a listed hazardous waste. However, we are also aware that, in the case of Florida, its state definition of hazardous waste would likely prohibit the beneficial use of CCRs were the co-proposed RCRA subtitle C regulation finalized and were there no change to Florida's definition of hazardous waste.

The primary concern raised by these commenters is the fact that CCRs would be labeled a "hazardous waste" (even if only when disposed) and will change the public perception of products made from CCRs. To address this concern, EPA is proposing, as one alternative, to codify the listing in a separate, unique section of the regulations. Currently, hazardous wastes are listed in 40 CFR 261, Subpart D, which identifies the currently regulated industrial wastes, and which is labeled, "Lists of Hazardous Wastes." EPA would create a new Subpart F and label the section as "List of Special Wastes Subject to Subtitle C," to distinguish it from the industrial hazardous wastes. The regulations would identify CCRs as a "Special Waste" rather than a K-listed hazardous waste, so that CCRs would not automatically be identified with all other hazardous wastes. *See* sections V through VII for the full description of our regulatory proposal.

EPA believes that this action could significantly reduce the likelihood that products made from or containing CCRs would automatically be perceived as universally "hazardous." When taken in combination with (1) the fact that beneficially used CCRs will remain exempt and (2) EPA's continued promotion of the beneficial use of CCRs, we believe this will go a long way to address any stigmatic impact that might otherwise result from the regulation of CCRs under subtitle C of RCRA. We are seeking comment on other suggestions on how EPA might promote the beneficial use of CCRs, as well as suggestions that would reduce any perceived impacts resulting from "stigma" due to the identification of CCRs as "special wastes regulated under subtitle C authority."

In summary, based on our experiences, we expect that it will be more likely that the increased costs of disposal of CCRs as a result of regulation of CCR disposal under subtitle C would increase their usage in non-regulated beneficial uses, simply as a result of the economics of supply and demand. The economic driver—availability of a low-cost, functionally equivalent or often superior substitute for other raw materials—would continue to make CCRs an increasingly desirable product.

[146] *See,* for example, ASTM Volume 15.05, Engine Coolants, Halogenated Organic Solvents and Fire Extinguishing Agents; Industrial and Specialty Chemicals, at *http://www.normas.com/ASTM/BOS/volume1505.html. See also* ASTM D5396—04 Standard Specification for Reclaimed Perchloroethylene, at *http://www.astm.org/Standards/D5396.htm.*

[147] *See http://www.nytimes.com/gwire/2020/01/13/13greenwire-recycling-questions-complicate-epa-coal-ash-de-90614.html.*

VII. How would the proposed subtitle c requirements be implemented?

A. Effective Dates

If EPA were to finalize the subtitle C regulatory alternative proposed today, the rule, as is the case with all RCRA subtitle C rules, would become effective six months after promulgation by the appropriate regulatory authority—that is, six months after promulgation of the federal rule in States and other jurisdictions where EPA implements the hazardous waste program (Iowa, Alaska, Indian Country, and the territories, except Guam) and in authorized States, six months after the State promulgates its regulations that EPA has approved via the authorization process (unless State laws specify an alternative time). This means that facilities managing CCRs must be in compliance with the provisions of these regulations on their effective date, unless the compliance date is extended. For this proposed regulatory alternative, the compliance dates for several of the proposed requirements for existing units are being extended due to the need for additional time for facilities to modify their existing units. The precise dates that facilities will need to be in compliance with the various requirements will depend on whether they are in a jurisdiction where EPA administers the RCRA subtitle C program or whether they are in a State authorized to administer the RCRA subtitle C program.

To summarize, (1) In States and jurisdictions where EPA administers the RCRA program (Iowa, Alaska, the territories [except Guam], and Indian Country), most of the subtitle C requirements go into effect and are enforceable by EPA six months after promulgation of the final rule. This includes the generator requirements, transporter requirements, including the manifest requirements, permitting requirements for facilities managing CCRs, interim status standards, surface impoundment stability requirements, and the Land Disposal Restriction (LDR) treatment standards for non-wastewaters in 40 CFR part 268. However, we are proposing that existing CCR landfills and surface impoundments (as defined in this regulation) will be given additional time to comply with several of the proposed requirements as specified later in this section. Any new CCR landfills, including lateral expansions (as defined in the regulation), must be in compliance with all the requirements of any final regulation before CCRs can be placed in the unit.

(2) In States that are authorized to administer the RCRA program, the requirements that are part of the RCRA base program (*i.e.,* those promulgated under the authority of RCRA and not the HSWA amendments) will not be effective until the State develops and promulgates its regulations. Once those regulations are effective in the States, they are enforceable as a matter of State law and facilities must comply with those requirements under the schedule established by the State. These RCRA base requirements will become part of the RCRA authorized program and enforceable as a matter of federal law once the State submits and EPA approves a modification to the State's authorized program. (*See* the State Authorization section (section VIII) for a more detailed discussion.) The requirements that are more stringent or broader in scope than the existing regulations and are promulgated pursuant to HSWA authority will become effective and federally enforceable on the effective date of the approved state law designating CCRs as a special waste subject to subtitle C—that is, they are federally enforceable without waiting for authorization of the program revision applicable to the HSWA provisions. On the other hand, any requirements that are promulgated pursuant to HSWA authority, but are less stringent than the existing subtitle C requirements (*e.g.,* modifications promulgated pursuant to Section 3004(x)) will become effective only when the State promulgates those regulations (and federally enforceable when the State program revision is authorized), as the State has the discretion to not adopt those less stringent requirements.

B. What are the requirements with which facilities must comply?

It is EPA's intention that this proposed alternative, if finalized, will be implemented in the same manner as previous regulations under RCRA subtitle C have been. The following paragraphs describe generally how this proposal will be implemented. While this notice provides some details on specific requirements, it is EPA's intention that, unless otherwise noted, all current Subtitle C requirements become applicable to the facilities generating, transporting, or treating, storing or disposing of CCRs listed as special wastes. While in this notice EPA has described the major subtitle C requirements, EPA has not undertaken a comprehensive description of all of the subtitle C regulatory requirements which may be applicable; therefore, we encourage commenters to refer to the regulations at 40 CFR parts 260 to 268, 270 to 279, and 124 for details.

1. Generators and Transporters

i. Requirements

Under this proposed regulation, regulated CCRs destined for disposal become a newly listed special waste subject to the subtitle C requirements. Persons that generate this newly identified waste is required to notify EPA within 90 days after the wastes are identified or listed [148] (by EPA or the state) and obtain an EPA identification number if they do not already have one in accordance with 40 CFR 262.12. (If the person who generates regulated CCRs already has an EPA identification number, EPA is proposing not to require that they re-notify EPA; however, EPA is seeking comment on this issue.) Moreover, on the effective date of this rule in the relevant state, generators of CCRs must be in compliance with the generator requirements set forth in 40 CFR part 262. These requirements include standards for waste determination (40 CFR 262.11), compliance with the manifest (40 CFR 262.20 to 262.23), pre-transport procedures (40 CFR 262.30 to 262.34), generator accumulation (40 CFR 262.34), record keeping and reporting (40 CFR 262.40 to 262.44), and the import/export procedures (40 CFR 262.50 to 262.60). It should be noted that the current generator accumulation provisions of 40 CFR 262.34 allow generators to accumulate hazardous wastes without obtaining interim status or a permit only in units that are container accumulation units, tank systems or containment buildings; the regulations also place a limit on the maximum amount of time that wastes can be accumulated in these units. If these wastes are managed in landfills, surface impoundments or other units that are not tank systems, containers, or containment buildings, these units are subject to the permitting requirements of 40 CFR parts 264, 265, and 267 and the generator is required to obtain interim status and seek a permit (or modify interim status or a permit, as appropriate). These requirements would be applied to special wastes as well. Permit requirements are described in Section VII.D below.

Transporters of CCRs destined for disposal will be transporting a special waste subject to subtitle C on the effective date of this regulation. Persons who transport these newly identified wastes will be required to obtain an EPA identification number as described

[148] *See* section 3010 of RCRA.

above and must comply with the transporter requirements set forth in 40 CFR part 263 on the effective date of the final rule. In addition, generators and transporters of CCRs destined for disposal should be aware that an EPA identified waste subject to the EPA waste manifest requirements under 40 CFR part 262 meets the definition for a hazardous material under the Department of Transportation's Hazardous Materials Regulations (HMR; 49 CFR parts 171–180) and must be offered and transported in accordance with all applicable HMR requirements, including materials classification, packaging, and hazard communication.[149]

ii. Effective Dates and Compliance Deadlines

Generators must notify EPA within 90 days after the date that CCRs are identified or listed as special wastes (by EPA or the state). The other requirements for generators and transporters (in 40 CFR parts 262 and 263) are effective and generators and transporters must be in compliance with these requirements on the effective date of the final rules. The effective date of these rules is six months after promulgation of the federal rule in non-authorized States and in authorized States generally six months after promulgation of the State regulations. (*See* previous section for a more detailed discussion of effective dates.)

2. Treatment, Storage, and Disposal Facilities (TSDs)

i. Requirements

Facilities treating, storing, or disposing of the newly listed CCRs are subject to the RCRA 3010 notification requirements, the permit requirements in 40 CFR part 270, and regulations in 40 CFR part 264 or 267 for permitted facilities or part 265 for interim status facilities, including the general facility requirements in subpart B, the preparedness and prevention requirements in subpart C, the contingency plan and emergency procedure requirement in subpart D, the manifest, recordkeeping and reporting requirements in subpart E, the closure and post-closure requirements in subpart G, the corrective action requirements, including facility-wide corrective action in subpart F, and the financial assurance requirements in subpart H.

[149] *See* the definition for "hazardous waste" in 49 CFR 171.8.

C. RCRA Section 3010 Notification

Pursuant to RCRA section 3010 and 40 CFR 270.1(b), facilities managing these special wastes subject to subtitle C must notify EPA of their waste management activities within 90 days after the wastes are identified or listed as a special waste. (As noted above, for facilities in States where EPA administers the program, this will be 90 days from the date of promulgation of the final federal regulation; in authorized States, it will be 90 days from the date of promulgation of listing CCRs as a special waste by the state, unless the state provides an alternative timeframe.) This requirement may be applied even to those TSDs that have previously notified EPA with respect to the management of hazardous wastes. The Agency is proposing to waive this notification requirement for persons who handle CCRs and have already: (1) Notified EPA that they manage hazardous wastes, and (2) received an EPA identification number because requiring persons who have notified EPA and received an EPA identification number would be duplicative and unnecessary, although the Agency requests comment on whether it should require such persons to re-notify the Agency that they generate, transport, treat, store or dispose of CCRs. However, any person who treats, stores, or disposes of CCRs and has not previously received an EPA identification number for other waste must obtain an identification number pursuant to 40 CFR 262.12 to generate, transport, treat, store, or dispose of CCRs within 90 days after the wastes are identified or listed as special wastes subject to subtitle C, as described above.

D. Permit Requirements

As specified in 40 CFR 270.1(b), six months after promulgation of a new regulation, the treatment, storage or disposal of hazardous waste or special waste subject to subtitle C by any person who has not applied for and received a RCRA permit is prohibited from managing such wastes. Existing facilities, however, may satisfy the permit requirement by submitting Part A of the permit application. Timely submission of Part A and the notification qualifies a facility for interim status under section 3005 of RCRA and facilities with interim status are treated as having been issued a permit until a final decision is made on a permit application.

The following paragraphs provide addition details on how the permitting requirements would apply to various categories of facilities:

1. Facilities Newly Subject to RCRA Permit Requirements

Facilities that treat, store, or dispose of regulated CCRs at the time the rule becomes effective would generally be eligible for interim status pursuant to section 3005 of RCRA. (*See* section 3005(e)(1)(A)(ii) of RCRA).[150] EPA believes most, if not all utilities generating CCRs and most if not all off-site disposal sites will be in this situation. In order to obtain interim status based on treatment, storage, or disposal of such newly listed CCRs, eligible facilities are required to comply with 40 CFR 270.70(a) and 270.10(e) (or more likely with analogous state regulations) by providing notice under RCRA section 3010 (if they do not have an EPA identification number) and submitting a Part A permit application no later than six months after date of publication of the regulations which first require them to comply with the standards. (In most cases, these would be the state regulations implementing the federal program; however, in those States and jurisdictions where EPA implements the program, the deadline will be six months after promulgation of the final federal rule.) Such facilities are subject to regulation under 40 CFR part 265 until EPA or the state issues a RCRA permit. In addition, under section 3005(e)(3) and 40 CFR 270.73(d), not later than 12 months after the effective date of the regulations that render the facility subject to the requirement to have a RCRA permit and which is granted interim status, land disposal facilities newly qualifying for interim status under section 3005(e)(1)(A)(ii) also must submit a Part B permit application and certify that the facility is in compliance with all applicable ground water monitoring and financial responsibility requirements. If the facility fails to submit these certifications and the Part B permit application, interim status will terminate on that date.

2. Existing Interim Status Facilities

EPA is not aware of any utilities or CCR treatment or disposal sites in RCRA interim status currently, and therefore

[150] Section 3005(e) of RCRA states, in part, that "Any person who * * * is in existence on the effective date of statutory or regulatory changes under this Act that render the facility subject to the requirement to have a permit under this section * * * shall be treated as having been issued such permit until such time as final administrative disposition of such application is made, unless the Administrator or other plaintiff proves that final administrative disposition of such application has not been made because of the failure of the applicant to furnish information reasonably required or requested in order to process the application.

EPA does not believe the standard federal rules on changes in interim status will apply. However, in case such a situation exists, EPA describes below the relevant provisions. Again, EPA is describing the federal requirements, but because the proposed requirements that subject these facilities to permitting requirements are part of the RCRA base program, authorized state regulations will govern the process, and the date those regulations become effective in the relevant state will trigger the process.

Pursuant to 40 CFR 270.72(a)(1), all existing hazardous waste management facilities (as defined in 40 CFR 270.2) that treat, store, or dispose of newly identified hazardous wastes and are currently operating pursuant to interim status under section 3005(e) of RCRA, must file an amended Part A permit application with EPA no later than the effective date of the final rule in the State where the facility is located. By doing this, the facility may continue managing the newly listed wastes. If the facility fails to file an amended Part A application by such date, the facility will not receive interim status for management of the newly listed wastes (in this case CCRs) and may not manage those wastes until the facility receives either a permit or a change in interim status allowing such activity (40 CFR 270.10(g)). This requirement, if applicable to any electric utilities, will be applied to those facilities managing CCRs destined for disposal since these facilities will now be managing CCRs subject to the subtitle C requirements.

3. Permitted Facilities

EPA also believes that no electric utilities treating, storing, or disposing of CCRs currently has a RCRA permit for its CCR management unit(s), nor is EPA aware of any on-going disposal of CCRs at permitted hazardous waste TSDs, although the latter situation is a possibility. Federal procedures for how permitted hazardous waste facilities manage newly listed hazardous wastes are described below, but again in practice (with the exception of those jurisdictions in which EPA administers the hazardous waste program), the authorized state regulations will govern the process.

Under 40 CFR 270.42(g), facilities that already have RCRA permits must request permit modifications if they want to continue managing the newly listed wastes (*see* 40 CFR 270.42(g) for details). This provision states that a permittee may continue managing the newly listed wastes by following certain requirements, including submitting a Class 1 permit modification request on or before the date on which the waste or unit becomes subject to the new regulatory requirements (*i.e.,* the effective date of the final federal rule in those jurisdictions where EPA administers the program or the effective date of the State rule in authorized States), complying with the applicable standards of 40 CFR parts 265 and 266 and submitting a Class 2 or 3 permit modification request within 180 days of the effective date of the final rule. Again, these requirements, if applicable to any electric utilities, will be applied to those facilities managing CCRs destined for disposal since they are now subject to the subtitle C requirements.

E. Requirements in 40 CFR Parts 264 and 265

The requirements of 40 CFR part 264 and 267 for permitted facilities or part 265 for interim status facilities, including the general facility standards in subpart B, the preparedness and prevention requirements in subpart C, the contingency plan and emergency procedure requirements in subpart D, the manifest, recordkeeping and reporting requirements in subpart E, the corrective action requirements, including facility-wide corrective action in subpart F, and the financial assurance requirements in Subpart H, are applicable to TSDs and TSDs must be in compliance with those requirements on the effective date of the final (usually state) regulation, except as noted below. These requirements will apply to those facilities managing CCRs destined for disposal.

Moreover, all units in which newly identified hazardous wastes are treated, stored, or disposed of after the effective date of the final (usually state) rule that are not excluded from the requirements of 40 CFR parts 264, 265 and 267 will be subject to both the general closure and post-closure requirements of subpart G of 40 CFR parts 264 and 265 and the unit-specific closure requirements set forth in the applicable unit technical standards in subparts 40 CFR parts 264 or 265 (*e.g.,* subpart N for landfill units). In addition, EPA promulgated a final rule that allows, under limited circumstances, regulated landfills or surface impoundments, (or land treatment units which is not used for the management of CCR waste) to cease managing hazardous waste, but to delay subtitle C closure to allow the unit to continue to manage non-hazardous waste for a period of time prior to closure of the unit (*see* 54 FR 33376, August 14, 1989). Units for which closure is delayed continue to be subject to all applicable 40 CFR parts 264 and 265 requirements. Dates and procedures for submittal of necessary demonstrations, permit applications, and revised applications are detailed in 40 CFR 264.113(c) through (e) and 265.113(c) through (e). As stated earlier, these requirements will be applicable to those facilities managing CCRs destined for disposal, since they will be managing a newly listed waste subject to subtitle C requirements.

Except as noted below, existing facilities are required to be in compliance with the surface impoundment stability requirements, the LDR treatment standards for non-wastewaters, and the fugitive dust controls on the effective date of the final rule.

For certain of the other requirements, existing facilities will have:

(a) 60 days from the effective date of the final rule to install a permanent identification marker on each surface impoundment as required by 40 CFR 264.1304(d) and 40 CFR 265.1304(d).

(b) 1 year from the effective date of the final rule:

To submit plans for each surface impoundments as required by 264.1304(b) and 265.1304(b).

To adopt and submit to the Regional Administrator a plan for carrying out the inspection requirements for each surface impoundment in 40 CFR 264.1305 and 40 CFR 265.1305.

To comply with the groundwater monitoring requirements for each landfill and surface impoundment in 40 CFR 264, Subpart F and 265, Subpart F.

(c) 2 years from the effective date of the final rule:

To install, operate, and maintain run-on and run-off controls as required by 264.1304(g) and 265.1304(g) for surface impoundments and by 264.1307(d) and 265.1307(d) for landfills.

(d) 5 years from the effective date of the final rule:

To comply with the LDR wastewater treatment standard.

To stop receiving CCR waste in surface impoundments.

(e) 7 years from the effective date of the final rule to close surface impoundments handling CCRs.

Any new CCR landfills, including lateral expansions of existing landfills (as defined in the regulation), must be in compliance with all the requirements of the final regulation before CCRs can be placed in the unit.

The table below (Table 9) provides a summary of the effective dates for the various requirements:

TABLE 9—CCR RULE REQUIREMENTS

	Compliance date non authorized state	Compliance date authorized state
Remove Bevill Exclusion	6 months after promulgation of final rule	6 months after State adopts regulations (under State law); federally enforceable when state program revision is authorized.
Listing CCRs as a Special Waste Subject to subtitle C.	Same	Same.
Notification (generators and TSDs)	90 days after rule promulgation (that is, the date the CCRs are listed as a Special Waste subject to subtitle C.	90 days after State rule promulgation (that is, the date the CCRs are listed as a Special Waste subject to subtitle C.
Generator requirements (40 CFR part 262)	6 months after promulgation	On the effective date of the State regulations.
Transporter Requirements (40 CFR part 263)	6 months after promulgation	On the effective date of State regulations.
Permit Requirement/Interim Status	File Part A of the permit application within six months of effective date of final rule.	File Part A of the permit application within six months of effective date of State final rule.
Facility Standards in Part 264/265	On effective date unless specifically noted	On effective date of state regulation unless specifically noted.
Install a permanent identification marker on each surface impoundment as required by 40 CFR 264.1304(d) and 40 CFR 265.1304(d).	60 days from the effective date of the final rule.	60 days from the effective date of the State regulation.
Submit plans required by 264.1304(b) and 265.1304(b).	1 year from the effective date of the final rule	1 year from the effective date of the State regulation.
Adopt and submit to the Regional Administrator a plan for carrying out the inspection requirements in 40 CFR 264.1305 and 40 CFR 265.1305.	1 year from the effective date of the final rule	1 year from the effective date of the State regulation.
Comply with ground water monitoring requirements in 40 CFR 264 Subpart F and 40 CFR 265 Subpart F.	1 year from the effective date of the final rule	1 year from the effective date of the State regulation.
Install, operate, and maintain run-on and run-off controls as required by 264.1304 (g) and 265.1304 (g) for surface impoundments and by 264.1307 (d) and 265.1307 (d) for landfills.	2 years from the effective date of the final rule	2 years from the effective date of the State regulation.
Comply with the LDR wastewater treatment standard.	5 years from the effective date of the final rule	5 years from the effective date of the State regulation.
Close surface impoundments receiving CCR waste.	7 years from the effective date of the final rule	7 years from the effective date of the State regulation.

VIII. Impacts of a Subtitle C Rule on State Authorization

A. Applicability of the Rule in Authorized States

Under section 3006 of RCRA, EPA authorizes qualified states to administer their own hazardous waste programs in lieu of the federal program within the state. Following authorization, EPA retains enforcement authority under sections 3008, 3013, and 7003 of RCRA, although authorized states have primary enforcement responsibility. The standards and requirements for state authorization are found at 40 CFR part 271.

Prior to enactment of the Hazardous and Solid Waste Amendments of 1984 (HSWA), a state with final RCRA authorization administered its subtitle C hazardous waste program in lieu of EPA administering the federal program in that state. The federal requirements no longer apply in the authorized state, and EPA could not issue permits for any facilities in that state, since only the state was authorized to issue RCRA permits. When new, more stringent federal requirements are promulgated, the state was obligated to enact equivalent authorities within specified time frames (one to two years). The new more stringent federal requirements did not take effect in the authorized state until the state adopted the federal requirements as state law, and the state requirements are not federally enforceable until EPA authorized the state program. This remains true for all of the requirements issued pursuant to statutory provisions that existed prior to HSWA.

In contrast, under RCRA section 3006(g) (42 U.S.C. 6926(g)), which was added by HSWA, new requirements and prohibitions imposed under HSWA authority take effect in authorized states at the same time that they take effect in unauthorized states. EPA is directed by the statute to implement these requirements and prohibitions in authorized states, until the state is granted authorization to do so. While states must still adopt new more stringent HSWA related provisions as state law to retain final authorization, EPA implements the HSWA provisions in authorized states until the states do so.

Authorized states are required to modify their programs only when EPA enacts federal requirements that are more stringent or broader in scope than the existing federal requirements. RCRA section 3009 allows the states to impose standards more stringent than those in the federal program (*see* also 40 CFR 271.1). Therefore, authorized states may, but are not required to, adopt federal regulations, both HSWA and non-HSWA, that are considered less stringent than previous federal regulations.

This alternative of the co-proposal is considered more stringent and broader in scope than current federal regulations and therefore States would be required to adopt regulations and modify their programs if this alternative is finalized.

B. Effect on State Authorization

If finalized, a subtitle C rule for CCRs would affect state authorization in the same manner as any new RCRA subtitle C requirement; *i.e.,* (1) this alternative of the co-proposal would be considered broader in scope and more stringent than the current federal program, so authorized states must adopt regulations so that their program remains at least as stringent as the federal program; and (2) they must receive authorization from

EPA for these program modifications. The process and requirements for modification of state programs at 40 CFR 271, specifically 271.21, will be used.

However, this process is made more complex due to the nature of this particular rulemaking and the fact that some of the provisions of this alternative, if finalized, would be finalized pursuant to the RCRA base program authority and some pursuant to HSWA authority. For RCRA base program or non-HSWA requirements, the general rule, as explained previously, is that the new requirements do not become enforceable as a matter of federal law in authorized states until states adopt the regulations, modify their programs, and receive authorization from EPA. For HSWA requirements, the general rule is that HSWA requirements are enforceable on the effective date of the final federal rule. If an authorized State has not promulgated regulations, modified their programs, and received authorization from EPA, then EPA implements the requirements until the State receives program authorization.

In accord with 271.2(e)(2), authorized states must modify their programs by July 1 of each year to reflect changes to the federal program occurring during the "12 months preceding the previous July 1." Therefore, for example, if the federal rule is promulgated in December 2011, the states would have until July 1, 2013 to modify their programs. States may have an additional year to modify their programs if an amendment to a state statute is needed. *See* 40 CFR 271.21(e)(2)(v).

As noted above, this alternative to the co-proposal is proposed pursuant in part to HSWA authority and in part to non-HSWA or RCRA base program authority. The majority of this alternative is proposed pursuant to non-HSWA authority. This includes, for example, the listing of CCRs destined for disposal as a special waste subject to subtitle C and the impoundment stability requirements. These requirements will be applicable on the effective date of the final federal rule only in those states that do not have final authorization for the RCRA program. These requirements will be effective in authorized states once a state promulgates the regulations and they will become a part of the authorized RCRA program and thus federally enforceable, once the state has submitted a program modification and received authorization for this program modification.

The prohibition on land disposal unless CCRs meet the treatment standards and modification of the treatment standards in 40 CFR part 268 are proposed pursuant to HSWA authority and would normally be effective and federally enforceable in all States on the effective date of the final federal rule. However, because the land disposal restrictions apply to those CCRs that are regulated under subtitle C, until authorized states revise their programs and become authorized to regulate CCRs as a special waste subject to RCRA subtitle C, the land disposal restriction requirements would apply only in those States that currently do not exclude CCRs from subtitle C regulation (that is, CCRs are regulated under subtitle C if they exhibit one or more of the characteristics) and the CCRs in fact exhibit one or more of the RCRA subtitle C characteristics. However, once the state has the authority to regulate CCRs as a special waste, the LDR requirements become federally enforceable in all States.

In addition, the tailored management standards promulgated pursuant to section 3004(x) of RCRA are also proposed pursuant to HSWA authority. However, as these tailored standards are less stringent than the existing RCRA subtitle C requirements, States would not be required to promulgate regulations for these less stringent standards—should a State decide not to promulgate such regulations, the facilities in that state would be required to comply with the full subtitle C standards. Therefore, the tailored management standards will be effective in authorized States only when States promulgate such regulations.

Therefore, the Agency would add this rule to Table 1 in 40 CFR 271.1(j), if this alternative to the co-proposal is finalized, which identifies the federal program requirements that are promulgated pursuant to HSWA and take effect in all states, regardless of their authorization status. Table 2 in 40 CFR 271.1(j) would be modified to indicate that these requirements are self-implementing. Until the states receive authorization for the more stringent HSWA provisions, EPA would implement them, as described above. In implementing the HSWA requirements, EPA will work closely with the states to avoid duplication of effort. Once authorized, states adopt an equivalent rule and receive authorization for such rule from EPA, the authorized state rule will apply in that state as the RCRA subtitle C requirement in lieu of the equivalent federal requirement.

IX. Summary of the Co-Proposal Regulating CCRs Under Subtitle D Regulations

A. Overview and General Issues

EPA is co-proposing and is soliciting comment on an approach under which the May 2000 Regulatory Determination would remain in place, and EPA would issue regulations governing the disposal of CCRs under sections 1008(a), 2002, 4004 and 4005(a) of RCRA (*i.e.,* "Subtitle D" of RCRA). Under this approach, the CCRs would remain classified as a non-hazardous RCRA solid waste, and EPA would develop national minimum criteria governing facilities for their disposal. EPA's co-proposed subtitle D minimum criteria are discussed below.

Statutory standards for Subtitle D approach. Under RCRA 4005(a), upon promulgation of criteria under 1008(a)(3), any solid waste management practice or disposal of solid waste which constitutes the "open dumping" of solid waste is prohibited. The criteria under RCRA 1008(a)(3) are those that define the act of open dumping, and are prohibited under 4005(a), and the criteria under 4004(a) are those to be used by states in their planning processes to determine which facilities are "open dumps" and which are "sanitary landfills." EPA has in practice defined the two sets of criteria identically. *See, e.g.,* Criteria for Classification of Solid Waste Disposal Facilities and Practices, 44 FR 53438, 53438–39 (Sept. 13, 1979). EPA has designed today's co-proposed subtitle D criteria to integrate with the existing open dumping criteria in this respect, as reflected in the proposed changes to 257.1.

Section 4004(a) of RCRA provides that EPA shall promulgate regulations containing criteria distinguishing which facilities are to be classified as sanitary landfills and which are open dumps. This section provides a standard that varies from that under RCRA subtitle C. Specifically, subtitle C provides that management standards for hazardous waste treatment, storage, and disposal facilities are those "necessary to protect human health or the environment." *See, e.g.,* RCRA 3004(a). By contrast, Section 4004(a) provides that

> *[a]t a minimum,* the such criteria shall provide that a facility may be classified as a sanitary landfill and not an open dump only if there is *no reasonable probability of adverse effects on health or the environment* from disposal of solid waste at such facility. Such regulations may provide for the classification of the types of sanitary landfills.

Thus, under the RCRA subtitle D regulatory standard in 4004, EPA is to develop requirements based on the adverse effects on health or the environment from disposal of solid waste at a facility, and accordingly, EPA looked at such effects in developing today's co-proposed Subtitle D rule.

At the same time, EPA believes that the differing standards, in particular the reference to the criteria as those which are needed to assure that there is "no reasonable probability" of adverse effects, allows the Agency the ability to adopt standards different from those required under the subtitle C proposal where appropriate. EPA notes that the 4004(a) standard refers to the "probability" of adverse effect on health or the environment. In EPA's view, this provides it the discretion to establish requirements that are less certain to eliminate a risk to health or the environment than otherwise might be required under Subtitle C, and allows additional flexibility in how those criteria may be applied to facilities. At the same time, however, EPA notes that the requirements meeting the "no reasonable probability" standard are those "at a minimum"—thus, EPA is not constrained to limit itself to that standard should it determine that additional protections are appropriate.

Statements in the legislative history of 4004(a) are also consistent with EPA's interpretation of the statutory language. While it provides little in the way of guidance on the meaning of the "reasonable probability" standard, the legislative history does indicate that Congress was aware of effects from solid waste disposal facilities that included surface runoff, leachate contamination of surface- and groundwaters, and also identified concerns over the location and operations of landfills. *See* H. Rep. 94–1491, at 37–8. In addition, the legislative history confirms that the standard in 4004(a) was intended to set a minimum for the criteria. *See* H. Rep. 94–1491, at 40 ("This legislation requires that the Administrator define sanitary landfill as disposal site at which there is no reasonable chance of adverse effects on health and the environment from the disposal of discarded material at the site. *This is a minimum requirement of this legislation and does not preclude additional requirements.*" Emphasis added.)

1. Regulatory Approach

In developing the proposed RCRA subtitle D option for CCRs, EPA considered a number of existing requirements as relevant models for minimum national standards for the safe disposal of CCRs. The primary source was the existing requirements under 40 CFR part 258, applicable to municipal solid waste landfills, which provide a comprehensive framework for all aspects of disposal in land-based units, such as CCR landfills. Based on the Agency's substantial experience with these requirements, EPA believes that the part 258 criteria represent a reasonable balance between ensuring the protection of human health and the environment from the risks of these wastes and the practical realities of facilities' ability to implement the criteria. The engineered structures regulated under part 258 are very similar to those found at CCR disposal facilities, and the regulations applicable to such units would be expected to address the risks presented by the constituents in CCR wastes. Moreover, CCR wastes do not contain the constituents that are likely to require modification of the existing part 258 requirements, such as organics; for example, no adjustments would be needed to ensure that groundwater monitoring would be protective, as the CCR constituents are all readily distinguishable by standard analytical chemistry. As discussed throughout this preamble, each of the provisions adopted for today's subtitle D co-proposal relies, in large measure, on the record EPA developed to support the 40 CFR part 258 municipal solid waste landfill criteria, along with the other record evidence specific to CCRs, discussed throughout the co-proposed subtitle C alternative. EPA also relied on the Agency's Guide for Industrial Waste Management (EPA530–R–03–001, February 2003), to provide information on existing best management practices that facilities have likely adopted.

The Guide was developed by EPA and state and tribal representatives, as well as a focus group of industry and public interest stakeholders chartered under the Federal Advisory Committee Act, and reflects a consensus view of best practices for industrial waste management. It also contains recommendations based on more recent scientific developments, and state-of-the art disposal practices for solid wastes.

In addition, EPA considered that many of the technical requirements that EPA developed to specifically address the risks from the disposal of CCRs as part of the subtitle C alternative, would be equally justified under a RCRA subtitle D regime. Thus, for example, EPA is proposing the same MSHA-based standards for surface impoundments that are discussed as part of the subtitle C alternative. The factual record—*i.e.,* the risk analysis and the damage cases—supporting such requirements is the same, irrespective of the statutory authority under which the Agency is operating. Although the statutory standards under subsections C and D differ, EPA has historically interpreted both statutory provisions to establish a comparable level of protection, corresponding to an acceptable risk level ranging between 1 × 10–4 to 1 × 10–6. In addition, EPA does not interpret section 4004 to preclude the Agency from establishing more stringent requirements where EPA deems such more stringent requirements appropriate. Thus, several of the provisions EPA is proposing under RCRA subtitle D either correspond to the provisions EPA is proposing to establish for RCRA subtitle C, or are modeled after the existing subtitle C requirements. These provisions include the following regulatory provisions specific to CCRs that EPA is proposing to establish: Scope, and applicability (*i.e.,* who will be subject to the rule criteria/requirements), the Design Criteria and Operating Criteria (including provisions for surface impoundment integrity), and several of the provisions specifying appropriate pollution control technologies. Additional support for EPA's decision to specify appropriate monitoring, corrective action, closure, and post-closure care requirements (since the specific requirements correlate closely with the existing 40 CFR 258 requirements) is found in the risk analysis and damage case information. Finally, many of the definitions are the same in each section.

However, both the RCRA subtitle C proposals and the existing 40 CFR part 258 requirements were developed to be implemented in the context of a permitting program, where an overseeing authority evaluates the requirements, and can adjust them, as appropriate to account for site specific conditions. Because there is no corresponding guaranteed permit mechanism under the RCRA subtitle D regulations proposed today, EPA also considered the 40 CFR part 265 interim status requirements for hazardous waste facilities, which were designed to operate in the absence of a permit. The interim status requirements were particularly relevant in developing the proposed requirements for surface impoundments, since such units are not regulated under 40 CFR part 258. Beyond their self-implementing design, these requirements provided a useful model because, based on decades of experience in implementing these requirements, EPA has assurance that they provide national requirements that have proven to be protective for a variety of wastes, under a wide variety of site conditions. Past experience also demonstrates that facilities can feasibly implement these requirements.

Taking all of these considerations into account, EPA has generally designed the proposed RCRA subtitle D criteria to create self-implementing requirements. These self-implementing requirements typically consist of a technical design standard (*e.g.,* the composite liner requirement for new CCR landfills and surface impoundments). In addition, for many of these requirements, the Agency also has established performance criteria that the owner or operator can meet, in place of the technical design standard, which provides the facility with flexibility in complying with the minimum national criteria. EPA generally has chosen to propose an alternate performance standard for a number of reasons. In several cases, the alternative standard is intended to address the circumstances where the appropriate requirement is highly dependent on site-specific conditions (such as the spacing and location of ground-water wells); consequently, uniform, national standards that assure the requisite level of protection are extremely difficult to establish. EPA could establish a minimum national requirement, but to do so, EPA would need to establish the most restrictive criteria that would ensure protection of the most vulnerable site conditions. Because this would result in overregulation of less vulnerable sites, EPA questions whether such a restrictive approach would be consistent with the RCRA section 4004 standard of ensuring "no *reasonable* probability of adverse effects." (emphasis added). The existing 40 CFR part 258 requirements provide the flexibility to address this issue by establishing alternate performance standards and relying on the oversight resulting from state permitting processes, and supported by EPA approval of state plans. Indeed, EPA made clear in the final MSWLF rule that this was the reason that several of the individual performance standards in the existing 40 CFR part 258 requirements are available only in states with EPA approved programs. *See, e.g.,* 56 FR 51096 (authorizing alternative cover designs). However, EPA cannot rely on these oversight mechanisms to implement the RCRA 4004 subtitle D requirements. Under these provisions of RCRA, EPA lacks the authority to require state permits, approve state programs, and to enforce the criteria. Moreover as discussed in Section IV, the level of state oversight varies appreciably among states. Consequently, for these provisions EPA is also proposing to require the owner or operator of the facility to obtain certifications by independent registered professional engineers to provide verification that these provisions are properly applied. EPA has also proposed to require certifications by independent professional engineers more broadly as a mechanism to facilitate citizen oversight and enforcement. As discussed in greater detail below, EPA is proposing to require minimum qualifications for the professionals who are relied upon to make such certifications. In general, EPA expects that professionals in the field will have adequate incentive to provide an honest certification, given that the regulations require that the engineer not be an employee of the owner or operator, and that they operate under penalty of losing their license.

EPA believes that these provisions allow facilities the flexibility to account for site conditions, by allowing them to deviate from the specific technical criteria, provided the alternative meets a specified performance standard, yet also provide some degree of third-party verification of facility practices. The availability of meaningful independent verification is critical to EPA's ability to conclude that these performance standards will meet the RCRA section 4004 protectiveness standard. EPA recognizes that relying upon third party certifications is not the same as relying upon the state regulatory authority, and will likely not provide the same level of "independence." For example, although not an employee, the engineer will still have been hired by the utility. EPA therefore broadly solicits comment on whether this approach provides the right balance between establishing sufficient guarantee that the regulations will be protective, and offering facilities sufficient flexibility to be able to feasibly implement requirements that will be appropriate to the site conditions. In this regard, EPA would also be interested in receiving suggestions for other mechanisms to provide facility flexibility and/or verification.

There is a broad range of the extent to which states already have some of these requirements in place under their current RCRA subtitle D waste management programs established under state law, as explained previously in this preamble. EPA and certain commenters, however, have identified significant gaps in state programs and current practices. For example, EPA does not believe that many, if any, states currently have provisions that would likely cause the closure of existing surface impoundments, such as the provisions in today's proposed rule that surface impoundments must either retrofit to meet all requirements, such as installing a composite liner, or stop receiving CCRs within a maximum of five years of the effective date of the regulation. The RCRA subtitle D proposal outlined here is intended to fill such gaps and ensure national minimum standards. EPA intends to provide a complete set of requirements, designed to ensure there will be no reasonable probability of adverse effects on health or the environment caused by CCR landfills or surface impoundments. EPA's co-proposed RCRA subtitle D minimum criteria are discussed below.

2. Notifications

In response to EPA's lack of authority to require a state permit program or to oversee state programs, EPA has sought to enhance the protectiveness of the proposed RCRA subtitle D standards by providing for state and public notifications of the third party certifications, as well as other information that documents the decisions made or actions taken to comply with the performance criteria. As discussed in the section-by-section analysis below, documentation of how the various standards are met must be placed in the operating record and the state notified.

The owner or operator must also maintain a web site available to the public that contains the documentation that the standard is met. EPA is proposing that owners and operators provide notification to the public by posting notices and relevant information on an internet site with a link clearly identified as being a link to notifications, reports, and demonstrations required under the regulations. EPA believes the internet is currently the most convenient and widely accessible means for gathering information and disseminating it to the public. However, the Agency solicits comments regarding the methods for providing notifications to the public and the states. EPA also solicits comments on whether there could be homeland security implications with the requirement to post information on an internet site and whether posting certain information on the internet may duplicate information that is already available to the public through the state.

The co-proposed subtitle D regulation accordingly includes a number of public notice provisions. In particular, to ensure that persons residing near CCR surface impoundments are protected from potential catastrophic releases, we are proposing that when a potentially hazardous condition develops regarding the integrity of a surface impoundment, that the owner or operator immediately notify potentially affected persons and the state. The Agency is also proposing to require that owners or operators notify the state, and place the report and other supporting materials in the operating record and on the company's internet site of various demonstrations, documentation, and certifications. Accordingly, notice must be provided: (1) Of demonstrations that CCR landfills or surface impoundments will not adversely affect human health or the environment; (2) of demonstrations of alternative fugitive dust control measures; (3) annually throughout the active life and post-closure care period that the landfill or surface impoundment is in compliance with the groundwater monitoring and corrective action provisions; (4) when documentation related to the design, installation, development, and decommission of any monitoring wells, piezometers and other measurement, sampling, and analytical devices has been placed in the operating record; (5) when certification of the groundwater monitoring system by an independent registered professional engineer or hydrologist has been placed in the operating record; (6) when groundwater monitoring sampling and analysis program documentation has been placed in the operating record; (7) when the use of an alternative statistical method is to be used in evaluating groundwater monitoring data and a justification for the alternative statistical method has been placed in the operating record; (8) when the owner or operator finds that there is a statistically significant increase over background for one or more of the constituents listed in Appendix III of the proposed rule, at any groundwater monitoring well; (9) when a notice of the results of assessment monitoring that may be required under the groundwater monitoring program is placed in the operating record; (10) when a notice is placed in the operating record that constituent levels that triggered assessment monitoring have returned to or below background levels; (11) when a notice of the intent to close the unit has been placed in the operating record; and (12) when a certification, signed by an independent registered professional engineer verifying that post-closure care has been completed in accordance with the post-closure plan, has been placed in the operating record. Please consult the proposed subtitle D regulation provided with this notice for all the proposed notification and documentation requirements.

As explained earlier, the RCRA subtitle D approach relies on state and citizen enforcement. EPA believes that it cannot conclude that the RCRA subtitle D regulations will ensure there is no reasonable probability of adverse effects on health or the environment, unless there is a mechanism for states and citizens to monitor the situation, such as when groundwater monitoring shows exceedances, so that they can determine when intervention is appropriate. EPA also believes that notifications, such as those described above, will minimize the danger of owners or operators abusing the self-implementing system through increased transparency and by facilitating the citizen suit enforcement mechanism.

EPA is proposing that owners and operators provide notification to the public by posting notices and relevant information on an internet site with a link clearly identified as being a link to notifications, reports, and demonstrations required under the regulations. EPA believes the internet is currently the most convenient and widely accessible means for gathering information. However, the Agency solicits comments regarding the methods for providing notifications to the public and the states.

B. Section-by-Section Discussion of RCRA Subtitle D Criteria

1. Proposed Modifications to Part 257, Subpart A

EPA is proposing to modify the existing open dumping criteria found in 40 CFR 257.1, *Scope and Purpose,* to recognize the creation of a new subpart D, which consolidates all of the criteria adopted for determining which CCR Landfills and CCR Surface impoundments pose a reasonable probability of adverse effects on health or the environment under sections 1008(a)(3) and 4004(a) of the Act. Facilities and practices failing to satisfy these consolidated subpart D criteria violate RCRA's prohibition on open dumping. The proposed regulation also excludes CCR landfills and surface impoundments subject to proposed subpart D from subpart A, except as otherwise provided in subpart D.

In general, these provisions are intended to integrate the new requirements with the existing open dumping criteria, and have only been modified to clarify that the proposed RCRA subtitle D regulations define which CCR landfills and surface impoundments violate the federal standards, and therefore may be enforced by citizen suit under RCRA 4005(a) and 7002. EPA has also proposed language to make clear that those CCR landfills and surface impoundments that are subject to the new proposed Subpart D would not also be subject to Subpart A, with the exception of three of the existing Subpart A criteria (257.3–1, *Floodplains,* 257.3–2 *Endangered Species,* 257.3–3 *Surface water*) that would continue to apply to these facilities. The applicability of these three provisions to CCR disposal facilities is discussed later in this preamble.

Finally, EPA also notes that its intent in excluding CCR landfills and surface impoundments from 40 CFR 257 Subpart A in this manner is to consolidate the requirements applicable to those particular facilities in one set of RCRA subtitle D regulations. EPA does not intend to modify the coverage of 40 CFR 257 subpart A as to other disposal facilities and practices for CCRs, such as beneficial uses of CCRs when they are applied to the land used for food-chain crops. It is EPA's intent that such activities would continue to be subject to the existing criteria under Subpart A.

2. General Provisions

The proposed general provisions address the applicability of the new proposed RCRA Subpart D requirements, the continuing applicability of certain of the existing open dumping criteria, provide for an effective date of 180 days after promulgation, and define key terms for the proposed criteria.

Applicability. The applicability provisions identify those solid waste disposal facilities subject to the new proposed RCRA Subpart D (*i.e.,* CCR landfills and CCR surface impoundments as defined under proposed 257.40(b)). The applicability section also identifies three of the existing subpart A criteria that would continue to apply to these facilities: 257.3–1, *Floodplains,* 257.3–2 *Endangered Species,* 257.3–3 *Surface water.* The applicability of these provisions to CCR disposal facilities is discussed later in this preamble.

The applicability section also specifies an effective date of 180 days after publication of the final rule. EPA believes that, with the specific exceptions discussed below, this time frame strikes a reasonable balance between the time that owners and operators of CCR units would need in order to come into compliance with the rule's requirements, and the need to implement the proposed requirements in a timeframe that will maximize protection of health and the environment. We note that 180 days is the timeframe for persons to come into compliance with most of the requirements under RCRA subtitle C, and believe that if persons can meet the hazardous waste provisions within this time period under RCRA subtitle C, that it is reasonable to conclude that persons should be able to meet those same or similar requirements under RCRA subtitle D. EPA also notes that pending finalization of any regulations, facilities continue to be subject to the existing part 257 open dumping criteria as they may apply.

3. Definitions

This section of the proposed regulation discusses the definitions of some of the key terms used in the proposed RCRA subtitle D rule that are necessary for the proper interpretation of the proposed criteria. Because EPA is creating a separate section of the regulations specific to CCR units, EPA is also consolidating the existing definitions in this section. However, by simply incorporating these unmodified definitions into this new section of the regulations, EPA is not proposing to reopen, or soliciting comments on these requirements. Nor, for definitions where the only modification relates to an adjustment specific to CCRs, is EPA proposing to revise or reopen the existing part 257 or part 258 definitions as they apply to other categories of disposal facilities, as those will remain unaltered. Accordingly, EPA will not respond to any comments on these definitions.

Aquifer. EPA has defined aquifer for this proposal as a geologic formation, group of formations, or portion of a formation capable of yielding significant quantities of ground water to wells or springs. This is the same definition currently used in EPA's hazardous waste program and MSWLF criteria in 40 CFR 258.2 and differs from the original criteria definition (40 CFR 257.3–4(c)(1)) only in that it substitutes the term "significant" for "usable." The Agency is proposing to adopt the modified definition to make the subtitle C and subtitle D alternatives consistent.

Coal Combustion Residuals (CCRs) means fly ash, bottom ash, boiler slag, and flue gas desulfurization wastes. CCRs are also known as coal combustion wastes (CCWs) and fossil fuel combustion (FFC) wastes.

CCR Landfill. The co-proposed criteria includes a definition of "CCR landfill" to mean an area of land or an excavation, including a lateral expansion, in which CCRs are placed for permanent disposal, and that is not a land application unit, surface impoundment, or injection well. For purposes of this proposed rule, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. EPA modeled this definition after the definition of "Municipal solid waste landfill (MSWLF) unit" contained in the existing criteria for those facilities. Although this is somewhat different than the definition proposed under the subtitle C alternative (which is based on the existing part 260 definition), EPA intends for this proposed definition to capture those landfills and other large-scale disposal practices that are described in EPA's damage cases and risk assessments discussed in sections II, VI, and the RIA.

CCR Surface Impoundment. EPA has proposed to define this term to mean a facility or part of a facility, including a lateral expansion, that is a natural topographic depression, human-made excavation, or diked area formed primarily of earthen materials (although it may be lined with human-made materials), that is designed to hold an accumulation of liquid CCR wastes or CCR wastes containing free liquids and that is not an injection well. EPA has included as examples of surface impoundments settling and aeration pits, ponds, and lagoons. This is the same definition that EPA is proposing as part of the subtitle C alternative, and is generally consistent with the definition of "surface impoundment or impoundment" contained in the existing 257.2 criteria.

EPA further proposes in the definition a description of likely conditions at a CCR surface impoundment, stating that CCR surface impoundments often receive CCRs that have been sluiced (flushed or mixed with water to facilitate movement), or wastes from wet air pollution control devices. EPA intends for this proposed definition to capture those surface impoundments that are described in EPA's damage cases and risk assessments described in sections II, VI, and the RIA.

Existing CCR Landfill/Existing CCR Surface Impoundment. EPA has included a proposed definition of this term to mean a CCR landfill or surface impoundment, which was in operation on, or for which construction commenced prior to the effective date of the final rule. The proposed definition states that a CCR landfill or surface impoundment has commenced construction if: (1) The owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and (2) either (i) a continuous on-site, physical construction program has begun; or (ii) the owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill or surface impoundment to be completed within a reasonable time. These definitions are identical to the co-proposed subtitle C definitions, described in section VI. EPA sees no reason to establish separate definitions of these units for purposes of RCRA subtitle D since the question of whether these units are existing should not differ between whether they are regulated under RCRA subtitles C or D.

Factor of Safety (Safety Factor). The proposed definition is the ratio of the forces tending to resist the failure of a structure to the forces tending to cause such failure as determined by accepted engineering practice. This definition is the same as the co-proposed subtitle C definitions, described in section VI. EPA sees no reason to establish a separate definition for this term for purposes of RCRA subtitle D since the question of "Factor of safety" should not differ between units that would be regulated under RCRA subtitles C or D.

Hazard potential classification. This term is proposed to be defined as the possible adverse incremental consequences that result from the release of water or stored contents due to failure of a dam (or impoundment) or misoperation of the dam or appurtenances.

The proposed definition further delineates the classification into four categories:

—*High hazard potential surface impoundment* which is a surface impoundment where failure or misoperation will probably cause loss of human life;

—*Significant hazard potential surface impoundment* which is a surface impoundment where failure or misoperation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns; and

—*Low hazard potential surface impoundment* means a surface impoundment where failure or misoperation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

—*Less than low hazard potential surface impoundment* means a surface impoundment not meeting the definitions for High, Significant, or Low Hazard Potential.

This definition, just like the proposed RCRA subtitle C definition, follows the

Hazard Potential Classification System for Dams, developed by the U.S. Army Corps of Engineers for the National Inventory of Dams. This system is a widely-used definitional scheme for classifying the hazard potential posed by dams, and EPA expects that the regulated community's familiarity with these requirements will make their application to CCR surface impoundments relatively straightforward.

Independent registered professional engineer or hydrologist. This term is defined as a scientist or engineer who is not an employee of the owner or operator of a CCR landfill or surface impoundment who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in groundwater hydrology and related fields as may be demonstrated by state registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgments regarding groundwater monitoring, contaminant fate and transport, and corrective action.

Because the proposed RCRA subtitle D requirements cannot presuppose the existence of a permit or state regulatory oversight, the criteria in today's proposed rule are self-implementing. However, as discussed earlier, to try to minimize the potential for overregulation, and to provide some degree of flexibility, EPA is proposing to allow facilities to deviate from the criteria upon a demonstration that the alternative meets a specified performance standard. But to provide for a minimum level of verification and to reduce the opportunity for abuse, the Agency believes it is imperative to have an independent party review, and certify the facility's demonstrations. The Agency also believes that those professionals certifying the requirements of today's proposed rule should meet certain minimum qualifications. The Agency is proposing to define a "qualified ground-water scientist" to be a scientist or engineer who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in ground-water hydrology and related fields as may be demonstrated by State registration, professional certification, or completion of accredited university programs that enable that individual to make sound professional judgments regarding ground-water monitoring, contaminant fate and transport, and corrective action. This requirement is the same as the current requirement at § 258.50(f). The Agency believes that specialized coursework and training should include, at a minimum, physical geology, ground-water hydrology or hydrogeology, and environmental chemistry (*e.g.,* soil chemistry or low temperature geochemistry). Some national organizations, such as the American Institute of Hydrology and the National Water Well Association, currently certify or register ground-water professionals. States may of course establish more stringent requirements for these professionals, including mandatory licensing or certification. As discussed above, EPA seeks comment on the proposed reliance on independent professionals in implementing the proposed flexibility of performance standards.

Lateral expansion means a horizontal expansion of the waste boundaries of an existing CCR landfill, or existing CCR surface impoundment made after the effective date of the final rule. This definition is identical to the co-proposed subtitle C definition, described in section VI. EPA sees no reason to establish a separate definition of this term for purposes of RCRA subtitle D since whether a lateral expansion has occurred at a CCR landfill or surface impoundment should not differ between those units regulated under RCRA subtitles C or D.

New CCR landfill means a CCR landfill from which there is placement of CCRs without the presence of free liquids, which began operation, or for which the construction commenced after the effective date of the rule. This definition is identical to the co-proposed subtitle C definition, described in section VI. EPA sees no reason to establish a separate definition for this term for purposes of RCRA subtitle D since whether a landfill is new should not differ between those landfills that are regulated under RCRA subtitles C or D.

New CCR surface impoundment means a CCR surface impoundment into which CCRs with the presence of free liquids have been placed, which began operation, or for which the construction commenced after the effective date of the rule. EPA sees no reason to establish a separate definition for this term for purposes of RCRA subtitle D since whether a surface impoundment is new should not differ between those surface impoundments that are regulated under RCRA subtitles C or D.

Recognized and generally accepted good engineering practices means engineering maintenance or operation activities based on established codes, standards, published technical reports, recommended practice, or similar document. Such practices detail generally approved ways to perform specific engineering, inspection, or mechanical integrity activities. In several provisions, EPA requires that the facility operate in accordance with "recognized and generally accepted good engineering practices," or requires an independent engineer to certify that a design or operating parameter meets this standard. The definition references but does not attempt to codify any particular set of engineering practices, but to allow the professional engineer latitude to adopt improved practices that reflect the state-of-the art practices, as they develop over time. This definition is the same as the definition EPA is proposing under the subtitle C alternative.

4. Location Restrictions

To provide for no reasonable probability of adverse effects on health or the environment from the disposal of CCRs at CCR landfills and surface impoundments, EPA believes that any RCRA subtitle D regulation would need to ensure that CCR disposal units were appropriately sited. The proposed location restrictions include requirements relating to placement of the CCRs above the water table, wetlands, fault areas, seismic impact zones, and unstable areas. In addition, as previously noted, the location standards in subpart A of 40 CFR part 257 for floodplains, endangered species, and surface waters would also continue to apply. Finally, the proposed regulations also address the closure of existing CCR landfills and surface impoundments.

The location standards in this proposal are primarily based on the location standards developed for municipal solid waste landfill units, and represent provisions to ensure that the structure of the disposal unit is not adversely impacted by conditions at the site, or that the location of a disposal unit at the site would not increase risks to human health or the environment. The criteria for municipal solid waste landfills provide restrictions on siting units in wetlands, fault areas, seismic impact zones, and unstable areas.[151]

[151] The proposed definition of seismic impact zone was modified from the part 258 definition as explained in the "Discussion of Individual Location Requirements" section below. The part 258 criteria also include location restrictions relating to airport safety and floodplains, in 258.10 and 258.11, respectively. EPA has not proposed an analogue to 258.10 because the hazard addressed by that criterion, bird strikes to aircraft, is inapplicable in the context of CCR disposal units, which do not tend to attract birds to them. As discussed in the

Continued

Each of those factors is generally recognized as having the potential to impact the structure of a disposal unit negatively or increase the risks to human health and the environment. As discussed below in more detail, each of these provisions adopted for today's RCRA subtitle D co-proposal relies in large measure, on the record EPA developed to support the 40 CFR part 258 municipal solid waste landfill criteria. EPA's Guide for Industrial Waste Management (EPA530–R–03–001, February 2003) also identifies these location restrictions as appropriate for industrial waste management. These proposed requirements are all discussed in turn below, after a general explanation of the Agency's proposed treatment of new CCR disposal units compared to existing CCR disposal units.

a. Differences in Location Restrictions for Existing and New CCR Landfills and Surface Impoundments, and Lateral Expansions. EPA is proposing different sets of location restrictions under the Subtitle D approach, depending on whether a unit is a CCR landfill or surface impoundment, and whether it is an existing or new unit. Lateral expansions fall within the definitions of new units, and are treated accordingly.

While new landfills would be required to comply with all of the location restrictions, EPA is proposing to subject existing landfills to only two of the location restrictions—floodplains, and unstable areas—in today's rule. Existing landfills are already subject to the floodplains location restriction because it is contained in the existing 40 CFR part 257, subpart A criteria, which have been in effect since 1979. Because owners and operators of existing landfills already should be in compliance with this criterion, applying this location restriction will have no impact to the existing disposal capacity, while continuing to provide protection of human health and the environment.

The Agency decided to apply today's final unstable area location restriction to existing CCR landfills, because the Agency believes that the impacts to human health and the environment that would result from the rapid and catastrophic destruction of these units outweighs any disposal capacity concerns resulting from the closure of existing CCR disposal units.

On the other hand EPA is not proposing to impose requirements on existing CCR landfills in wetlands, fault areas, or seismic impact areas. We base this decision on the possibility that a significant number of CCR landfills may be located in areas subject to this requirement. The Agency believes that such landfills pose less risks and are structurally less vulnerable than surface impoundments, and disposal capacity shortfalls, which could result if existing CCR landfills in these locations were required to close, raise greater environmental and public health concerns than the potential risks caused by existing units in these locations. For example, if existing CCR landfills located in wetlands were required to close, there would be a significant decrease in disposal capacity, particularly given the Agency's expectation that many existing surface impoundments will choose to close, in response to this proposed rule. In addition, wetlands are more prevalent in some parts of the country (*e.g.,* Florida and Louisiana). In these States, the closure of all existing CCR landfills located in wetlands could potentially significantly disrupt statewide solid waste management. Therefore, the Agency believes that it may be impracticable to require the closure of existing CCR landfills located in wetlands. However, EPA seeks comment and additional information regarding the number of existing CCR landfills that are located in such areas.

Concern about impacts on solid waste disposal capacity as well as the lower level of risks and the structural vulnerability of landfills, as compared to surface impoundments, were also the primary reasons the Agency is not proposing to subject existing CCR landfills to today's proposed fault area location restrictions. The closure of a significant number of existing CCR landfills located in fault areas could result in a serious reduction of CCR landfill capacity in certain regions of the U.S. where movement along Holocene faults is common, such as along the Gulf Coast and in much of California and the Pacific Northwest. The Agency, however, does not have specific data showing the number of units and the distance between these disposal units and the active faults, and therefore, is unable to precisely estimate the number of these existing CCR landfills that would not meet today's fault area restrictions. EPA therefore solicits comment and additional data and information regarding the extent to which existing CCR landfills are currently located in such locations. However, given the potential for impacts on solid waste capacity and the lower levels of risk associated with landfills compared to surface impoundments, EPA has concluded that it may not be appropriate to subject existing CCR landfills to the proposed fault area requirements.

Similarly, the Agency is not proposing to impose the seismic impact zone restrictions on existing CCR landfills located in these areas. As with the other location restrictions, the Agency anticipates that a significant number of existing CCR disposal units are located in these areas. EPA is concerned that such facilities would be unable to meet the requirements, because retrofitting would be prohibitively expensive and technically very difficult in most cases, and would therefore be forced to close.

EPA generally seeks comment and additional information regarding the extent to which CCR landfill capacity would be affected by applying these location restrictions to existing CCR landfills. Information on the prevalence of existing CCR landfills in such areas would be of particular interest to the Agency. EPA also notes that the proposed location requirements do not reflect a complete prohibition on siting facilities in such areas, but provide a performance standard that facilities must meet in order to site a unit in such a location. EPA therefore solicits comment on the extent to which facilities could comply with these performance standards, and the necessary costs that would be incurred to retrofit the unit to meet these standards.

As discussed earlier in this preamble, this proposed approach is generally consistent with the proposed approach to existing landfills under subtitle C of RCRA, and with Congressional distinctions between the risks presented by landfills and surface impoundments. Existing landfills that are brought into the hazardous waste system because they are receiving newly listed hazardous wastes are not generally required to be retrofitted with a new minimum-technology liner/leachate collection and removal system (or to close), and they would not be subject to such requirements under today's proposal. EPA sees no reason or special argument to adopt more stringent requirements under the co-proposed subtitle D criteria for CCR landfills, particularly given the volume of the material and the disruption that could be involved if these design requirements were applied to existing landfills.

By contrast, and consistent with its approach to existing surface impoundments under subtitle C, the proposed regulations would apply all of the location restrictions to existing surface impoundments. This means that facilities would need to either

main text, EPA is proposing to maintain the existing criterion in 257, subpart A for floodplains.

demonstrate that the surface impoundment meets the performance standard that serves as the alternative to the prohibition, retrofit the unit so that it can meet the performance standard, or close. EPA is making this distinction because, as discussed in sections IV–VI, the record indicates that the risks associated with CCR surface impoundments are substantially higher than the risks posed by CCR landfills. The impacts to human health and the environment that would result from the rapid and catastrophic destruction of these units could result in injuries to human health and the environment, that are far more significant, as illustrated by the impacts of the recent TVA spill in Tennessee. The risks to human health and the environment of such a catastrophic collapse far outweigh the costs of requiring surface impoundments to retrofit or close. Moreover, there are significant economic costs associated with the failure of a surface impoundment; as noted earlier, the direct cost to clean up the TVA spill is currently estimated to exceed one billion dollars. Surface impoundments also are more vulnerable to structural problems if located in unstable areas, fault areas and seismic impact areas. Finally, as already noted, the distinction EPA is making between existing landfills and existing surface impoundments is also consistent with Congressional direction; as discussed in section VI, Congress specifically required existing surface impoundments receiving hazardous wastes to retrofit to meet the new statutory requirements or to close, in direct contrast to their treatment of existing landfills.

Although many surface impoundments may close as a result of these requirements, EPA believes that it is proposing to take a number of actions to alleviate concerns that this will present significant difficulties with regard to disposal capacity in the short-term: *e.g.,* “grandfathering” in existing CCR landfills, allowing CCR landfills to vertically expand without retrofitting, and delayed implementation dates. At the same time, as discussed in greater detail in section VI, with regard to the subtitle C co-proposal, EPA is soliciting comment on the appropriate amount of time necessary to meet these time frames as well as measures that could help to address the potential for inadequate disposal capacity. EPA notes, however, that unlike under the subtitle C co-proposal, EPA is not proposing to require facilities to cease wet handling. Thus EPA expects that both the impacts and the time frames needed for facilities to come into compliance would be lower.

While the proposed requirements relating to the placement above the water table, wetlands, fault areas, and seismic impact zones would not apply to existing CCR disposal units, all of these restrictions apply to lateral expansions of existing CCR disposal units, as well as new CCR disposal units. Therefore, under the proposal, owners and operators of existing CCR landfills could vertically expand their existing facilities in these locations, but must comply with the provisions governing new units if they wish to laterally expand. EPA expects that allowing such vertical expansion will allow for increased capacity, which will be particularly important, if, as EPA expects, many surface impoundments would close, should this regulation be adopted. At the same time, EPA believes that the risks to human health or the environment will be mitigated because facilities will be required to otherwise comply with the more stringent environmental restrictions, such as the corrective action and closure provisions proposed below.

b. Discussion of Individual Location Requirements

Placement above the water table. The co-proposed subtitle D regulations would prohibit new CCR landfills and all surface impoundments from being located within two feet of the upper limit of the natural water table. EPA is proposing to define the natural water table as the natural level at which water stands in a shallow well open along its length and penetrating the surficial deposits just deeply enough to encounter standing water at the bottom. This is the level of water that exists, when uninfluenced by groundwater pumping or other engineered activities.

Floodplains. CCR landfills and surface impoundments are currently subject to the open dumping criteria contained in 40 CFR 257, Subpart A. These minimum criteria include restrictions on floodplain impacts under 257.3–1. As facilities should already be complying with this requirement, EPA is not proposing to modify it as part of today’s rule. Accordingly, EPA is not reopening this requirement.

Wetlands. The regulations require that the facility prepare and make available a written demonstration that such engineering measures have been incorporated into the unit’s design to mitigate any potential adverse impact, and require certification by an independent registered professional engineer either that the new CCR disposal unit is not in a prohibited area, as defined by the regulation, or that the demonstration meets the regulatory standards.

Today’s proposed wetland provisions would apply only to new CCR landfills, including lateral expansions of existing CCR disposal units, and all surface impoundments. New CCR landfills, which include lateral expansions, as well as all surface impoundments, are barred from wetlands unless the owner or operator of the disposal unit can make the following demonstrations certified by an independent registered professional engineer or hydrologist. First, the owner or operator must rebut the presumption that a practicable alternative to the proposed CCR disposal unit or lateral expansion is available that does not involve wetlands. Second, the owner or operator must show that the construction or operation of the unit will not cause or contribute to violations of any applicable State water quality standard, violate any applicable toxic effluent standard or prohibition, jeopardize the continued existence of endangered or threatened species or critical habitats, or violate any requirement for the protection of a marine sanctuary. Third, the owner or operator must demonstrate that the CCR disposal unit or lateral expansion will not cause or contribute to significant degradation of wetlands. To this end, the owner or operator must ensure the integrity of the CCR disposal unit, and its ability to protect ecological resources by addressing: erosion, stability, and migration potential of native wetland soils, muds and deposits used to support the unit; erosion, stability, and migration potential of dredged and fill materials used to support the unit; the volume and chemical nature of the CCRs; impacts on fish, wildlife, and other aquatic resources and their habitat from release of CCRs; the potential effects of catastrophic release of CCRs to the wetland and the resulting impacts on the environment; and any additional factors, as necessary, to demonstrate that ecological resources in the wetland are sufficiently protected. Fourth, the owner or operator must demonstrate that steps have been taken to attempt to achieve no net loss of wetlands by first avoiding impacts to wetlands to the maximum extent practicable, then minimizing unavoidable impacts to the maximum extent practicable, and finally offsetting remaining unavoidable wetland impacts through all appropriate and practicable compensatory mitigation actions. The owner or operator must place the demonstrations in the operating record and the company's Internet site, and notify the state that the demonstrations have been placed in the operating record.

For facilities that cannot make such a demonstration, this proposed provision effectively bans the siting of new CCR landfills or surface impoundments in wetlands, and would require existing surface impoundments to close.

EPA notes that this section of the proposal is consistent with regulatory provisions currently governing the CWA section 404 program, including the definition of wetlands contained in proposed 257.61. *See* 40 CFR 232.2(r). EPA believes that wetlands are very important, fragile ecosystems that must be protected, and has identified wetlands protection as a top priority. Nevertheless, EPA has proposed to continue to allow existing CCR landfills to be sited in wetlands to minimize the disruption to existing CCR disposal facilities, as it is EPA's understanding that many existing CCR landfills are located near surface water bodies, in areas that also may qualify as wetlands under the proposed criteria. Likewise, EPA is concerned that an outright ban of new CCR landfills in wetlands would severely restrict the available sites or expansion possibilities, given that EPA is proposing to impose other conditions on surface impoundments that may cause many to ultimately close. As noted in section VI, concerns have been raised regarding the potential for disposal capacity shortfalls, which could lead to other health and environmental impacts, such as the transportation of large volumes of CCRs over long distances to other sites. Accordingly to provide additional flexibility in the proposed RCRA Subtitle D rules, and to address concerns regarding the potential for disposal capacity shortfalls, EPA is not proposing an outright ban on siting of existing CCR disposal units in wetlands.

However, EPA continues to believe that siting new CCR disposal units in wetlands should only be done under very limited conditions. The Agency is therefore proposing a comprehensive set of demonstration requirements. In addition, the Agency believes that when such facilities are sited in a wetland, that the owner or operator should offset any impacts through appropriate and practicable compensatory mitigation actions (*e.g.,* restoration of existing degraded wetlands or creation of man-made wetlands). This approach is consistent with the Agency's goal of achieving no overall net loss of the nation's remaining wetland base, as defined by acreage and function. Specifically, § 257.61(a)(4) requires owners or operators of new CCR landfills and surface impoundments to demonstrate that steps have been taken to achieve no net loss of wetlands (as defined by acreage and function) by first avoiding impacts to wetlands and then minimizing such impacts to the maximum extent feasible, and finally, offsetting any remaining wetland impacts through all appropriate and feasible compensatory mitigation actions (*e.g.,* restoration of existing degraded wetlands or creation of man-made wetlands).

The Agency has also included other requirements to ensure that the demonstrations required under the proposed rule are comprehensive and ensure no reasonable probability of adverse effects to human health and the environment. First, EPA has included language in § 257.61(a)(2) clarifying that the owner or operator must demonstrate that both the construction and operation of the unit will not result in violations of the standards specified in § 257.61(a)(2)(i)–(iv). Second, in § 257.61(a)(3) EPA proposes to identify the factors the owner or operator must address in demonstrating that the unit will not cause or contribute to significant degradation of wetlands. These factors, which were partially derived from the section 404(b)(1) guidelines, address the integrity of the CCR unit and its ability to protect the ecological resources of the wetland. In addition, EPA is proposing requirements for third-party certification and state/public notice, to provide some verification of facility practices, and to generally assist citizens' ability to effectively intervene and enforce the requirements, as necessary.

Fault Areas. The proposed rule would ban the location of new CCR landfills and any surface impoundment within 200 feet (60 meters) of faults that have experienced displacement during the Holocene Epoch. The Holocene is a unit of geologic time, extending from the end of the Pleistocene Epoch to the present and includes the past 11,000 years of the Earth's history. EPA is proposing to define a fault to include a zone or zones of rock fracturing in any geologic material along which there has been an observable amount of displacement of the sides relative to each other. Faulting does not always occur along a single plane of movement (a "fault"), but rather along a zone of movement (a "fault zone"). Therefore, "zone of fracturing," which means a fault zone in the context of the definition, is included as part of the definition of fault, and thus the 200-foot setback distance will apply to the outermost boundary of a fault or fault zone.

The 200-foot setback was first adopted by EPA in the criteria for municipal solid waste landfills (MSWLFs), codified at 40 CFR part 258. In the course of that proceeding, EPA documented that seismologists generally believed that the structural integrity of MSWLFs could not be unconditionally guaranteed when they are built within 200-feet of a fault along which movement is highly likely to occur. Moreover, EPA relied on a study that showed that damage to engineered structures from earthquakes is most severe when the structures were located within 200-feet of the fault along which displacement occurred. Because the engineered structures found at MSWLFs are similar to those found in CCR disposal units, EPA expects that the potential for damage to those structures would be similar in the event of an earthquake near a CCR landfill or surface impoundment. Therefore, EPA is proposing a similar setback requirement for new CCR landfills and all surface impoundments. In general, EPA believes that the 200-foot buffer zone is necessary to protect engineered structures from seismic damages. EPA also expects that the 200-foot buffer is appropriate for CCR surface impoundments, but seeks comment and data on whether the buffer zone should be greater for such units.

However, the Agency is also concerned that the 200-foot setback may be overly protective in some geologic formations, but it is unable to provide a clear definition of these geologic formations. Therefore, the Agency is proposing to allow the opportunity for an owner or operator of a new CCR disposal unit to demonstrate that an alternative setback distance of less than 200 feet will prevent damage to the structural integrity of facility and will be protective of human health and the environment. The demonstration must be certified by an independent registered professional engineer and the owner or operator of the CCR disposal unit must notify the state that the demonstration has been placed in the operating record and on the company's internet site. This approach is consistent with other sections of today's RCRA subtitle D co-proposal for alternatives to the specified self-implementing requirement.

Seismic Impact Zones. As noted, the proposed rule would also ban the location of new CCR landfills and any surface impoundments in seismic impact zones, unless owners or operators demonstrate that the unit is designed to resist the maximum horizontal acceleration in lithified earth material for the site. The design features to be protected include all containment structures (*i.e.,* liners, leachate collection systems, and surface water control systems). The demonstration must be certified by an independent registered professional engineer and the owner or operator must notify the state that the demonstration has been placed in the operating record and on the company's internet site. For purposes of this requirement, EPA is proposing to define seismic impact zones as areas having a 10 percent or greater probability that the maximum expected horizontal acceleration in hard rock, expressed as a percentage of the earth's gravitation pull (g), will exceed 0.10g in 250 years. This is based on the existing part 258.14 definition of seismic impact. The maps for the 250-year intervals are readily available for all of the U.S. in the U.S. Geological Survey Open-File Report 82–1033, entitled "Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States."

Another approach would be to adopt criteria of the National Earthquake Hazards Reduction Program (NEHRP) of the U.S. Geological Survey used to develop national seismic hazard maps. The NEHRP uses ground motion probabilities of 2, 5, and 10% in 50 years to provide a relative range of seismic hazard across the country. The larger probabilities indicate the level of ground motion likely to cause problems in the western U.S. The smaller probabilities show how unlikely damaging ground motions are in many places of the eastern U.S. The maps are available at *http://earthquake.usgs.gov/hazards/products/.* A 50 year time period is commonly used because it represents the typical lifespan of a building, and a 2% probability level is generally considered an acceptable hazard level for building codes. For areas along known active faults, deterministic and scenario ground motion maps could be used to describe the expected ground motions and effects of specific hypothetical large earthquakes (*see* http://earthquake.usgs.gov/hazards/products/scenario/). The Agency solicits comments on the proposed definition and whether there are variants like those used to develop the national seismic hazard maps that could lessen the burden on the industry and the geographic areas covered by the proposed definition. For additional information on the National Seismic Hazard Mapping Project, *see http://earthquake.usgs.gov/hazards/about/.*

Unstable Areas. EPA is proposing to require owners or operators of all CCR landfills, surface impoundments and lateral expansions located in unstable areas to demonstrate that the integrity of the structural components of the unit will not be disrupted. EPA's damage cases have provided indirect evidence of the kind of environmental and human health risks that would be associated with failure of the structural components of the surface impoundment from subsidence or other instability of the earth at a CCR disposal unit. Accordingly, EPA believes that, to provide a reasonable probability of preventing releases and consequent damage to health and the environment from CCRs released from landfills or surface impoundments, limits on the siting of such disposal units is appropriate.

The proposed Subtitle D rule provides that "unstable areas" are locations that are susceptible to natural or human-induced events or forces capable of impairing the integrity of some or all of the CCR disposal unit's structural components responsible for preventing releases from such units. Unstable areas are characterized by localized or regional ground subsidence, settling (either slowly, or very rapidly and catastrophically) of overburden, or by slope failure. The owner or operator must consider the following factors when determining whether an area is unstable: (1) On-site or local soil conditions that may result in significant differential settling; (2) on-site or local geologic or geomorphologic features; and (3) on-site or local human-made features or events (on both the surface and subsurface). The structural components include liners, leachate collection systems, final cover systems, run-on and run-off control systems, and any other component used in the construction and operation of the CCR landfill, surface impoundment or lateral expansion that is necessary for protection of human health and the environment.

Unstable areas generally include:

(1) Poor foundation conditions—areas where features exist that may result in inadequate foundation support for the structural components of the CCR landfill, surface impoundment or lateral expansion (this includes weak and unstable soils);

(2) Areas susceptible to mass movement—areas where the downslope movement of soil and rock (either alone or mixed with water) occurs under the influence of gravity; and

(3) Karst terraces—areas that are underlain by soluble bedrock, generally limestone or dolomite, and may contain extensive subterranean drainage systems and relatively large subsurface voids whose presence can lead to the rapid development of sinkholes.

Karst areas are characterized by the presence of certain physiographic features such as sinkholes, sinkhole plains, blind valleys, solution valleys, losing streams, caves, and big springs, although not all these features are always present. EPA's intent in this proposed requirement is to include as an unstable area only those karst terraces in which rapid subsidence and sinkhole development have been a common occurrence in recent geologic time. Many of the karst areas are shown on the U.S. Geological Survey's National Atlas map entitled "Engineering Aspects of Karst," published in 1984.

Specific examples of such natural or human-induced phenomena include: Debris flows resulting from heavy rainfall in a small watershed; the rapid formation of a sinkhole as a result of excessive local or regional ground-water withdrawal; rockfalls along a cliff face caused by vibrations set up by the detonation of explosives, sonic booms, or other mechanisms; or the sudden liquefaction of a soil with the attendant loss of shear strength following an extended period of constant wetting and drying. Various naturally-occurring conditions can make an area unstable and these can be very unpredictable and destructive, especially if amplified by human-induced changes to the environment. Such conditions can include the presence of weak soils, over steepened slopes, large subsurface voids, or simply the presence of large quantities of unconsolidated material near a watercourse.

The Agency recognizes that rapid sinkhole formation that occurs in some karst terraces can pose a serious threat to human health and the environment by damaging the structural integrity of dams, liners, caps, run-on/run-off control systems, and other engineered structures. However, EPA is not proposing an outright ban of CCR landfills and surface impoundments in all karst terraces because of concerns regarding the impacts of such a ban in certain regions of the country. For example, several States (*i.e.,* Kentucky, Tennessee) are comprised mostly of karst terraces and banning all CCR disposal facilities in karst terraces would cause severe statewide disruptions in capacity available for CCR disposal. Moreover, the Agency believes that some karst terraces may provide sufficient structural support for CCR disposal units and has accordingly tried to provide flexibility for siting in these areas. Therefore, EPA is proposing to allow the construction of new CCR units, and the continued operation of existing CCR landfills and surface impoundments in karst terraces where the owner or operator can demonstrate that engineering measures have been incorporated into the landfill, surface impoundment, or lateral expansion design to ensure that the integrity of the structural components of the landfill or surface impoundment will not be disrupted. The demonstration must be certified by an independent registered professional engineer, and the owner or operator must notify the state that the demonstration has been placed in the operating record and on the company's internet site.

Closure of Existing CCR Landfills and Surface Impoundments. The proposed rule would require owners and operators of existing CCR landfills and surface impoundments that cannot make the demonstrations required under § 257.62(a) after the effective date of the rule, to close the landfill or surface impoundment within five years of the date of publication of the final rule. Closure and post-closure care must be done in accordance with § 257.100 and § 257.101. The proposed rule would also allow for a case-by-case extension for up to two more years if the facility can demonstrate that there is no alternative disposal capacity and there is no immediate threat to health or the environment. This demonstration must be certified by an independent registered professional engineer or hydrologist. The owner or operator must place the demonstration in the operating record and on the company's internet site and notify the state that this action was taken.

Thus, the proposed rule allows a maximum of 7 years from the effective date of the final rule if this alternative is finally promulgated for existing CCR landfills to comply with the unstable area restrictions, and existing CCR surface impoundments to comply with the location restrictions or to close. As discussed under the subtitle C option, EPA believes that five years will, in most cases, be adequate time to complete proper and effective facility closure and to arrange for alternative waste management. However, there may be cases where alternative waste management capacity may not be readily available or where the siting and construction of a new facility may take longer than five years. EPA believes the two-year extension should provide sufficient time to address these potential problems. EPA continues to believe that impacts on human health and the environment need to be carefully considered, and therefore, today's proposed rule requires the owner or operator to demonstrate that there is no available alternative disposal capacity and there is no potential threat to human health and the environment before adopting the two-year extension. These time frames are consistent with those EPA is proposing under its subtitle C co-proposal for surface impoundments. EPA is aware of no reason that the time frames would need to differ under subtitle D, but solicits comment on this issue.

5. Design Requirements

The CCR damage cases and EPA's quantitative groundwater risk assessment clearly show the need for effective liners—namely composite liners—to very significantly reduce the probability of adverse effects. The co-proposed subtitle D design standards would require that new landfills and all surface impoundments that have not completed closure prior to the effective date of the rule, can only continue to operate if composite liners and leachate collection and removal systems have been installed. Units must be retrofitted or closed within five years of the effective date of the final rule, which is the time frame EPA is proposing for surface impoundments to retrofit or close under the subtitle C alternative. EPA is proposing to require the same liner and leachate collection and removal systems as part of the subtitle D criteria that are being proposed under the RCRA subtitle C co-proposal. The technical justification for these requirements is equally applicable to the wastes and the units, irrespective of the statutory authority under which the requirement is proposed.

EPA is also proposing to adopt the same approach to new and existing units under RCRA subtitle D that it is proposing under RCRA subtitle C. EPA would only require new landfills (or new portions of existing landfills) to meet these minimum technology requirements for liners and leachate collection and removal systems. Existing landfills that continue to receive CCRs after the effective date of the final rule, would not be required to be retrofitted with a new minimum-technology liner/leachate collection and removal system (or to close). They can continue to receive CCRs, and continue to operate as compliant landfills, without violating the open dumping prohibition. However, existing landfills would have to meet groundwater monitoring, corrective action, and other requirements (except as noted) of the subtitle D criteria, to assure that any groundwater releases from the unit were identified and promptly remediated. EPA sees no reason or special argument to adopt any different approach under the co-proposed subtitle D regulations for CCR landfills, particularly given the volume of the material and the disruption that would be involved if these design requirements were applied to existing landfills.

By contrast, existing surface impoundments that have not completed closure by the effective date of the final rule would be required to retrofit to install a liner. This is consistent with, but not identical to, the approach proposed under the RCRA subtitle C alternative. Under the subtitle C alternative, EPA is not proposing to require existing surface impoundments to install the proposed liner systems because the impoundments would only continue to operate for a limited period of time. EPA's proposed treatment standards—dewatering the wastes—will effectively phase out wet handling of CCRs. During this interim period (seven years as proposed), EPA believes that it would be infeasible to require surface impoundments to retrofit, and that compliance with the groundwater monitoring and other subtitle C requirements would be sufficiently protective. EPA lacks the authority under RCRA subtitle D to establish a comparable requirement; EPA only has the authority under RCRA section 4004 to establish standards relating to "disposal," not treatment, of solid wastes. Although EPA expects that many surface impoundments will choose to close rather than install a liner, wet-handling of CCRs can continue, even in existing units, and EPA's risk assessment confirms that the long-term operation of such units would not be protective without the installation of the composite liner and leachate collection system described below.

The composite liner would consist of two components: An upper component consisting of a minimum 30-mil flexible membrane liner (FML), and a lower component consisting of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than $1{\times}10^{-7}$cm/sec. The FML component would be required to be installed in direct and uniform contact with the compacted soil component. (In other words, the new landfill or new surface impoundment would be required to have a liner and leachate collection and removal system meeting the same design standard now included in EPA's municipal solid waste landfill criteria.) EPA solicits comment, however, on whether any subtitle D option should allow facilities to use an alternative design for new disposal units, so long as the owner or operator of a unit could obtain certification from an independent registered professional engineer or hydrologist that the alternative design would ensure that the appropriate concentration values for a set of constituents typical of CCRs will not be exceeded in the uppermost aquifer at the relevant point of compliance—*i.e.,* 150 meters from the unit boundary down gradient from the unit, or the property boundary if the point of compliance (*i.e.,* the monitoring well) is beyond the property boundary. Although the existing part 258 requirements allow for such a demonstration, EPA is not proposing such a requirement in today's rule. EPA's risk assessment shows that only a composite liner would ensure that disposal of CCR will meet the RCRA section 4004 standard on a national level, even though site specific conditions could support the use of alternate liner designs in individual instances. In the absence of a strong state oversight mechanism, such as a permit, EPA is reluctant to allow facilities to modify this key protection. Nevertheless, EPA would be interested in receiving data and information that demonstrates whether under other site conditions, an alternative liner would be equally protective. In this regard, EPA would also be interested in information documenting the extent to which such conditions currently exist at CCR units. If EPA adopts such a performance standard, EPA anticipates adopting a requirement that is as consistent as possible with the existing part 258 requirements, and would require the same documentation and notification procedures as with the other self-implementing provisions in the co-proposed subtitle D option.

—*Stability requirements for surface impoundments.* In our recent assessment of surface impoundments managing CCRs, EPA has identified deficiencies in units currently receiving wet-handled CCRs.[152] The damage cases also demonstrate the need for requirements to address the stability of surface impoundments, to prevent the damages associated with a catastrophic failure, such as occurred at the TVA facility in 2008. EPA is therefore proposing to adopt as part of the subtitle D operating criteria for surface impoundments, the same stability requirements that are proposed as part of the subtitle C alternative. As explained in that section, these are based on the long-standing MSHA requirements, with only minor modifications necessary to tailor the requirements to CCR unit conditions.

For those surface impoundments which continue to operate, (*i.e.,* both new and existing) the proposed regulation would require that an independent registered professional engineer certify that the design of the impoundment is in accordance with recognized and generally accepted good engineering practices for the maximum volume of CCR slurry and wastewater that will be impounded therein, and that together design and management features ensure dam stability. The proposed regulation also requires the facility to conduct weekly inspections to ensure that any potentially hazardous condition or structural weakness will be quickly identified. As with the co-proposed RCRA subtitle C option, the proposed RCRA subtitle D regulation also requires that existing and new CCR surface impoundments be inspected annually by an independent registered professional engineer to assure that the design, operation, and maintenance of the surface impoundment is in accordance with current, prudent engineering practices for the maximum volume of CCR slurry and CCR waste water which can be impounded. EPA has concluded, subject to consideration of public comment, that these requirements are necessary to ensure that major releases do not occur that would cause adverse effects on health or the environment.

6. Operating Requirements

EPA is proposing to establish specific criteria to address the day-to-day operations of the CCR landfill or surface impoundment. The criteria were developed to prevent the health and environmental impacts from CCR landfills and surface impoundments identified in EPA's quantitative risk groundwater risk assessment and the damage cases. Included among these criteria are controls relating to runon and runoff from the surface of the facilities, discharges to surface waters, and pollution caused by windblown dust from landfills, and recordkeeping.

—*Existing criteria for Endangered Species and Surface Water.* CCR landfills and surface impoundments are currently subject to the open dumping criteria contained in 40 CFR 257, Subpart A. These minimum criteria include restrictions on impacts to endangered species under 257.3–2, and impacts to surface water under 257.3–3. As facilities should already be complying with these requirements, EPA is not proposing to modify these existing requirements in today's co-proposal. EPA notes that the surface water criterion is not enforceable by RCRA citizen suit. The extent to which this criterion may be enforced is governed by the remedies available under the CWA, which is the source of the requirement, rather than RCRA. *See, e.g., Arc Ecology* v. *U.S. Maritime Admin.,* No. 02:07–cv–2320 (E.D. Cal. Jan. 21, 2010); Guidelines for the Development and Implementation of State Solid Waste Management Plans and Criteria for Classification of Solid Waste Disposal Facilities and Practices, 46 Fed. Reg. 47048, 47050 (Sept. 23, 1981).

—*Run-on and run-off controls.* The purpose of the run-on standard is to minimize the amount of surface water entering the landfill and surface impoundment facility. Run-on controls prevent (1) Erosion, which may damage the physical structure of the landfill; (2) the surface discharge of wastes in solution or suspension; and (3) the downward percolation of run-on through wastes, creating leachate. The proposed regulation requires run-on control systems to prevent flow onto the active portion of the CCR landfill or surface impoundment during the peak discharge from a 24-hour, 25-year storm. This helps to ensure that run-off does not cause an overflow of the surface impoundment or scouring of material from a landfill or the materials used to build the surface impoundment.

Run-off is one of the major sources of hazardous constituent releases from mismanaged waste disposal facilities, including CCR landfills and surface impoundments. Additionally, run-off control systems from the active portion of CCR disposal units are required to collect and control at least the water volume resulting from a 24-hour, 25-year storm. This protects surface water that would otherwise flow untreated into a body of water. The facility is required to prepare a report, available to the public, documenting how relevant calculations were made, and how the control systems meet the standard. A registered professional engineer must certify that the design of the control systems meet the standard. Also, the owner or operator is required to prepare a report, certified by an independent registered professional engineer, and documenting how relevant calculations were made, and how the control systems meet the standard. The state must be notified that the report was placed in the operating record for the site, and the owner or operator must make it available to the public on the owner's or operator's internet site. Under the existing part 257 requirements, to which CCR units are currently subject, runoff must not cause

[152] For the findings of the assessment, *see: http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/surveys/index.htm#surveyresults.*

a discharge of pollutants into waters of the United States that is in violation of the National Pollutant Discharge Elimination System (NPDES) under section 402 of the Clean Water Act. (40 CFR 257.3–3). EPA is not proposing to revise the existing requirement, but is merely incorporating it here for ease of the regulated community.

The Agency chose the 24-hour period because it is an average that includes storms of high intensity with short duration and storms of low intensity with long duration. EPA believes that this is a widely used standard, and is also the current standard used for hazardous waste landfills and municipal solid waste landfill units under 40 CFR Part 258. EPA has no information that warrants a more restrictive standard for CCR landfills and surface impoundments than for MSWLFs and hazardous waste landfills.

Fugitive dust requirements. EPA has included under the co-proposed RCRA subtitle D regulation requirements similar to those included under the Subtitle C co-proposal, based upon its risk assessment findings that fugitive dust control at 35 μg/m3 or less is protective of human health or the environment. This is discussed in section VI above. Due to the lack of a permitting oversight mechanism under the RCRA Subtitle D alternative, and to facilitate citizen-suit enforcement of the criteria, EPA has provided for certification by an independent registered professional engineer, notification to the state that the documentation has been placed in the operating record, and provisions making available to the public on the owner's or operator's internet site documentation of the measures taken to comply with the fugitive dust requirements.

Recordkeeping requirements. EPA believes that it is appropriate for interested states and citizens to be able to access all of the information required by the proposed rule in one place. Therefore, the co-proposed Subtitle D alternative requires the owner or operator of a CCR landfill or surface impoundment to record and retain near the facility in an operating record which contains all records, reports, studies or other documentation required to demonstrate compliance with §§ 257.60 through 257.83 (relating to the location restrictions, design criteria, and operating criteria) and 257.90 through 257.101 (relating to ground water monitoring and corrective action, and closure and post-closure care).

The proposed rule would also require owners and operators of CCR surface impoundments that have not been closed in accordance with the closure criteria to place in the operating record a report containing several items of information. The reports would be required beginning every twelfth months after existing CCR surface impoundments would be required to comply with the design requirements in section 257.71 (that is, no later than seven years after the effective date of the final rule) and every twelfth month following the date of the initial plan for the design, construction, and maintenance of new surface impoundments and lateral expansions required under § 257.72(b)) to address:

(1) Changes in the geometry of the impounding structure for the reporting period;

(2) Location and type of installed instruments and the maximum and minimum recorded readings of each instrument for the reporting period;

(3) The minimum, maximum, and present depth and elevation of the impounded water, sediment, or slurry for the reporting period;

(4) Storage capacity of the impounding structure;

(5) The volume of the impounded water, sediment, or slurry at the end of the reporting period;

(6) Any other change which may have affected the stability or operation of the impounding structure that has occurred during the reporting period; and

(7) A certification by an independent registered professional engineer that all construction, operation, and maintenance were in accordance with the plan. The owner or operator would be required to notify the state that the report has been placed in the operating record and on the owner's or operator's internet site.

These reporting requirements are similar to those required under MSHA regulations for coal slurry impoundments (30 CFR 77.216–4). As the Agency has stated previously, MSHA has nearly 40 years of experience writing regulations and inspecting dams associated with coal mining, which is directly relevant to the issues presented by CCRs in this proposal. In our review of the MSHA regulations, we found them to be comprehensive and directly applicable to and appropriate for the dams used in surface impoundments at coal-fired utilities to manage CCRs.

The proposed rule would also allow the owner or operator to submit a certification by an independent registered professional engineer that there have been no changes to the information in items (1)–(6) above to the surface impoundment instead of a full report, although a full report would be required at least every 5 years.

7. Groundwater Monitoring/Corrective Action

EPA's damage cases and risk assessments all indicate the potential for CCR landfills and surface impoundments to leach hazardous constituents into groundwater, impairing drinking water supplies and causing adverse impacts on human health and the environment. Indeed, groundwater contamination is one of the key environmental risks EPA has identified with CCR landfills and surface impoundments. Furthermore, as mentioned previously, the legislative history of RCRA section 4004 specifically evidences concerns over groundwater contamination from open dumps. To this end, groundwater monitoring is a key mechanism for facilities to verify that the existing containment structures, such as liners and leachate collection and removal systems, are functioning as intended. Thus, EPA believes that, in order for a CCR landfill or surface impoundment to show no reasonable probability of adverse effects on health or the environment, a system of routine groundwater monitoring to detect any such contamination from a disposal unit, and corrective action requirements to address identified contamination, is necessary.

Today's co-proposed subtitle D criteria require a system of monitoring wells be installed at new and existing CCR landfills and surface impoundments. The co-proposed criteria also provide procedures for sampling these wells and methods for statistical analysis of the analytical data derived from the well samples to detect the presence of hazardous constituents released from these facilities. The Agency is proposing a groundwater monitoring program consisting of detection monitoring, assessment monitoring, and a corrective action program. This phased approach to groundwater monitoring and corrective action programs provide for a graduated response over time to the problem of groundwater contamination as the evidence of such contamination increases. This allows for proper consideration of the transport characteristics of CCR constituents in ground water, while protecting human health and the environment, and minimizing unnecessary costs.

In EPA's view, the objectives of a groundwater monitoring and corrective action regime and analytical techniques for evaluating the quality of groundwater are similar regardless of the particular wastes in a disposal unit, and regardless of whether the unit is a landfill or surface impoundment. Therefore, EPA has largely modeled the proposed groundwater monitoring and corrective action requirements for CCR landfills and surface impoundments after those for MSWLFs in the 40 CFR part 258 criteria, and for disposal units that may receive conditionally-exempt small quantity generator (CESQG) hazardous waste under 40 CFR part 257, subpart B. EPA believes that the underlying rationale for those requirements is generally applicable to groundwater monitoring and corrective action for CCR landfills and surface impoundments. Accordingly, EPA does not discuss these requirements at length in today's preamble. Rather, EPA refers the reader to the detailed discussions of these requirements in the preambles to the final and proposed rules for the MSWLF criteria for more information.[153] *See* Solid Waste Disposal Facility Criteria, 56 Fed. Reg. 50978 (Oct. 9, 1991) (final rule); Solid Waste Disposal Facility Criteria, 53 Fed. Reg. 33314 (Aug. 30, 1988) (proposed rule).

However, for a number of the requirements, EPA is proposing to modify or revise these requirements. Below, EPA discusses the particular areas where the Agency is proposing to make modifications, and solicits comment on those specific differences. EPA, more generally, solicits comment on whether relying on the existing groundwater monitoring and corrective action requirements for MSWLFs and CESQG facilities, as modified in today's proposal, are appropriate for CCR landfills and surface impoundments.

Relying on the existing criteria in 40 CFR 258 and 257 Subpart B has several advantages. Specifically, like the co-proposed Subtitle D regulations for CCR disposal, these requirements are structured to be largely self-implementing. In addition, states and citizens should already be familiar with those processes, which have been in place since 1991, and EPA expects that this familiarity with the processes may facilitate the states' creation of regulatory programs for CCR disposal facilities under state law, to the extent they do not already exist, and thus providing oversight (which EPA believes is important in implementing these rules) that is already found through MSWLFs and CESQG landfill permitting programs. Furthermore, familiarity with the overall approach may facilitate the states' and citizens' oversight of CCR disposal activities through the citizen suit mechanism, which is available, regardless of whether a state has adopted a regulatory program under state law for CCR disposal facilities.

At the same time, however, EPA is mindful of the differences in the statutory authorities for establishing criteria for CCR landfills and surface impoundments versus MSWLFs and CESQG facilities, and in particular, the possibility that a state may lack a permit program for CCR disposal units. Accordingly, EPA has sought to tailor these proposed requirements in the CCR disposal context, in particular by including in several of the proposed requirements a certification by an independent registered professional engineer or, in some cases, hydrologist, in lieu of the state approval mechanisms that are used in the 40 CFR part 258/257, Subpart B criteria. Such certifications are found in proposed §§ 257.95(h) (establishment of an alternative groundwater protection standard for constituents for which MCLs have not been established); and 257.97(e) (determination that remediation of a release of an Appendix IV constituent from a CCR landfill or surface impoundment is not necessary). As discussed earlier in this preamble, EPA believes that this provides an important independent validation of the particular route chosen. EPA solicits comment in particular on the appropriateness of relying on such a mechanism under the proposed groundwater monitoring and corrective action criteria.

In other instances, however, EPA has decided not to propose to allow facilities to operate under an alternative standard, such as the existing provisions under 257.21(g) and 258.50(h) (establishing alternative schedules for groundwater monitoring and corrective action); and 258.54(a)(1) and (2), and 257.24(a)(1) and (2), which allow the Director of an approved State to delete monitoring parameters, and establish an alternative list of indicator parameters, under specified circumstances. EPA is proposing not to adopt these alternatives for CCR disposal facilities because groundwater monitoring is the single most critical set of protective measures on which EPA is relying to protect human health and the environment. EPA is not proposing to require existing landfills to retrofit to install a composite liner. Since these units will continue to operate in the absence of a composite liner, groundwater monitoring is the primary means to prevent groundwater contamination. Although EPA is proposing to require existing surface impoundments to retrofit with composite liners, these units are more susceptible to leaking, and thus the need for a rigorous groundwater monitoring program is correspondingly high. Moreover, EPA is concerned that provisions allowing such modification of these requirements are particularly susceptible to abuse, since such provisions would allow substantial cost avoidance. Therefore, in the absence of a state oversight mechanism in place to ensure such modifications are technically appropriate, such a provision may operate at the expense of protectiveness. In addition, given the extremely technical nature of these requirements, EPA is concerned that such provisions would render the requirements appreciably more difficult for citizens to effectively enforce. In some instances, including these alternative standards would not be workable. For example, establishing alternative schedules under the groundwater monitoring and corrective action provisions (as currently provided under 257.21(g) and 258.50(h)) the Agency believes would not be workable in the context of a self-implementing rule, because there is no regulatory entity to judge the reasonableness of the desired alternatives. The Agency thus solicits comments on these omissions from today's proposed rule, and also on whether a more prescriptive approach could or should be developed under subtitle D of RCRA. EPA also solicits comment on whether the requirement for certification by an independent professional engineer would be effective or appropriate in such a case.

Applicability. The co-proposed subtitle D criteria require facilities to install a groundwater monitoring system at existing landfills and surface impoundments within one year of the effective date of the regulation so that any releases from these units will be detected, thus providing an opportunity to detect and, if necessary, take corrective action to address any releases from the facilities. The proposed rule also provides that new CCR landfills and surface impoundments comply with the groundwater monitoring requirements in the rule before CCRs can be placed in the units. EPA expects that the one-year timeframe for existing units is a reasonable time for facilities to install the necessary systems. This is the same time frame provided to

[153] The preambles to the CESQG rules have more limited discussions of these requirements. See Criteria for Classification of Solid Waste Disposal Facilities and Practices; Identification and Listing of Hazardous Waste; Requirements for Authorization of State Hazardous Waste Programs, 61 FR 34252, 34259–61 (July 1, 1996) (final rule); Criteria for Classification of Solid Waste Disposal Facilities and Practices; Identification and Listing of Hazardous Waste; Requirements for Authorization of State Hazardous Waste Programs, 60 FR 30964, 30975–77 (June 12, 1995) (proposed rule).

facilities under the existing part 265 interim status regulations, and past experience demonstrates this implementation schedule would generally be feasible. Although one year for the installation of groundwater monitoring is a shorter time frame than EPA provided to facilities as part of the original part 258 or part 257 subpart A requirements, there are good reasons to establish a shorter time frame here. As discussed in section IV, many of the existing units into which much of the CCR is currently disposed are unlined, and they are aging. Under these circumstances, EPA believes that installation of groundwater monitoring is critical to ensure that releases from these units are detected and addressed appropriately. Moreover, EPA offered a longer implementation period in 1991 based on a factual finding that a shortage of drilling contractors existed; in the 1995 rule establishing groundwater monitoring requirements for CESQG facilities, EPA determined that this shortage had ended. EPA is aware of no information to suggest that a similar shortage exists today, but specifically solicits comment on this issue.

EPA has not included provisions for suspension of ground water monitoring that is currently allowed under 257.21(b) and 258.50(b). This is one of those provisions discussed above, that EPA believes are potentially, particularly susceptible to abuse, and EPA is reluctant to adopt a comparable provision in the absence of an approved state permit program. In addition, since these proposed criteria are designed to be applied even in the absence of state action, EPA has not included provisions for state establishment of a compliance schedule under 257.21(d) and 258.50(d). EPA solicits comment on whether these types of provisions are appropriate for CCR landfills and surface impoundments.

Section 257.90 also requires that the owner or operator of the CCR landfill or surface impoundment must notify the state once each year throughout the active life and post-closure care period that such landfill or surface impoundment is in compliance with the groundwater monitoring and corrective action provisions of this subpart. This notification must also be placed on the owner or operator's internet site. EPA believes that annual notification will facilitate state oversight of the groundwater monitoring and corrective action provisions.

Groundwater monitoring systems. The co-proposed subtitle D criteria require facilities to install, at a minimum, one up gradient and three down gradient wells at all CCR units. EPA is proposing this requirement based on the subtitle C interim status self-implementing requirements.

The design of an appropriate groundwater monitoring system is particularly dependent on site conditions relating to groundwater flow, and the development of a system must have a sufficient number of wells, installed at appropriate locations and depths, to yield groundwater samples from the uppermost aquifer that represents the quality of background groundwater that has not been affected by contaminants from CCR landfills or surface impoundments. EPA's existing requirements under parts 257, Subpart B, 258, and 264 all recognize this, and because they operate in a permitting context, these requirements do not generally establish inflexible minimum requirements. Because the same guarantee of permit oversight is not available under the criteria developed for this proposal, EPA believes that establishing a minimum requirement is necessary. Past experience demonstrates that these monitoring requirements will be protective of a wide variety of conditions and wastes, and that facilities can feasibly implement these requirements. Moreover, in many instances a more detailed groundwater monitoring system may need to be in place, and EPA is therefore requiring a certification by the independent registered professional engineer or hydrologist that the groundwater monitoring system is designed to detect all significant groundwater contamination.

Groundwater sampling and analysis requirements. Owners and operators need to ensure that consistent sampling and analysis procedures are in place to determine whether a statistically significant increase in the level of a hazardous constituent has occurred, indicating the possibility of groundwater contamination. The co-proposed subtitle D criteria would require the same provisions addressing groundwater sampling and analysis procedures with those already in use for CESQG and MSWLF facilities, since generally the same constituents and analysis procedures would be appropriate in both instances. However, EPA is requesting comment on one issue in particular. In the final MSWLF criteria, EPA noted that in order to ensure protection of human health and the environment at MSWLFs, it was important to make sure that the right test methodology from among those listed in this section was selected for the conditions present at a particular MSWLF. At the time, EPA indicated its expectation that as states gained program approval, they would take on the responsibility of approving alternate statistical tests proposed by the facilities. *See* 56 Fed. Reg. 51071. Because states may choose not to create a regulatory oversight mechanism under the co-proposed subtitle D rule for CCR landfills and surface impoundments, however, EPA is requesting comment on whether the lack of such an oversight mechanism will impair selection of appropriate test methodologies, and whether EPA should instead adopt a different approach to ensure the protection of human health and the environment at CCR disposal facilities. For example, one approach might be for EPA to tailor a list of methodologies to particular site conditions. EPA would welcome suggestions from commenters on alternative approaches to this issue.

Detection monitoring program. The parameters to be used as indicators of groundwater contamination are the following: boron, chloride, conductivity, fluoride, pH, sulphate, sulfide, and total dissolved solids (TDS). In selecting the parameters for detection monitoring, EPA selected constituents that are present in CCRs, and would rapidly move through the subsurface and thus provide an early detection as to whether contaminants were migrating from the disposal unit. EPA specifically solicits comment on the appropriateness of this list of parameters.

In this provision of the proposed RCRA subtitle D co-proposed rule, EPA has decided not to include provisions parallel to 258.54(a)(1) and (2), and 257.24(a)(1) and (2) which allow the Director of an approved State to delete monitoring parameters, and establish an alternative list of indicator parameters, under specified circumstances. EPA is not including these provisions because it believes that a set of specified parameters are necessary to ensure adequate protectiveness, since EPA's information on CCRs indicates that their composition would not be expected to vary such that the parameters are inappropriate. Under the proposed rule, monitoring would be required no less frequently than semi-annually. EPA has again decided not to include a provision that would allow an alternative sampling frequency, because of the lack of guaranteed state oversight and potential for this provision to diminish protection of human health and the environment, as mentioned in the introductory discussions above. EPA solicits comments on whether it should allow deletion of monitoring parameters and alternative sampling frequencies, based on compliance with a performance standard that has been documented by an independent registered professional engineer or hydrologist. Commenters interested in supporting such an option are encouraged to provide data to demonstrate the conditions under which such alternatives would be protective, as well as information to indicate the prevalence of such conditions at CCR facilities.

Assessment monitoring program. When a statistically significant increase over background levels is detected for any of the monitored constituents, the rule would require the facility to begin an assessment monitoring program to detect releases of CCR constituents of concern including aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, copper, fluoride, iron, lead, manganese, mercury, molybdenum, pH, selenium, sulphate, sulfide, thallium, and total dissolved solids.

EPA specifically solicits comment on the appropriateness of this list of parameters. For the same reasons as discussed under the proposed requirements for detection monitoring, EPA has chosen not to include in the proposed requirements for assessment monitoring provisions for allowing a subset of wells to be sampled, the deletion of assessment monitoring parameters, or alternative sampling frequencies. EPA again solicits comment on whether these options are appropriate for CCR landfills and surface impoundments.

Assessment of corrective measures. The proposed rule also requires that whenever monitoring results indicate a statistically significant level of any appendix IV constituent exceeding the groundwater protection standard, the owner or operator must initiate an assessment of corrective action remedies. Unlike for the MSWLF and CESQG criteria, the proposed rule provides a discrete time frame for completion of the assessment, at 90 days, while the earlier criteria provided for its completion within a "reasonable period of time." EPA believes that without a state oversight mechanism, a finite time frame is appropriate. EPA selected 90 days as the period over which the assessment must be completed because it expects that this will be a sufficient length of time to complete the required activities. EPA solicits comment on the appropriateness of the 90-day timeframe.

Selection of Remedy. The proposed rule establishes a framework for remedy selection based upon the existing requirements for MSWLFs and CESQG facilities. These provisions have been modified to eliminate consideration of "practicable capabilities" where such considerations have been included in the MSWLF and CESQG criteria. EPA believes that it does not have the discretion to include this consideration under the RCRA subtitle D co-proposal, because this consideration is explicitly required under the terms of RCRA section 4010. That section by its terms applies to facilities that may receive household hazardous wastes and CESQG wastes, and so is inapplicable to today's co-proposed standards for CCR landfills and surface impoundments. *See* 42 U.S.C. 6949a(c)(1). EPA solicits comment on these modifications, specifically, on how this modification may affect the ability of the regulated community to comply with the proposed criteria, and on how this modification may affect the protectiveness of the proposed standards for human health and the environment.

In the provisions discussing factors to be considered in determining whether interim measures are necessary, EPA has modified proposed 257.98(a)(3)(vi), to eliminate consideration of risks of fire or explosion, since EPA does not expect that these risks would be relevant to the disposal of CCRs in CCR landfills and surface impoundments.

Implementation of the corrective action remedy. The co-proposed subtitle D criteria require that the owner or operator comply with several requirements to implement the corrective action program, again modeled after the existing requirements for MSWLFs and CESQG facilities. Similar to proposed section 257.97, these provisions have been made consistent with the underlying statutory authorities for this proposed rule. *See* discussions above.

In these provisions, EPA has decided not to include a provision that is included in the MSWLF criteria in 258.58(e)(2) and 257.28(e)(2), allowing an alternative length of time during which the owner or operator must demonstrate that concentrations of constituents have not exceeded the ground water protection standards, in support of a determination that the remedy is complete. *See* proposed 257.98(e)(2). Instead, the proposed rule would require a set period of three consecutive years. EPA solicits comment on whether to allow for a different period of time. EPA is particularly concerned with whether such a provision would provide protection to human health or the environment because of the lack of a guaranteed state oversight mechanism.

8. Closure and Post-Closure Care

Effective closure and post-closure care requirements, such as requirements to drain the surface impoundment, are essential to ensuring the long-term safety of disposal units. Closure requirements, such as placing the cover system on the disposal unit, ensure that rainfall is diverted from the landfill or surface impoundment, minimizing any leaching that might occur based on the hydraulic head placed on the material in the unit. EPA's Guide for Industrial Waste Management, prepared in consultation with industry experts, a Tribal representative, state officials, and environmental groups, documents the general consensus on the need for effective closure and post-closure requirements.[154] Post-closure care requirements are also particularly important for CCR units because the time to peak concentrations for selenium and arsenic, two of the more problematic constituents contained in CCR wastes, is particularly long, and therefore the peak concentrations in groundwater may not occur during the active life of the unit. Continued groundwater monitoring is therefore necessary during the post-closure care period to ensure the continued integrity of the unit and the safety of human health and the receiving environment. For these provisions, then, EPA has again modeled its proposed requirements for CCR landfills on those already in place for MSWLFs with modifications to reflect the lack of a mandatory permitting mechanism, and other changes that it believes are appropriate to ensure that there is no reasonable probability of adverse effects from the wastes that remain after a unit has closed. For surface impoundments, EPA has modeled its proposed requirements on the part 265 interim status closure requirements for surface impoundments, as well as the MSHA requirements. EPA solicits comment on whether these proposed requirements are appropriate for CCR landfills and surface impoundments.

Requirements specific to closure of CCR landfills and surface impoundments include proposed 257.100(a)–(c). These provisions provide that prior to closure of any CCR unit, the owner or operator must develop a plan describing the closure of the unit, and a schedule for implementation. The plan must describe the steps necessary to close the CCR landfill or surface impoundment at any point during the active life in

[154] Guide for Industrial Waste Management, *available at http://www.epa.gov/epawaste/nonhaz/industrial/guide/index.htm.*

accordance with the requirements in paragraphs (c) and (d) or (e) of this section, as applicable, and based on recognized and generally accepted good engineering practices. EPA is proposing to define recognized and generally accepted good engineering practices in the same manner as it is proposing under the subtitle C alternative. The definition references but does not attempt to codify any particular set of engineering practices, but to allow the professional engineer latitude in adopting improved practices that reflect the state-of-the art practices, as they develop over time. The plan must be certified by an independent registered professional engineer. In addition, the owner or operator must notify the state that a plan has been placed in the operating record and on the owner's or operator's publically accessible Internet site.

These provisions are modeled after the closure plan requirements in 258.60(c). Of note here is that, while EPA rejected a certification requirement for MSWLF closure plans, EPA is proposing to require one here to increase the ability of citizens to effectively enforce the rules. In the MSWLF rule, EPA rejected a certification requirement because "it will be relatively easy to verify that the plan meets the requirements," due to the specific design criteria specified in the rule. However, this was in the context of a state program, where EPA could assure that states would play an active role in overseeing and enforcing the facility's implementation of the requirements.

EPA is also proposing that the closure plan provide, at a minimum, the information necessary to allow citizens and states to determine whether the facility's closure plan is reasonable. This includes an estimate of the largest area of the CCR unit ever requiring a final cover during the active life of the unit, and an estimate of the maximum inventory of CCRs ever on-site during the active life of the unit.

Proposed 257.100(b) of the rule allows closure of a CCR landfill or surface impoundment with CCRs in place or through CCR removal and decontamination of all areas affected by releases from the landfill or surface impoundment. Proposed paragraph (c) provides that CCR removal and decontamination are complete when constituent concentrations throughout the CCR landfill or surface impoundment and any areas affected by releases from the CCR landfill or surface impoundment do not exceed the numeric cleanup levels for those CCR constituents, to the extent that the state has established such clean up levels in which the CCR landfill or surface impoundment is located. These "clean-closure" provisions are modeled after EPA's "Guide for Industrial Waste Management," found at *http://www.epa.gov/epawaste/nonhaz/industrial/guide/chap11s.htm*. As previously noted, the Guide represents a consensus view of best practices for industrial waste management, based on involvement from EPA, and state and tribal representatives, as well as a focus group of industry and public interest stakeholders chartered under the Federal Advisory Committee Act. EPA has included this provision to allow some flexibility in the self-implementing scheme for facilities in their closure options, while providing protection for health and the environment under either option. Although EPA anticipates that facilities will mostly likely not clean close their units, given the expense and difficulty of such an operation, EPA believes that they are generally preferable from the standpoint of land re-use and redevelopment, and so wishes explicitly to allow for such action in the proposed subtitle D rule. EPA is also considering whether to adopt a further incentive for clean closure, under which the owner or operator of the CCR landfill or surface impoundment could remove the deed notation required under proposed 257.100(m), if all CCRs are removed from the facility, and notification is provided to the state. In the absence of state cleanup levels, metals should be removed to either statistically equivalent background levels, or to maximum contaminant levels (MCLs), or health-based numbers. One tool that can be used to help evaluate whether waste removal is appropriate at the site is the risk-based corrective action process (RBCA) using recognized and generally accepted good engineering practices such as the ASTM Ec0–RBCA process. EPA solicits comment on the appropriateness of this provision under a RCRA subtitle D rule, and information on the number of facilities that may take advantage of a clean-closure option.

For closure of surface impoundments with CCRs in place, EPA has developed substantive requirements modeled on a combination of the existing 40 CFR part 265 interim status requirements for surface impoundments, and the long-standing MSHA standards. At closure, the owner or operator of a surface impoundment would be required to either drain the unit, or solidify the remaining wastes. EPA is also proposing to require that the wastes be stabilized to a bearing capacity sufficient to support the final cover. The proposed criteria further require that, in addition to the technical cover design requirements applicable to landfills, any final cover on a surface impoundment would have to meet requirements designed to address the nature of the large volumes of remaining wastes. Specifically, EPA is proposing that the cover be designed to minimize, over the long-term, the migration of liquids through the closed impoundment; promote drainage; and accommodate settling and subsidence so that the cover's integrity is maintained. Finally, closure of the unit is also subject to the general performance standard that the probability of future impoundment of water, sediment, or slurry is precluded. This general performance standard is based on the MSHA regulations, and is designed to ensure the long-term safety of the surface impoundment.

The proposed RCRA subtitle D regulation requires that CCR landfills and surface impoundments have a final cover system designed and constructed to have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-5} cm/sec, whichever is less; it also requires an infiltration layer that contains a minimum of 18 inches of earthen material. The regulation also requires an erosion layer that contains a minimum of 6 inches of earthen material that is capable of sustaining native plant growth as a way to minimize erosion of the final cover. These requirements are generally modeled after the performance standard and technical requirements contained in the existing RCRA subtitle D rules for MSWLFs, in 258.60. EPA is also proposing, however a fourth requirement not found in those criteria modeled after the interim status closure requirements of 265.228(a)(iii)(D) that accounts for the conditions found in surface impoundments. Specifically, EPA is proposing that the final cover be designed to minimize the disruption of the final cover through a design that accommodates settling and subsidence. EPA believes that these requirements strike a reasonable balance between the costs of a protective final cover, and avoiding risks to health and the environment from the remaining wastes at the CCR landfill or surface impoundment. The regulation requires certification by an independent registered professional engineer that these standards were met. The design of the final cover system, including the certification, must be placed in the operating record and on the owner's or operator's Internet site. Based on the MSHA standards, EPA is also proposing that unit closure must provide for major slope stability to prevent the sloughing of the landfill over the long term.

Alternatively, the rule allows the owner or operator of the CCR landfill or surface impoundment to select an alternative final cover design, provided the alternative cover design is certified by an independent registered professional engineer and notification is provided to the state that the alternative cover design has been placed in the operating record and on the owner's or operator's Internet site. The alternative final cover design must include a infiltration layer that achieves an equivalent reduction in infiltration, and an erosion layer that provides equivalent protection from wind and water erosion, as the infiltration and erosion layers specified in the technical standards in paragraph (d). Under this alternative, EPA expects that evapo-transpiration covers may be an effective alternative, which are not appropriately evaluated based on permeability alone. For example, an independent registered professional engineer might certify an alternative cover design that prevents the same level of infiltration as the system described above (*i.e.,* no greater than 1×10^{-5} cm/sec, etc), based on: (1) hydrologic modeling and lysimetry or instrumentation using a field scale test section, or (2) Hydrologic modeling and comparison of the soil and climatic conditions at the site with the soil and climatic conditions at an analogous site with substantially similar cover design. In this case, the owner or operator of the disposal unit must obtain certification from an independent registered professional engineer that the alternative cover would minimize infiltration at least as effectively as the "design" cover described above. As with the other final covers, the design of the evapo-transpiration cover must be placed on the owner's or operator's Internet site.

EPA has included this alternative cover requirement to increase the flexibility for the facility to account for site-specific conditions. However, EPA is specifically soliciting comment on whether this degree of flexibility is appropriate, given the lack of guaranteed state oversight. In the final MSWLF rule, EPA adopted a comparable provision, but concluded that this alternative would not be available in States without approved programs. *See,* 56 FR 51096. Given that EPA can neither approve state programs, nor rely on the existence of a state permit process, EPA questions whether this kind of requirement is appropriate. Commenters who believe this requirement would be appropriate are encouraged to include examples documenting the need for flexibility in developing cover requirements, as well as data and information to demonstrate that alternative cover designs would be protective. EPA would also welcome suggestions for other methods to allow owners and operators of CCR landfills and surface impoundment facilities to account for site-specific conditions that provide a lower degree of individual facility discretion, such as a list of approved cover designs.

The proposed rule includes the same 30- and 180-day deadlines for beginning and completing closure, respectively, that are contained in existing section 258.60(f) and (g) for MSWLFs. However, EPA has decided not to propose to include a provision under which the owner and operator could extend those deadlines under the MSWLF criteria. EPA believes that extending the closure deadlines in this context is inappropriate because, in the absence of an approved State program, the owner or operator could unilaterally decide to extend the time for closure of the unit, without any basis, or oversight by a regulatory authority.

The proposed closure requirements also include a provision addressing required deed notations. In this regard, EPA is considering whether to include a provision for removing the deed notation once all CCRs are removed from the facility, and notification is provided to the state of this action. In the MSWLF rule, we adopted such a provision, but determined that state oversight of such a provision was essential, given the potential for abuse. As we noted in the final MSWLF rule, "EPA strongly believes that a decision to remove the deed notation must be considered carefully and that in practice very few owners or operators will be able to take advantage of the provision." EPA solicits comment on the propriety of such a provision, and encourages commenters who are interested in supporting such an option, to suggest alternatives to state oversight to provide for facility accountability.

Following closure of the CCR management unit, the co-proposed subtitle D approach requires post-closure care modeled after the requirements in 258.60. The owner or operator of the disposal unit must conduct post-closure care for 30 years. EPA is proposing to allow facilities to conduct post-closure care for a decreased length of time if the owner or operator demonstrates that (1) the reduced period is sufficient to protect human health and the environment, as certified by an independent registered professional engineer; (2) notice is provided to the state that the demonstration has been placed in the operating record and on the owner's or operator's Internet site; and (3) the owner or operator notifies the state of the company's findings. The proposed rule also allows an increase in this period, again, with notification to the state, if the owner or operator of the CCR landfill or surface impoundment determines that it is necessary to protect human health and the environment. The 30-year period is consistent with the period required under the criteria for MSWLFs, as well as under the subtitle C interim status requirements. EPA has no information to indicate that a different period would be appropriate for post-closure care for CCR disposal units. EPA recognizes that state oversight can be critical to ensure that post-closure care is conducted for the length of time necessary to protect human health and the environment; however, EPA also recognizes that there is no set length of time for post-closure care that will be appropriate for all possible sites, and all possible conditions. EPA therefore solicits comment on alternative methods to account for different conditions, yet still provide methods of oversight to assure facility accountability.

During post-closure care, the owner or operator of the disposal unit is required to maintain the integrity and effectiveness of any final cover, maintain and operate the leachate collection and removal system in accordance with the leachate collection and removal system requirements described above, maintain the groundwater monitoring system and monitor the groundwater in accordance with the groundwater monitoring requirements described above, and place the maintenance plan in the operating record and on the company's Internet site.

EPA is also considering whether to adopt a number of provisions to increase the flexibility available under these requirements. For example, EPA is considering a self-certified stoppage of leachate management, such as provided for in 258.61(a)(2), and is soliciting public comment on the need for such a provision, as well as its propriety, in light of the absence of guaranteed state oversight. EPA is also considering whether to adopt a provision to allow any other disturbance, provided that the owner or operator of the CCR landfill or surface impoundment demonstrates that disturbance of the final cover, liner or other component of the containment system, including any removal of CCRs, will not increase the potential threat to human health or the environment. The demonstration would need to be certified by an independent registered professional engineer, and notification provided to the state that the demonstration had been placed in the operating record and on the owner's or operator's Internet site. In the MSWLF rule, EPA limited this option to approved states, on the ground that, "under very limited circumstances it may be possible or desirable to allow certain post-closure uses of land, including some recreational uses, without posing a significant threat to human health and the environment, but such situations are likely to be very limited and need to be considered very carefully." Commenters interested in supporting such an option should address why such a provision would nevertheless be appropriate in this context. In this regard, EPA would also be interested in suggestions for other mechanisms providing facility flexibility and/or oversight.

9. Financial Assurance

EPA currently requires showings of financial assurance under multiple programs, including for RCRA subtitle C hazardous waste treatment, storage and disposal facilities; the RCRA subtitle I underground storage tank program; and under other statutory authorities. Financial assurance requirements generally help ensure that owners and operators adequately plan for future costs, and help ensure that adequate funds will be available when needed to cover these costs if the owner or operator is unable or unwilling to do so; otherwise, additional governmental expenditures may otherwise be necessary to ensure continued protection of human health and the environment. Financial assurance requirements also encourage the development and implementation of sound waste management practices both during and at the end of active facility operations, since the associated costs of any financial assurance mechanism should be less when activities occur in an environmentally protective manner.

Today's proposed RCRA subtitle D alternative does not include proposed financial responsibility requirements. Any such requirements would be proposed separately. Specifically, on January 6, 2010, EPA issued an advance notice of proposed rulemaking ("ANPRM"), identifying classes of facilities within the Electric Power Generation, Transmission, and Distribution industry, among others, as those for which it plans to develop, as necessary, financial responsibility requirements under CERCLA § 108(b). *See* Identification of Additional Classes of Facilities for Development of Financial Responsibility Requirements under CERCLA Section 108(b), 75 FR 816 (January 6, 2010). EPA solicits comments on whether financial responsibility requirements under CERCLA § 108(b) should be a key Agency focus should it regulate CCR disposal under a RCRA subtitle D approach. (By today's proposed rule, EPA is not reopening the comment period on the January 2010 ANPRM, which closed on April 6, 2010. *See* Identification of Additional Classes of Facilities for Development of Financial Responsibility Requirements under CERCLA Section 108(b), 75 FR 5715 (Feb. 4, 2010) (extending comment period to April 6, 2010).) However, EPA also solicits comment on existing state waste programs for financial assurance for CCR disposal facilities, and whether and how the co-proposed RCRA subtitle D regulatory approach might integrate with those programs.

10. Off-Site Disposal

Under a subtitle D regulation, regulated CCR wastes shipped off-site for disposal would have to be sent to facilities that meet the standards above.

11. Alternative RCRA Subtitle D Approaches

A potential modification to the subtitle D option that was evaluated in our Regulatory Impact Analysis (RIA) is what we have termed a subtitle "D prime" option. Under this modification, the regulations would not require the closure or installation of composite liners in existing surface impoundments; rather, these surface impoundments could continue to operate for the remainder of their useful life. New surface impoundments would be required to have composite liners. The other co-proposed subtitle D requirements would remain the same. This modification results in substantially lower costs, but also lower benefits as described in section XII, which presents costs and benefits of the RCRA subtitle C, D, and D prime options. EPA solicits comments on this approach.

Finally, another approach that has been suggested to EPA is a subtitle D regulation with the same requirements as spelled out in the co-proposal, for example, composite liners for new landfills and surface impoundments, groundwater monitoring, corrective action, closure, and post-closure care requirements as co-proposed in this notice; however, in lieu of the phase-out of surface impoundments, EPA would establish and fund a program for conducting annual (or other frequency) structural stability (assessments) of impoundments having a "High" or "Significant" hazard potential rating as defined by criteria developed by the U.S. Army Corps of Engineers for the National Inventory of Dams. EPA would conduct these assessments and, using appropriate enforcement authorities already available under RCRA, CERCLA, and/or the Clean Water Act, would require facilities to respond to issues identified with their surface impoundments. The theory behind this suggested approach is that annual inspections would be far more cost effective than the phase-out of surface impoundments—approximately $3.4 million annually for assessments versus $876 million annually for phase-out. EPA also solicits comments on this approach and its effectiveness in ensuring the structural integrity of CCR surface impoundments.

X. How would the proposed subtitle D regulations be implemented?

A. Effective Dates

The effective date of the proposed RCRA subtitle D alternative, if this alternative is ultimately promulgated, would be 180 days after promulgation of a final rule. Thus, except as noted below, owners and operators of CCR landfills and surface impoundments would need to meet the proposed minimum federal criteria 180 days after promulgation of the final rule. As noted elsewhere in today's preamble (*see* Section XI.), facilities would need to comply with the RCRA subtitle D criteria, irrespective of whether or not the states have adopted the standards. For the remaining requirements, the compliance dates would be as follows:

- For new CCR landfills and surface impoundments that are placed into service after the effective date of the final rule, the location restrictions and design criteria would apply the date that such CCR landfills and surface impoundments are placed into service.
- For existing CCR surface impoundments, the compliance date for the liner requirement is five years after the effective date of the final rule.
- For existing CCR landfills and surface impoundments, the compliance date for the groundwater monitoring requirements is one year after the effective date of the final rule.
- For new CCR landfills and surface impoundments, and lateral expansions of existing CCR landfills and surface impoundments, the groundwater monitoring requirement must be in place and in compliance with the

groundwater monitoring requirements before CCRs can be placed in the unit.

Note: As discussed in Section IX, if EPA determines that financial assurance requirements would be implemented pursuant to CERCLA 108(b) authority, the compliance date for this provision would be the date specified in those regulations.

B. Implementation and Enforcement of Subtitle D Requirements

As stated previously, EPA has no authority to implement and enforce the co-proposed RCRA subtitle D regulation. Therefore, the proposed RCRA subtitle D standards have been drafted so that they can be self implementing—that is, the facilities can comply without interaction with a regulatory agency. EPA can however take action under section 7003 of RCRA to abate conditions that "may present an imminent and substantial endangerment to health or the environment." EPA could also use the imminent and substantial endangerment authorities under CERCLA, or under other federal authorities, such as the Clean Water Act, to address those circumstances where a unit may pose a threat.

In addition, the federal RCRA subtitle D requirements would be enforceable by states and by citizens using the citizen suit provisions of RCRA 7002. Under this section, any person may commence a civil action on his own behalf against any person, who (1) is alleged to be in violation of any permit, standard, regulation * * * which has become effective pursuant to this chapter" Because a RCRA subtitle D proposal relies heavily on citizen enforcement, our proposal requires facilities to make any significant information related to their compliance with the proposed requirements publicly available.

XI. Impact of a Subtitle D Regulation on State Programs

Under today's co-proposal, EPA is proposing to establish minimum nationwide criteria under RCRA subtitle D as one alternative. If the Agency were to choose to promulgate such nationwide criteria, EPA would encourage the states to adopt such criteria; however, the Agency has no authority to require states to adopt such criteria, or to implement the criteria upon their finalization. Nor does EPA have authority in this instance to require federal approval procedures for state adoption of the minimum nationwide criteria. States would be free to develop their own regulations and/or permitting programs using their solid waste laws or other state authorities. While states are not required to adopt such minimum nationwide criteria, some states (about 25) incorporate federal regulations by reference or have specific state statutory requirements that their state program can be no more stringent than the federal regulations (about 12, with varying degrees of exceptions). In those cases, EPA would expect that if the minimum nationwide criteria were promulgated, these states would adopt them, consistent with their state laws and administrative procedures.

If the states do not adopt or adopt different standards for the management of CCRs, facilities would still have to comply with the co-proposed subtitle D criteria, if finalized, independently of those state regulations. Thus, even in the absence of a state program, CCR landfills and CCR surface impoundments would be required to meet the proposed federal minimum criteria as set out in 40 CFR part 257, subpart D. As a result and to make compliance with the requirements as straightforward as possible, we have drafted the proposed criteria so that facilities are able to implement the standards without interaction with regulatory officials—that is, the requirements are self-implementing. Also, even in the absence of a state regulatory program for CCRs, these federal minimum criteria are enforceable by citizens and by states using the citizen suit provision of RCRA (Section 7002). EPA is also able to take action under RCRA Section 7003 to abate conditions that may pose an imminent and substantial endangerment to human health or the environment or and can rely on other federal authorities. *See* the previous section for a full discussion of this issue.

XII. Impacts of the Proposed Regulatory Alternatives

A. What are the economic impacts of the proposed regulatory alternatives?

EPA prepared an analysis of the potential costs and benefits associated with this action contained in the "Regulatory Impact Analysis" (RIA). A copy of the RIA is available in the docket for this action and the analysis is briefly summarized here. For purposes of evaluating the potential economic impacts of the proposed rule, the RIA evaluated baseline (*i.e.,* current) management of CCRs consisting of two baseline components: (1) The average annual cost of baseline CCR disposal practices by the electric utility industry, and (2) the monetized value of existing CCR beneficial uses in industrial applications. Incremental to this baseline, the RIA estimated (1) future industry compliance costs for CCR disposal associated with the regulatory options described in today's action, and (2) although not completely quantified or monetized, three categories of potential future benefits from RCRA regulation of CCR disposal consisting of (a) Groundwater protection benefits at CCR disposal sites, (b) CCR impoundment structural failure prevention benefits, and (c) induced future annual increases in CCR beneficial use. The findings from each of these main sections of the RIA are summarized below. These quantified benefit results are based on EPA's initial analyses using existing information and analytical techniques.

1. Characterization of Baseline Affected Entities and CCR Management Practices

Today's action will potentially affect CCRs generated by coal-fired electric utility plants in the NAICS industry code 221112 (*i.e.,* the "Fossil Fuel Electric Power Generation" industry within the NAICS 22 "Utilities" sector code). Based on 2007 electricity generation data published by the Energy Information Administration (EIA), the RIA estimated a total of 495 operational coal-fired electric utility plants in this NAICS code could be affected by today's action. These plants are owned by 200 entities consisting of 121 companies, 18 cooperative organizations, 60 state or local governments, and one Federal Agency. A sub-total of 51 of the 200 owner entities (*i.e.,* 26%) may be classified as small businesses, small organizations, or small governments.

Based on the most recent (2005) EIA data on annual CCR tonnages generated and managed by electric utility plants greater than 100 megawatts nameplate capacity in size, supplemented with additional estimates made in the RIA for smaller sized electric utility plants between 1 and 100 megawatts capacity, these 495 plants generate about 140 million tons of CCRs annually, of which 311 plants dispose 57 million tons in company-owned landfills, 158 plants dispose 22 million tons in company-owned surface impoundments, and an estimated 149 plants may send upwards of 15 million tons of CCRs to offsite disposal units owned by other companies (*e.g.,* NAICS 562 commercial waste management service companies). Based on lack of data on the type of offsite CCR disposal units, and the fact that it costs much more to transport wet CCRs than dry CCRs (*i.e.,* CCRs which have been de-watered), the RIA assumes all offsite CCR disposal units are landfills. Because some plants use more than one CCR management method, these management plant counts exceed 495 total plants. Based on the estimates developed for the RIA, total CCR disposal is about 94 million tons annually which is two-thirds of annual CCR generation. (EPA notes that the alternative, lower CCR generation and disposal estimates of 131 million tons and 75 million tons cited elsewhere in today's notice were derived from different and less comprehensive ACAA and EIA survey data sources, respectively, that do not include tonnage estimates for plants between 1 and 100 megawatt capacity.) In addition, 272 of the 495 plants supply CCRs which are not disposed for beneficial uses in at least 14 industries, of which 28 of the 272 plants solely supply CCRs for beneficial uses. As of 2005, CCR beneficial uses (*i.e.,* industrial applications) involved about 47 million tons annually representing one-third of annual CCR generation, which the RIA estimates may grow to an annual quantity of 62 million tons by 2009. For 2008, the American Coal Ash Association estimates CCR beneficial use has grown to 60.6 million tons.[155]

2. Baseline CCR Disposal

For each of the 467 operating electric utility plants which dispose CCRs onsite or offsite (28 of the 495 total plants solely send their CCRs for beneficial use and not disposal), the RIA estimated baseline engineering controls at CCR disposal units and associated baseline disposal costs for two types of CCR disposal units: landfills and surface impoundments. Impoundments are sometimes named by electricity plant personnel as basins, berms, canals, cells, dams, embankments, lagoons, pits, ponds, reservoirs, or sumps. The baseline is defined as existing (current) conditions with respect to the presence or absence of 10 types of environmental engineering controls and eight ancillary regulatory elements, plus projection of future baseline conditions of CCR disposal units without regulation over the 50-year future period-of-analysis—2012 to 2061—applied in the RIA. A 50-year future period was applied in the RIA to account for impacts of the proposed regulatory options which are specific only to future new disposal units given average lifespans of over 40-years. Existing conditions were determined based on review of a sample of current state government regulations of CCR disposal in 34 states, as well as limited survey information on CCR disposal units from studies published in 1995, 1996, and 2006 about voluntary engineering controls installed for CCR disposal units at some electric utility plants. The 10 baseline engineering controls evaluated in the RIA are (1) Groundwater monitoring, (2) bottom liners, (3) leachate collection and removal systems, (4) dust controls, (5) rainwater run-on and run-off controls, (6) financial assurance for corrective action, disposal unit closure, and post-closure care, (7) disposal unit location restrictions, (8) closure capping of disposal units, (9) post-closure groundwater monitoring, and (10) CCR storage design and operating standards prior to disposal (**Note:** Although listed here, this 10th element was not estimated in the RIA because of EPA's lack of information on baseline CCR storage practices). This specific set of engineering controls represents the elements of the RCRA 3004(x) custom-tailored technical standards proposed in today's notice for the RCRA subtitle C option. The eight ancillary elements evaluated in the RIA are (11) offsite transport and disposal, (12) disposal unit structural integrity inspections, (13) electricity plant facility-wide environmental investigations, (14) facility-wide corrective action requirements, (15) waste disposal permits, (16) state government regulatory enforcement inspections, (17) environmental release remediation requirements, and (18) recordkeeping and reporting to regulatory agencies. Some states require many of these technical standards for future newly-constructed CCR disposal units, some states require them for existing units, and some states have few or no regulatory requirements specific to CCR disposal and thus were not estimated in the baseline cost. Furthermore, some of the ancillary elements are only relevant to the regulatory options based on subtitle C as co-proposed in today's notice. The percentage of CCR landfills with baseline controls ranged from 61% to 81%, and the percentage of CCR surface impoundments with baseline controls ranged from 20% to 49%, depending upon the type of control. Based on this estimation methodology, the RIA estimates the electric utility industry spends an average of $5.6 billion per year for meeting state-required and company voluntary environmental standards for CCR disposal. Depending upon state location for any given electricity plant (which determines baseline regulatory requirements), and whether any given plant disposes CCRs onsite or offsite, this baseline cost is equivalent to an average cost range of $2 to $80 per ton of CCRs disposed of.

3. Baseline CCR Beneficial Use

In addition to evaluating baseline CCR disposal practices, the RIA also estimated the baseline net benefits associated with the 47 million tons per year (2005) of industrial beneficial uses of CCRs. CCRs are beneficially used nationwide as material ingredients in at least 14 industrial applications according to the American Coal Ash Association: (1) Concrete, (2) cement, (3) flowable fill, (4) structural fill, (5) road base, (6) soil modification, (7) mineral filler in asphalt, (8) snow/ice control, (9) blasting grit, (10) roofing granules, (11) placement in mine filling operations,[156] (12) wallboard, (13) waste solidification, and (14) agriculture. The baseline annual sales revenues (as of 2005) received by the electric utility industry for sale of CCRs used in these industrial applications are estimated at $177 million per year. In comparison, substitute industrial ingredient materials (*e.g.,* portland cement, quarried stone aggregate, limestone, gypsum) would cost industries $2,477 million per year. Thus, the beneficial use of CCRs provides $2,300 million in annual cost savings to these industrial applications, labeled economic benefits in the RIA. Based on the lifecycle materials and energy flow economic framework presented in the RIA, although only based on limited data representing 47% of annual CCR beneficial use tonnage involving only three of the 14 industrial applications (*i.e.,* concrete, cement and wallboard), baseline lifecycle benefits of beneficially using CCRs compared to substitute industrial materials are (a) $4,888 million per year in energy savings, (b) $81 million per year in water consumption savings, (c) $365 million per year in greenhouse gas (*i.e.,* carbon dioxide and methane) emissions reductions, and (d) $17,772 million per year in other air pollution reductions. Altogether, industrial beneficial uses of CCRs provide over $23 billion in annual environmental benefits as of 2005. In addition, baseline CCR beneficial use provides $1,830 million per year in industrial raw materials costs savings to beneficial users, and $2,927 million per year in avoided CCR disposal cost to the electric utility industry as of 2005. The sum of environmental benefits,

[155] Note that ACAA's definition of beneficial use does not align with that used by EPA in this rulemaking. For example, ACAA includes minefilling as a beneficial use, where EPA classifies it as a separate category of use.

[156] While today's proposed rule does not deal directly with the mine filling of CCRs, the RIA includes it as a baseline beneficial use because the RIA uses the categories identified by the American Coal Ash Association (*http://acaa.affiniscape.com/displaycommon.cfm?an=1&subarticlenbr=3*). However, as noted previously in today's notice, the Agency is working with OSM of the Department of Interior on the placement of CCRs in mine fill operations.

industrial raw materials costs savings, and CCR disposal cost savings, $27.9 billion per year, gives the baseline level of what the RIA has labeled social benefits from the beneficial use of CCRs.

4. Estimated Costs for RCRA Regulation of CCR Disposal

The RIA includes estimates of the costs associated with the options described in today's notice are summarized here: (1) RCRA subtitle C regulation of CCRs as a "special waste"; (2) RCRA subtitle D regulation as "non-hazardous waste"; and (3) the subtitle "D prime" options. Full descriptions of each option are presented in a prior section of today's notice. The RIA assumes that the engineering controls that would be established under the RCRA subtitle C option would be tailored on the basis of RCRA section 3004(x). The controls for the RCRA subtitle D option are identical to the subtitle C option. The controls under the subtitle "D prime" option would be identical as well, except that existing surface impoundments would not have to close or be dredged and have composite liners installed within five years of the effective date of the regulation. The RIA also assumes all three options retain the existing Bevill exemption for CCR beneficial uses.

The estimated costs for each option are incremental to the baseline, and are estimated in the RIA using both an average annualized and a present value equivalent basis over a 50-year period-of-analysis (2012 to 2061) using both a 7% and an alternative 3% discount rate. These two alternative discount rates are required by the Office of Management and Budget's September 2003 "Regulatory Analysis" Circular A–4. For the purpose of summary here, only the 7% discount rate results are presented for each option because the 7% rate represents the "base case" in the RIA for the reason that most of the regulatory compliance costs will be incurred by industry (*i.e.,* private capital). On an average annualized basis, the estimated regulatory compliance costs for the three options are $1,474 million (subtitle C special waste), $587 million (subtitle D), and $236 million (subtitle "D prime") per year. On a present value basis discounted at 7% over the 50-year future period-of-analysis applied in the RIA, estimated future regulatory compliance costs for the three options total $20,349 million, $8,095 million, and $3,259 million present value, respectively. EPA requests public comment on all data sources and analytical approaches.

5. Benefits for RCRA Regulation of CCR Disposal

The potential environmental and public health benefits of CCR regulation estimated and monetized in the RIA include three categories:

1. Groundwater protection benefits consisting of (a) human cancer prevention benefits and (b) avoided groundwater remediation costs at CCR disposal sites;
2. CCR impoundment structural failure prevention benefits (*i.e.,* cleanup costs avoided); and
3. Induced future increase in industrial beneficial uses of CCRs.

As was done with the cost estimates described above, the RIA estimated benefits both at the 7% and 3% discount rates using the same 50-year period-of-analysis. However, only the benefit estimates based on the 7% rate are summarized here. While the RIA focused on monetizing these three impact categories, there are also human non-cancer prevention benefits, ecological protection benefits, surface water protection benefits, and ambient air pollution prevention benefits, which are not monetized in the RIA, but qualitatively described below.

i. Groundwater Protection Benefits

The RIA estimated the benefits of reduced human cancer risks and avoided groundwater remediation costs associated with controlling arsenic leaching from CCR landfills and surface impoundments. These estimates are based on EPA's risk assessment (described elsewhere in today's notice), which predicts arsenic leaching rates using SPLP and TCLP data. Furthermore, recent research and damage cases indicate that these leaching tests under-predict risks from dry disposal.[157] Therefore, the groundwater protection benefits may be underestimated in the RIA. The RIA based estimation of future human cancer cases avoided on the individual "excess" lifetime cancer probabilities reported in the EPA risk assessment, although the RIA also used more recent (2001) science published by the National Research Council on arsenic carcinogenicity.

The RIA estimated groundwater protection benefits by categorizing electric utility plants according to their individual types of CCR disposal units (*i.e.,* landfill or impoundment) and presence/types of liners in those units. For each category, GIS data were used to determine the potentially affected populations of groundwater drinkers residing within 1-mile of the disposal units. Results from the risk assessment were applied to these populations by using a linear extrapolation, starting from a risk of zero to the peak future risk as demonstrated by the risk assessment. The count of people who might potentially get cancer was then adjusted upward to account for the more recent and more widely accepted arsenic carcinogenicity research by the National Research Council.[158] The RIA then segregated the future cancer counts into lung cancers and bladder cancers, as well as into those that were predicted to result in death versus those that were not. The RIA monetized each of these cancer sub-categories using EPA-published economic values for statistical life and cost of illness.

The RIA further adjusted these monetized future cancer counts, to take into account existing state requirements for groundwater monitoring at CCR disposal units, such that fewer cancer

[157] Recent EPA research demonstrates that CCRs can leach significantly more aggressively under different pH conditions potentially present in disposal units. In the EPA Office of Research & Development report "Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data," EPA–600/R–09/151, Research Triangle Park, NC, December 2009, CCRs from 19 of the 34 facilities evaluated in the study exceeded at least one of the Toxicity Characteristic regulatory values for at least one type of CCR (*e.g.,* fly ash or FGD residue) at the self-generated pH of the material. This behavior likely explains the rapid migration of constituents from disposal sites like Chesapeake, VA and Gambrills, MD. *See also* the EPA Office of Research & Development reports (a) "Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities Using Enhanced Sorbents for Mercury Control," EPA 600/R–06/008, January 2006; and (b) Characterization of Coal Combustion Residues from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control, EPA/600/R–08/077, July 2008.

[158] EPA's current Integrated Risk Information System (IRIS) has a cancer slope factor for arsenic developed in 1995. This slope factor is based on skin cancer incidence and was used in the 2010 EPA risk assessment. Skin cancer is a health endpoint associated with lower fatality risk than lung and bladder cancers induced by arsenic. Since the IRIS slope factors were developed, quantitative data on lung and bladder cancers have become available, and the skin cancer based slope factors no longer represent the current state of the science for health risk assessment for arsenic. The National Research Council (NRC) published the report, "Arsenic in Drinking Water: 2001 Update" (2001) which reviewed the available toxicological, epidemiological, and risk assessment literature on the health effects of inorganic arsenic, building upon the NRC's prior report, "Arsenic in Drinking Water" (NRC 1999). The 2001 report, developed by an eminent committee of scientists with expertise in arsenic toxicology and risk assessment provides a scientifically sound and transparent assessment of risks of bladder and lung cancers from inorganic arsenic. EPA's Science Advisory Board is currently reviewing EPA's new proposed IRIS cancer slope factors based on bladder and lung cancer. Because the more recent NRC scientific information is available, the RIA (2010) uses the NRC arsenic cancer data for the estimate of benefits associated with cancers avoided by the proposed regulation of CCR.

cases than initially projected would ultimately occur from early detection of groundwater contamination in those states. Therefore, a baseline was established for the operation of state regulatory and remedial programs which led to a reduction in expected cancer cases in states with existing groundwater protection requirements. However, once groundwater contamination was found in those states, remediation costs would be incurred. Thus, the RIA also accounted for these costs under each of the regulatory options as well, thus avoiding possible double-counting of cancer cases and remediation costs. On an average annualized basis, the human cancer prevention component of the groundwater protection benefit category for the three options are $37 million (RCRA subtitle C special waste), $15 million (RCRA subtitle D), and $8 million (subtitle "D prime") per year. On a present value basis, the human cancer prevention benefit totals $504 million, $207 million, and $104 million present value, respectively. On an average annualized basis, the estimated avoided groundwater remediation cost benefit component of the groundwater protection benefit category for the three options are $34 million (RCRA subtitle C special waste), $12 million (RCRA subtitle D), and $6 million (subtitle "D prime") per year. On a present value basis, the avoided remediation cost benefit totals to $466 million, $168 million, and $84 million present value, respectively. Added together on an average annualized basis, these two groundwater protection benefit components total to $71 million (RCRA subtitle C special waste), $27 million (RCRA subtitle D), and $14 million (subtitle "D prime") per year. On a present value basis, the groundwater protection benefit category totals to $970 million, $375 million, and $188 million present value, respectively.

ii. Impoundment Structural Failure Prevention Benefits

The December 2008 CCR surface impoundment collapse at the Tennessee Valley Authority's Kingston, Tennessee coal-fired electricity plant illustrated that structural failures of large CCR impoundments can lead to catastrophic environmental releases and large cleanup costs. The RIA estimated the benefit of avoiding future cleanup costs for impoundment failures, which the structural integrity inspection requirement of all regulatory options, and the future conversion or retrofitting of existing or new impoundments (under the subtitle C, subtitle D, and subtitle "D prime" options) would be expected to prevent.

The RIA based the estimate of future cleanup costs avoided on information contained in EPA's 2009 mail survey [159] of 584 CCR impoundments operated by the electric utility industry. In response to the survey request for information on known spills or non-permitted releases from CCR impoundments within the last 10 years, revealed 42 CCR impoundment releases spanning 1995 to 2009. Particularly, there were five significant releases between 4,950 cubic yards and 5.4 million cubic yards of CCRs, and one catastrophic release of 5.4 million cubic yards of CCRs during this time period at coal fired power plants. Given these historic releases, the RIA projected the probability of future impoundment releases using a Poisson distribution. In addition to this approach, the RIA formulated two alternative failure scenarios based on 96 high-risk CCR impoundments identified as at least 40 feet tall and at least 25 years old. The two alternative failure scenarios assumed impoundment failure rates involving these 96 impoundments of 10% and 20%, respectively. On an average annualized basis ranging across these three alternative failure probability estimation methods (scenarios), the avoided cleanup cost benefit category for the three options is estimated at $128 million to $1,212 million (subtitle C special waste), $58 million to $550 million (subtitle D), and $29 million to $275 million (subtitle "D prime") per year. On a present value basis, the avoided cleanup cost benefit category totals $1,762 million to $16,732 million (RCRA subtitle C special waste), $793 million to $7,590 million (RCRA subtitle D), and $405 million to $3,795 million present value (RCRA subtitle "D prime"), respectively.

iii. Benefit of Induced Future Increase in Industrial Beneficial Uses of CCRs

The third and final potential benefit category evaluated in the RIA includes the potential effects of RCRA regulation of CCR disposal on future annual tonnages of CCR beneficial use. As its base case, the RIA estimates an expected future increase in beneficial use induced by the increased costs of disposing CCR in RCRA-regulated disposal units. The RIA also evaluates the potential magnitude of a future decrease in beneficial use as a result of a potential "stigma" effect under the subtitle C option. Both scenarios are based on a baseline consisting of (a) projecting the future annual tonnage of CCR generation by the electric utility industry in relation to the Energy Information Administration's (EIA) future annual projection of coal consumption by the electric utility industry, and (b) projecting the future baseline growth in CCR beneficial use relative to the historical growth trendline (*i.e.,* absent today's proposed regulation).

For the induced increase "base case" scenario, the compliance costs for each regulatory option represent an "avoided cost incentive" to the electric utility industry to shift additional CCRs from disposal to beneficial use. Proportional to the estimated cost for each option, the RIA applied a beneficial use market elasticity factor to the projected baseline future growth in beneficial use to simulate the induced increase. On an average annualized basis, the monetized value—based on the same unitized (*i.e.,* per-ton) monetized social values assigned to the lifecycle benefits of baseline CCR beneficial uses—of the estimated potential induced increases in future annual CCR beneficial use tonnage for the three options are $6,122 million (RCRA subtitle C special waste), $2,450 million (RCRA subtitle D), and $980 million (subtitle "D prime") per year. On a present value basis, the potential induced increases in beneficial use totals to $84,489 million (RCRA subtitle C special waste), $33,796 million (RCRA subtitle D), and $13,518 million (subtitle "D prime") present value, respectively.

The RIA also monetized the alternative "stigma" scenario of future reduction in beneficial use induced by the RCRA subtitle C option. The RIA formulated assumptions about the percentage future annual tonnage reductions which might result to some of the 14 beneficial use markets. For example, federally purchased concrete was assumed to stay at baseline levels because of the positive influence of comprehensive procurement guidelines that are already in place to encourage such types of beneficial uses. Conversely, the levels of non-federally purchased concrete were assumed to decrease relative to the baseline. On an average annualized basis, the monetized value—based on the same unitized (*i.e.,* per-ton) monetized social values assigned to the lifecycle benefits of baseline CCR beneficial uses—of the potential "stigma" reduction in future annual CCR beneficial use for the RCRA subtitle C option is $16,923 million per year cost. On a present value basis, the potential "stigma" reduction in beneficial use totals to $233,549 million

[159] Descriptive information and electric utility industry responses to EPA's 2009 mail survey is available at the survey webpage *http://www.epa.gov/waste/nonhaz/industrial/special/fossil/surveys/.*

present value cost. The RIA did not estimate a potential "stigma" reduction effect on the RCRA subtitle D or subtitle "D prime" regulatory options.

B. Benefits Not Quantified in the RIA

1. Non-Quantified Plant and Wildlife Protection Benefits

EPA's risk assessment estimated significant risks of adverse effects to plants and wildlife, which are confirmed by the existing CCR damage cases and field studies published in peer-reviewed scientific literature. Such reported adverse effects include: (a) Elevated selenium levels in migratory birds, (b) wetland vegetative damage, (c) fish kills, (d) amphibian deformities, (e) snake metabolic effects, (f) plant toxicity, (g) elevated contaminant levels in mammals as a result of environmental uptake, (h) fish deformities, and (i) inhibited fish reproductive capacity. Requirements in the proposed rule should prevent or reduce these impacts in the future by limiting the extent of environmental contamination and thereby reducing the levels directly available.

2. Non-Quantified Surface Water Protection Benefits

In EPA's risk assessment, recreational fishers could be exposed to chemical constituents in CCR via the groundwater-to-surface water exposure pathway. Furthermore, State Pollutant Discharge Elimination System (SPDES) and National Pollutant Discharge Elimination System (NPDES) discharges from CCR wet disposal (*i.e.,* impoundments) likely exceed the discharges from groundwater to surface water. Thus, exposure to arsenic via fish consumption could be significant. However, EPA expects that most electric utility plants will eventually switch to dry CCR disposal (or to beneficial use), a trend which is discussed in the RIA. Such future switchover will reduce potential future exposures to these constituents from affected fish.

3. Non-Quantified Ambient Air Protection Benefits

Another impact on public health not discussed in the RIA is the potential reduction of excess cancer cases associated with hexavalent chromium inhaled from the air. As estimated in the RIA, over six million people live within the Census population data "zip code tabulation areas" for the 495 electric utility plant locations. Thus, the potential population health benefits of RCRA regulation may be quite large. Inhalation of hexavalent chromium has been shown to cause lung cancer.[160] By requiring fugitive dust controls, the proposed rule would reduce inhalation exposure to hexavalent chromium near CCR disposal units that are not currently required to control fugitive dust.

Furthermore, several non-cancer health effects associated with CCRs are a result of particulate matter inhalation due to dry CCR disposal. Human health effects for which EPA is evaluating causality due to particulate matter exposure include (a) Cardiovascular morbidity, (b) respiratory morbidity, (c) mortality, (d) reproductive effects, (e) developmental effects, and (f) cancer.[161] The potential for and extent of adverse health effects due to fugitive dusts from dry CCR disposal was demonstrated in the 2009 EPA report "Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills—DRAFT," which is available in the docket for today's co-proposed rules. The co-proposed rules' fugitive dust controls would serve to manage such potential risks by bringing them to acceptable levels.

CCR dust (and other types of particulate matter) can also be carried over long distances by wind and then settle on ground or water. The effects of this settling could include: (a) Changing the pH of lakes and streams; (b) changing the nutrient balance in coastal waters and large river basins; (c) depleting nutrients in soil; (d) damaging sensitive forests and farm crops; and (e) affecting the diversity of ecosystems.[162] Additionally, fine particulates are known to contribute to haze.[163] Thus, the fugitive dust controls contained in the proposed rule would improve visibility, and reduce the environmental impacts discussed above.

C. Comparison of Costs to Benefits for the Regulatory Alternatives

For purposes of comparing the estimated regulatory compliance costs to the monetized benefits for each regulatory option, the RIA computed two comparison indicators: Net benefits (*i.e.,* benefits minus costs), and benefit/cost ratio (*i.e.,* benefits divided by costs). The results of each indicator are displayed in the following tables (Table 10, Table 11 and Table 12) for three regulatory options, based on the 7% discount rate and the 50-year period-of-analysis applied in the RIA. There are three tables because three different scenarios were analyzed concerning potential impacts on beneficial use of CCRs impact under the regulatory options.

The three tables below represent three possible outcomes regarding impacts of the rule upon the beneficial use of CCR. In the first table, EPA presents the potential impact scenario that we view to be most likely. This first scenario assumes that the increased cost of disposal from regulation under subtitle C will encourage industry to seek out additional markets and greatly increase their beneficial use of CCRs. In the second table, EPA presents a negative effect on beneficial use, based on stigma, and the possibility of triggering use restrictions under state regulation and private sector standards due to subtitle C regulation. In the final table, EPA presents a scenario where beneficial use continues on its current path, without any changes as a result of the rule. On the basis of past experience, EPA believes that it is likely that recycling rates will increase as presented in the first scenario. Comments are requested on the impact of stigma on the beneficial use of CCRs.

TABLE 10—COMPARISON OF REGULATORY BENEFITS TO COSTS

[$Millions @ 2009$ prices and @ 7% discount rate over 50-year future period-of-analysis 2012 to 2061]

	Subtitle C "Special Waste"	Subtitle D	Subtitle "D prime"
A. Present Values:			
1. Regulatory Costs (1A+1B+1C):	$20,349	$8,095	$3,259.
1A. Engineering Controls	$6,780	$3,254	$3,254.

[160] ATSDR Texas. *Available at: http://www.atsdr.cdc.gov/toxfaq.html.*

[161] Source: EPA Office of Research & Development report "Integrated Science Assessment for Particulate Matter: First External Review Draft," EPA/600/R–08/139, 2008.

[162] Source: U.S. EPA Office of Air & Radiation, Particulate Matter "Health and Environment" Web site at *http://www.epa.gov/particles/health.html.*

[163] *Ibid;* and also *see http://www.intheairwebreathe.com/html/photo_gallery.html.*

TABLE 10—COMPARISON OF REGULATORY BENEFITS TO COSTS—Continued

[$Millions @ 2009$ prices and @ 7% discount rate over 50-year future period-of-analysis 2012 to 2061]

	Subtitle C "Special Waste"	Subtitle D	Subtitle "D prime"
1B. Ancillary Regulatory Requirements.	$1,480	$5	$5.
1C. Conversion to Dry CCR Disposal.	$12,089	$4,836	$0.
2. Regulatory Benefits (2A+2B+2C+2D):	$87,221 to $102,191	$34,964 to $41,761	$14,111 to $17,501.
2A. Monetized Value of Human Cancer Cases Avoided.	$504	$207	$104.
2B.Groundwater Remediation Costs Avoided.	$466	$168	$84.
2C. CCR Impoundment Failure Cleanup Costs Avoided.	$1,762 to $16,732	$793 to $7,590	$405 to $3,795.
2D. Included Future Increase in CCR Beneficial Use.	$84,489	$33,796	$13,518.
3. Net Benefits (2–1)	$66,872 to $81,842	$26,869 to $33,666	$10,852 to $14,242.
4. Benefit/Cost Ratio (2/1)	4.286 to 5.022	4.319 to 5.159	4.330 to 5.370.
B. Average Annualized Equivalent Values:*.			
1. Regulatory Costs (1A+1B+1C)	$1,474	$587	$236.
1A. Engineering Controls	$491	$236	$236.
1B. Ancillary Regulatory Requirements.	$107	<$1	<$1.
1C. Conversion to Dry CCR Disposal.	$876	$350	$0.
2. Regulatory Benefits (2A+2B+2C+2D):	$6,320 to $7,405	$2,533 to $3,026	$1,023 to $1,268.
2A. Monetized Value of Human Cancer Cases Avoided.	$37	$15	$8.
2B. Groundwater Remediation Costs Avoided.	$34	$12	$6.
2C. CCR Impoundment Failure Cleanup Costs Avoided.	$128 to $1,212	$58 to $550	$29 to $275.
2D. Included Future Increase in CCR Beneficial Use.	$6,122	$2,450	$980.
3. Net Benefits (2–1)	$4,845 to $5,930	$1,947 to $2,439	$786 to $1,032.
4. Benefit/Cost Ratio (2/1)	4.286 to 5.022	4.319 to 5.159	4.330 to 5.370.

* **Note:** Average annualized equivalent values calculated by multiplying the 50-year present values by a 50-year 7% discount rate "capital recovery factor" of 0.07246.

TABLE 11—COMPARISON OF REGULATORY BENEFITS TO COSTS UNDER SCENARIO #2—INDUCED BENEFICIAL USE DECREASE

[$Millions @ 2009$ prices @ 7% discount rate over 50-year future period-of-analysis 2012 to 2061]

	Subtitle C "Special Waste"	Subtitle D	Subtitle "D prime"
A. Present Values:			
1. Regulatory Costs (1A+1B+1C):	$20,349	$8,095	$3,259.
1A. Engineering Controls	$6,780	$3,254	$3,254.
1B. Ancillary Costs	$1,480	$5	$5.
1C. Conversion to Dry CCR Disposal.	$12,089	4,836	$0.
2. Regulatory Benefits (2A+2B+2C+2D):	($230,817) to ($215,847)	$1,168 to $7,965	$593 to $3,983.
2A. Monetized Value of Human Cancer Risks Avoided.	$504	$207	$104.
2B. Groundwater Remediation Costs Avoided.	$466	$168	$84.
2C. CCR Impoundment Failure Cleanup Costs Avoided.	$1,762 to $16,732	$793 to $7,590	$405 to $3,795.
2D. Induced Impact on CCR Beneficial Use.	($233,549)	N/A	N/A.
3. Net Benefits (2–1)	($251,166) to ($236,196)	($6,927) to ($130)	($2,666) to $724.
4. Benefit/Cost Ratio (2/1)	(11.343) to (10.607)	0.144 to 0.984	0.182 to 1.222.
B. Average Annualized Equivalent Values*.			
1. Regulatory Costs (1A+1B+1C):	$1,474	$587	$236.
1A. Engineering Controls	$491	$236	$236.
1B. Ancillary Costs	$107	$0.36	$0.36.

TABLE 11—COMPARISON OF REGULATORY BENEFITS TO COSTS UNDER SCENARIO #2—INDUCED BENEFICIAL USE DECREASE—Continued

[$Millions @ 2009$ prices @ 7% discount rate over 50-year future period-of-analysis 2012 to 2061]

	Subtitle C "Special Waste"	Subtitle D	Subtitle "D prime"
1C. Conversion to Dry CCR Disposal.	$876	$350	$0.
2. Regulatory Benefits (2A+2B+2C+2D):	($16,725) to ($15,640)	$85 to $577	$43 to $289.
2A. Monetized Value of Human Cancer Risks Avoided.	$37	$15	$8.
2B. Groundwater Remediation Costs Avoided.	$34	$12	$6.
2C. CCR Impoundment Failure Cleanup Costs Avoided.	$128 to $1,212	$57 to $550	$29 to $275.
2D. Induced Impact on CCR Beneficial Use.	($16,923)	NA	NA.
3. Net Benefits (2–1)	($18,199) to ($17,115)	($502) to ($9)	($193) to $52.
4. Benefit/Cost Ratio (2/1)	(11.347) to (10.610)	0.145 to 0.983	0.182 to 1.225.

* **Note:** Average annualized equivalent values calculated by multiplying 50-year present values by a 50-year 7% discount rate "capital recovery factor" of 0.07246.

TABLE 12—COMPARISON OF REGULATORY BENEFITS TO COSTS UNDER SCENARIO #3—NO CHANGE TO BENEFICIAL USE

[$Millions @ 2009$ prices @ 7% discount rate over 50-year future period-of-analysis 2012 to 2061]

Costs	Subtitle C "Special Waste"	Subtitle D	Subtitle "D prime"
A. Present Values:			
1. Regulatory Costs (1A+1B+1C):	$20,349	$8,095	$3,259.
1A. Engineering Controls	$6,780	$3,254	$3,254.
1B. Ancillary Costs	$1,480	$5	$5.
1C. Dry Conversion	$12,089	4,836	$0.
2. Regulatory Benefits (2A+2B+2C+2D):	$2,732 to $17,702	$1,168 to $7,965	$593 to $3,983.
2A. Monetized Value of Human Cancer Risks Avoided.	$504	$207	$104.
2B. Groundwater Remediation Costs Avoided.	$466	$168	$84.
2C. CCR Impoundment Failure Cleanup Costs Avoided.	$1,762 to $16,732	$793 to $7,590	$405 to $3,795.
2D. Induced Impact on CCR Beneficial Use.	$0	$0	$0.
3. Net Benefits (2–1)	($17,617) to ($2,647)	($6,927) to ($130)	($2,666) to $724.
4. Benefit/Cost Ratio (2/1)	0.134 to 0.870	0.144 to 0.984	0.182 to 1.222.
B. Average Annualized Equivalent Values.			
1. Regulatory Costs (1A+1B+1C):	$1,474	$587	$236.
1A. Engineering Controls	$491	$236	$236.
1B. Ancillary Costs	$107	$0.36	$0.36.
1C. Dry Conversion	$876	$350	$0.
2. Regulatory Benefits (2A+2B+2C+2D):	$198 to $1,283	$85 to $577	$43 to $289.
2A. Monetized Value of Human Cancer Risks Avoided.	$37	$15	$8.
2B. Groundwater Remediation Costs Avoided.	$34	$12	$6.
2C. CCR Impoundment Failure Cleanup Costs Avoided.	$128 to $1,212	$57 to $550	$29 to $275.
2D. Induced Impact on CCR Beneficial Use.	$0	$0	$0.
3. Net Benefits (2–1)	($1,277) to ($192)	($502) to ($9)	($193) to $52.
4. Benefit/Cost Ratio (2/1)	0.134 to 0.870	0.145 to 0.983	0.182 to 1.225.

* **Note:** Average annualized equivalent values calculated by multiplying 50-year present values by a 50-year 7% discount rate "capital recovery factor" of 0.07246.

EPA seeks comment on data and findings presented in the RIA, as well as on the cost and benefit estimation uncertainty factors identified in the RIA.

D. What are the potential environmental and public health impacts of the proposed regulatory alternatives?

The potential environmental and public health impacts of CCR regulation assessed within the RIA include the following three categories:

- Groundwater Benefits (human health benefits and cleanup costs avoided)
- Catastrophic Failure Benefits (catastrophic and significant releases avoided)
- Beneficial Use Benefits

The analyses of the groundwater impacts for the RIA were derived based on results from the risk assessment that was conducted for coal combustion residue landfills and surface impoundments. The second category of catastrophic impacts in the RIA was assessed, primarily based upon data on releases, as reported in EPA's 2009 Information Collection Request. And finally, the RIA assessment of beneficial use impacts was conducted using life-cycle analyses of current types and quantities of CCR beneficial use in the U.S. While the RIA focuses on monetizing these three impact categories, EPA notes that there are also likely noncancer health impacts, ecological impacts, other surface water impacts, and impacts on the ambient air, which are not monetized in this RIA.

1. Environmental and Public Health Impacts Estimated in the RIA

Groundwater Impacts

In the RIA, EPA estimated the benefits of reduced cancer risks and avoided groundwater remediation costs associated with controlling arsenic from landfills and surface impoundments that manage coal combustion residuals (CCRs). These estimates are based on EPA's risk assessment, which predicts leaching behavior using SPLP and TCLP data. Furthermore, recent research and damage cases indicate that these leaching tests may under-predict risks from dry disposal.[164] Therefore, the benefits estimated in this section are likely to underestimate the actual benefits provided by the proposed rule. EPA bases the cancer cases avoided on the individual "excess" lifetime cancer probabilities reported in the risk assessment, although for the present analysis, EPA uses more recent science on arsenic carcinogenicity, reflected in more recent NRC research.

The RIA began its groundwater impacts assessment by first segregating facilities by their individual type of liner and their respective Waste Management Unit (WMU) designations. For each class of facility, GIS data were used to determine the potentially affected populations of groundwater drinkers within 1-mile of the WMU. Results from the risk assessment were applied to these populations by using a linear extrapolation, starting from a risk of zero—to the peak future risk as demonstrated by the risk assessment. The number of people who might potentially get cancer was then adjusted to account for more recent research by the NRC.

Given the number of total potential cancers, EPA was able to use the same NRC data to split these cancers into lung cancers and bladder cancers, as well as into those that resulted in death versus those that did not. Once this subdivision was complete, EPA was then able to monetize these cancers using accepted economic values for a statistical life and cost of illness. In doing so, EPA was able to take account of both the potential lag in cancer cessation and the increase in value of a statistical life due to increases in income.

EPA also recognized that due to the relevant pre-existing state regulations in this area, fewer cancers than the number projected would ultimately occur. Therefore, a baseline was established for the operation of state regulatory and remedial programs. This led to the exclusion of some cancers where states would likely fill the gap in the absence of any EPA regulations. However, once contamination was found by states, cleanup costs would be incurred. Thus, EPA accounted for these costs under each of the regulatory options as well.

Once groundwater remediation costs and cancer costs under the baseline and each regulatory option were estimated, the aggregate benefits from each regulatory option were calculated (in comparison to the baseline). Net present value estimates were generated both at the 3% and 7% discount rate, as discussed in further detail within the RIA. To summarize, at a discount rate of 7%, the net present value of the groundwater benefits (including both the avoided cleanup costs and the value of cancer cases avoided) from the proposed rule totaled $970 million under the subtitle C option, and $375 million under the subtitle D option.

Catastrophic Failure Impacts

The 2008 surface impoundment failure at the TVA's Kingston, TN power plant illustrated that the improper handling of CCRs can lead to catastrophic releases. EPA's co-proposal for the management of CCRs includes requirements that would lead to all plants with surface impoundments converting to dry handling in landfills within 5-years of rule implementation. In the RIA, EPA estimated the avoided catastrophic failures and associated cleanup cost savings resulting from this provision of the rule.

First, EPA began by characterizing the releases reported in its 2009 Information Collection Request. In this data set, 42 releases were reported for the years 1995 through 2009. Particularly, there were 5 significant releases of between 1 million and 1 billion gallons, and one catastrophic release of over 1 billion gallons during this time period at coal fired power plants. Given these historic releases, EPA projected the occurrence of future releases using a Poisson distribution. EPA then estimated future avoided cleanup costs under the two proposed rules, and determined net present values of these benefits using both a 3% and 7% discount rate across the average and upper percentiles of risk demonstrated by the results of the Poisson distribution. The full details of these analyses are reported in the RIA. To summarize the results here at the 7% discount rate, the estimated net present value of avoided releases under the subtitle C requirements total $1,762 million on average (with the upper-bound estimates reaching from $3,140 to $4,177 million for the 90th and 99th percentiles). And under the subtitle D requirements and discount rate of 7%, the estimated net present value of avoided releases total $793 million on average (with the upper-bound estimates reaching from $1,413 to $1,880 million for the 90th and 99th percentiles).

In addition, a second Poisson distribution was developed as a sensitivity analysis, using an alternative historical rate of occurrence. This was done to see to what extent an increased release rate would pose in terms of greater risks. Given the age of many CCR surface impoundments, an increase in the release rate might be expected. The cleanup costs avoided under the two co-proposed rules were again calculated as described above and included in the

[164] Recent EPA research demonstrates that CCRs can leach significantly more aggressively under different pH conditions potentially present in disposal units. In U.S. EPA (2009c), a recent ORD study of 34 facilities, CCRs from 19 facilities exceeded at least one of the Toxicity Characteristic regulatory values for at least one type of CCR (*e.g.,* fly ash or FGD residue) at the self-generated pH of the material. This behavior likely explains the rapid migration of constituents from disposal sites like Chesapeake, VA and Gambrills, MD. *See also* U.S. EPA (2006, 2008b).

RIA, given this alternative higher occurrence rate. To summarize the results of this sensitivity analysis, at a 7% discount rate the estimated net present value of avoided releases under the subtitle C requirements total $5,154 million on average (with the upper-bound estimates reaching from $7,356 to $9,423 million for the 90th and 99th percentiles). And under the subtitle D requirements and same discount rate of 7%, the estimated net present value of avoided releases total $2,319 million on average (with the upper-bound estimates reaching from $3,310 to $4,240 million for the 90th and 99th percentiles).

Finally, a further sensitivity analysis was also performed to determine the extent to which these benefits would change if the catastrophic failures occurred sooner than projected by the Poisson distribution. Here, 96 impoundments were identified that were at least 40 feet tall and at least 25 years old. For the purposes of the assessment, benefit estimates were calculated based on assumed impoundment failure rates of both 10% and 20%. The RIA includes net present value estimates of the avoided cleanup costs under the two co-proposed rules for these two assumed failure rates, which are calculated using both 3% and 7% discount rates. Given the potential earlier releases, the analyses in the RIA find that at a 7% discount rate and a 10% failure rate, the net present value of avoided catastrophic failure costs is $8,366 under subtitle C, versus $3,795 million under subtitle D. Furthermore, when assuming a failure rate of 20% rather than 10%, the estimated net present value of avoided catastrophic failure costs increases to $16,732 million under Subtitle C, versus $7,590 million under subtitle D.

Beneficial Use Impacts

The last category of such impacts assessed within the RIA includes the potential effects that the different regulatory options for disposal of coal combustion residuals (CCRs) may have upon the quantities of CCRs that are being beneficially used. In the RIA, EPA estimates the expected increase in beneficial use associated with the increased costs of disposing CCRs, and also evaluates potential future changes in the beneficial uses of CCRs as a result of a potential "stigma" effect.

To begin, EPA projected the quantity of CCRs that will be produced in the future, based upon Energy Information Administration's (EIA) estimates of future coal supply and demand. At the same time, EPA also projected the growth in the percent of beneficial use that would take place absent any EPA rule. Combining these, EPA was able to project the total quantities of beneficially used CCRs under the baseline of no federal rule.

However, it is anticipated that the increased CCR disposal costs associated with a federal RCRA subtitle C rule, and the continued application of the Bevill exclusion to CCRs that are beneficially used, would provide significant incentive to electric utilities avoid higher disposal costs by increasing the quantity of CCRs going to beneficial use. Using the cost projections from the RIA for CCR disposal, EPA assumed that there would initially be unit elasticity with respect to cost, but that the elasticity would decrease with increasing market saturation. Based upon these assumptions, EPA projected the increased growth in beneficial use under a subtitle C rule. EPA then took the monetized benefits of current beneficial use, and applied them to our projected increases in beneficial use under the rule.

When monetized, the values of these increases are extremely large, summing to a net present value of $5,560 million in economic benefits at a 7% discount rate. Furthermore, when considering total social benefits (*e.g.,* decreased GHG emissions) the numbers are even greater, resulting in $84,489 million at a 7% discount rate. (Please note that because the total social benefits overlap with the economic benefits, these numbers should not be added together.) This number represents EPA's lower-bound estimate of the potential increase that it anticipates will occur.

On the basis of past experience, EPA believes it is realistic to expect that there is a possibility that recycling rates will increase under a subtitle C rule, increasing the beneficial use of CCRs. However, stakeholders have raised the potential issue of "stigma." Thus, the RIA also assesses this potential stigma effect and develops estimates of its potential impacts. Here, assumptions were made about what losses or reductions might result among the various sectors involved in the beneficial use of CCRs. For example, federally purchased concrete was assumed to stay at baseline levels because of the positive influence of comprehensive procurement guidelines that are already in place to encourage such types of beneficial uses. Conversely, for the purposes of assessing potential stigma effects, the levels of non-federally purchased concrete were assumed to decrease relative to the baseline.

When monetized, the values of these decreases are also large, summing to a net present value of $18,744 million in economic costs at a 7% discount rate. Furthermore, when considering total social benefits (*e.g.,* GHG emissions) the numbers are even greater, resulting in $233,549 million in economic costs at a 7% discount rate. This number represents EPA's estimate of the potential worst-case decrease that could occur in the event of potential stigma effect.

Since the potential increases in beneficial use as discussed above are driven largely by increases in disposal costs under the subtitle C option, EPA further estimated the effects that would result under a subtitle D rule by applying a ratio of the rule's respective costs under both the C and D options. Using the ratio of the subtitle D costs to the subtitle C costs (a ratio of 0.40:1); the net present value of social benefits associated with increased beneficial use under subtitle D would be approximately $33,796 million (at an assumed discount rate of 7%). It is important to note further that under the subtitle D option for the proposed rule, no such stigma effect would exist and is, therefore, not accounted for in our analyses. However, to the extent that a stigma effect is real, it could just as easily decrease beneficial use under a subtitle D option.

2. Environmental and Public Health Impacts Not Estimated in the RIA

Impacts on Plants and Wildlife

The risk assessment estimated significant risk of adverse effects to plants and wildlife, which is confirmed by the many impacts seen in the existing damage cases and field studies published in the peer-reviewed scientific literature. These include: elevated selenium levels in migratory birds, wetland vegetative damage, fish kills, amphibian deformities, snake metabolic effects, plant toxicity, elevated contaminant levels in mammals as a result of environmental uptake, fish deformities, and inhibited fish reproductive capacity. Requirements in the proposed rule should prevent or reduce these impacts in the future by limiting the extent of environmental contamination and thereby reducing the levels directly available.

Impacts on Surface Water Not Captured in the RIA

In EPA's risk assessment, recreational fishers could be exposed to constituents via the groundwater to surface water pathway. Furthermore, State Pollutant Discharge Elimination System (SPDES) and National Pollutant Discharge

Elimination System (NPDES) discharges from wet handling likely exceed the discharges from groundwater to surface water. Thus, exposure to arsenic via fish consumption could be significant. However, EPA expects that most facilities will eventually switch to dry handling of CCRs, a trend which is discussed in the RIA. This will reduce potential exposures to these constituents from affected fish.

Impacts on Ambient Air

Another impact on public health not discussed in the RIA is the potential reduction of excess cancer cases associated with hexavalent chromium inhaled from the air. Since over six million individuals are estimated to live within the Census population data "zip code tabulation areas" for the plant location zip codes of coal-fired power plants affected by this proposed rule,[165] the potential population health effects may be quite large. Inhalation of hexavalent chromium has been shown to cause lung cancer.[166] By requiring fugitive dust controls, the proposed rule would reduce inhalation exposure to hexavalent chromium near waste management units that are not currently required to control fugitive dust.

Non-Cancer Health Effects Associated With CCR Particulate Matter

There are several non-cancer health effects associated with CCRs are a result of particulate matter inhalation due to dry handling. Human health effects for which EPA is evaluating causality due to particulate matter exposure include cardiovascular morbidity, respiratory morbidity, and mortality, reproductive and developmental effects, and cancer.[167] The potential for and extent of adverse health effects due to fugitive dusts from dry handling of CCRs was demonstrated in U.S. EPA 2010b, "Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills—DRAFT." The proposed rule's fugitive dust controls would serve to manage such potential risks by bringing them to acceptable levels.

Particles can also be carried over long distances by wind and then settle on ground or water. The effects of this settling include: changing the pH of lakes and streams; changing the nutrient balance in coastal waters and large river basins; depleting nutrients in soil; damaging sensitive forests and farm crops; and affecting the diversity of ecosystems.[168] Additionally, fine particulates are known to contribute to haze.[169] Thus, the fugitive dust controls contained in the proposed rule would improve visibility, and reduce the environmental impacts discussed above.

XIII. Other Alternatives EPA Considered

In determining the level of regulation appropriate for the management of CCRs, taking into account both the need for regulations to protect human health and the environment and the practical difficulties associated with implementation of such regulations, the Agency considered a number of approaches in addition to regulating CCRs under subtitle C or subtitle D of RCRA. Specifically, the Agency also considered several combination approaches, such as regulating surface impoundments under subtitle C of RCRA, while regulating landfills under subtitle D of RCRA.

Under all of the approaches EPA considered, CCRs that were beneficially used would retain the Bevill exemption. In addition, under all the approaches, requirements for liners and ground water monitoring would be established, as well as annual inspections of all CCR surface impoundments by an independent registered professional engineer to ensure that the design, operation, and maintenance of surface impoundments are in accordance with recognized and generally accepted good engineering standards. However, the degree and extent of EPA's authority to promulgate certain requirements, such as permitting, financial assurance, facility-wide corrective action, varies under RCRA subtitle C versus subtitle D. In addition, the degree and extent of federal oversight, including enforcement, varies based on whether a regulation is promulgated under RCRA subtitle C or subtitle D authority. (*See* Section IV. for a more detailed discussion on the differences in EPA's authorities under RCRA subtitle C and subtitle D.)

Under one such approach, wet-handled CCRs—that is, those CCRs managed in surface impoundments or similar management units—would be regulated as a hazardous or special waste under RCRA subtitle C, while dry handled CCRs—that is, those CCRs managed in landfills—would be regulated under RCRA subtitle D. Wet-handled CCR wastes would be regulated under the co-proposed subtitle C alternative described earlier in the preamble (*see* section VI), while dry-handled CCRs would be regulated under the co-proposed RCRA subtitle D alternative described earlier in the preamble (*see* section IX). In addition, EPA would retain the existing Bevill exemption for CCRs that are beneficially used. Under this approach, EPA would establish modified requirements for wet-handled CCRs, pursuant to RCRA 3004(x), as laid out in the co-proposed subtitle C alternative.

This approach would have many of the benefits of both of today's co-proposed regulations. For example, this approach provides a high degree of federal oversight, including permit requirements and federally enforceable requirements, for surface impoundments and similar units that manage wet CCRs. Based on the results of our ground water risk assessment, it would also provide a higher level of protection for those wastes whose method of management presents the greatest risks (*i.e.,* surface impoundments). On the other hand, dry CCRs managed in landfills, while still presenting a risk if the CCRs are not properly managed, clearly present a lower risk, according to the risk assessment and, therefore, a subtitle D approach might be more appropriate. Also, landfills that manage CCRs are unlikely to present a risk of catastrophic failure, such as that posed by surface impoundments that contain large volumes of wet-handled CCRs. EPA also believes this approach could address the concerns of many commenters who expressed their views that subtitle C regulations would overwhelm off-site disposal capacity and would place a stigma on beneficial uses of CCRs.

Of course, this approach also shares the disadvantages of the subtitle C approach, as it applies to surface impoundments, and of the subtitle D approach, as it applies to landfills. For example, portions of the rules applicable to surface impoundments would not become enforceable until authorized states adopt the subtitle C regulations and become authorized; and rules applicable to landfills would not be directly federally enforceable. For a full discussion of the advantages and disadvantages of the subtitle C and subtitle D options *see* sections VI and IX.

Under another approach considered by EPA, the Agency would issue the proposed subtitle C regulations, but they would not go into effect for some time

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[165] U.S. EPA. Regulatory Impact Analysis for EPA's Proposed Regulation of Coal Combustion Wastes Generated by the Electric Utility Industry, 2009. Office of Resource Conservation and Recovery.

[166] ATSDR Texas. *Available at: http://www.atsdr.cdc.gov/toxfaq.html.*

[167] Integrated Science Assessment for Particulate Matter: First External Review Draft. EPA/600/R–08/139. Research Triangle Park, NC: U.S. Environmental Protection Agency, Office of Research and Development. 2008.

[168] *http://www.epa.gov/particles/health.html.*

[169] *Ibid.*

period, such as three years, as an example, after promulgation. The rule would include a condition that would exclude CCRs from regulation under subtitle C of RCRA in states that: (l) Had developed final enforceable subtitle D regulations that are protective of human health and the environment,[170] (2) had submitted those regulations to EPA for review within two years after the promulgation date of EPA's subtitle C rule, and (3) EPA had approved within one year, through a process allowing for notice and comment, possibly comparable to the current MSW subtitle D approval process. If a state failed to develop such a program within the two year timeframe for state adoption of the regulations or if EPA did not approve a state program within the one-year timeframe for state approval, the hazardous waste or special waste listing would become effective. Under this alternative, each state would be evaluated individually, which could lead to a situation where CCRs were managed as hazardous or special wastes in certain states, while in other states, they would be managed as non-hazardous wastes. Such an approach could present some implementation issues, particularly if CCRs were transported across state lines. In addition, EPA has serious questions as to whether RCRA, as currently drafted, would allow EPA to promulgate such a regulation. However, EPA solicits comments on this option, both generally and with respect to the specific time frames.

Commenters also have suggested an approach similar to that proposed for cement kiln dust (CKD) in an August 20, 1999 proposed rule (*see* 64 FR 45632 *available at http://www.epa.gov/fedrgstr/EPA–WASTE/1999/August/Day-20/f20546.htm*). Under the CKD approach, the Agency would establish detailed management standards under subtitle D of RCRA. CCRs managed in accordance with the standards would not be a hazardous or special waste. However, CCRs that were in egregious violation of these requirements, such as disposal in land-based disposal units that were not monitored for groundwater releases or in new units built without liners, would be considered listed hazardous or special waste and subject to the tailored subtitle C requirements. (EPA is soliciting comment on this approach because commenters have suggested it; interested commenters may wish to consult the CKD proposal for more detail on how it would work. *See* 64 FR 45632 *available at http://www.epa.gov/epawaste/nonhaz/industrial/special/ckd/ckd/ckd-fr.pdf*). Like the previous approach, EPA is evaluating (and in fact is re-evaluating) this approach, and whether RCRA provides EPA the authority to promulgate such a rule.

Other commenters suggested yet another approach whereby EPA would regulate CCRs going for disposal under RCRA subtitle C, but they assert that EPA would not have to specifically list CCR as a hazardous waste using the criteria established in 40 CFR 261.11. These commenters believe that RCRA § 3001(b)(3)(A) (the so-called Bevill Amendment) authorizes the Agency to regulate CCRs under subtitle C as long as the Agency determines that subtitle C regulation is warranted based on the consideration of the eight factors identified in RCRA § 8002(n). The commenters analysis of their approach is set forth in a memorandum submitted to the Agency and is in the docket for today's notice. EPA has not adopted the commenters suggested reading of the statute, but solicits comments on it. (*See* "EPA Has Clear Authority to Regulate CCW under RCRA's Subtitle C without Making a Formal Listing Determination," White Paper from Eric Schaeffer, Environmental Integrity Project which is available in the docket for this proposal.)

Finally, some commenters have suggested that EPA not promulgate any standards, whether it be RCRA subtitle C or D, but continue to rely on the states to regulate CCRs under their existing or new state authority, and that EPA could rely on RCRA section 7003 (imminent and substantial endangerment) authority, to the extent the Agency had information that a problem existed that it needed to address. The Agency does not believe that such an approach is at all acceptable, and that national regulations whether it be under RCRA subtitle C or D needs to be promulgated. First, RCRA was designed as a preventative statute and not one where EPA would get involved only after a problem has been discovered. Thus, such an approach would not be consistent with the purpose and objectives of RCRA. In addition, this approach would basically implement the status quo—that is, the control of CCRs over the last decade, which the Agency believes has not shown to be at all acceptable. Furthermore, imminent and substantial endangerment authority is facility-specific and resource intensive. That is, such authority can only be used when EPA has sufficient information to determine that disposal of CCRs are contributing to an imminent and substantial endangerment. Thus, relying on this authority, without national regulations, is poorly suited to address the many problems that have occurred, and are likely to occur in the future. Nevertheless, the Agency solicits comment on such an approach.

EPA solicits comments on all of the approaches discussed above. The Agency is still considering all of these approaches, as well as our legal authorities to promulgate them, and will continue to do so as we move toward finalizing the regulations applicable to the disposal of CCRs.

XIV. Is the EPA soliciting comments on specific issues?

Throughout today's preamble, the Agency has identified many issues for which it is soliciting comment along with supporting information and data. In order to assist readers in providing EPA comments and supporting information, in this section EPA is identifying many of the major issues on which comments with supporting information and data are requested.

Management of CCRs

- Whether regulatory approaches should be established individually for the four Bevill CCR wastes (fly ash, bottom ash, boiler slag, and FGD sludges) when destined for disposal.
- The extent to which the information currently available to EPA reflects current industry practices at both older and new units.
- The regulatory approaches proposed in the notice and the alternative approaches EPA is considering as discussed in Section XIII of the preamble.
- The Agency has documented, through proven damage cases and risk analyses, that the wet handling of CCRs in surface impoundments poses higher risks to human health and the environment than the dry handling of CCRs in landfills. EPA seeks comments on the standards proposed in this notice to protect human health and the environment from the wet handling of CCRs. For example, in light of the TVA Kingston, Tennessee, and the Martins Creek, Pennsylvania CCR impoundment failures, should the Agency require that owners or operators of existing and new CCR surface impoundments submit emergency response plans to the regulatory authority if wet handling of CCRs is practiced?
- The degree to which coal refuse management practices have changed and the impacts of those changes or, for

[170] Under this approach, EPA also would establish minimum national standards that ensure that CCRs that are managed under the "D" regulations would be protective of human health and the environment.

example, groundwater monitoring and the use of liners.

• Information and data on CCRs that are generated by non-utility industries, such as volumes generated, characteristics of the CCRs, and whether they are co-managed with other wastes generated by the non-utility industry.

Risk Assessment

• Are there any additional data that are representative of CCR constituents in surface impoundment or landfill leachate (from literature, state files, industry or other sources) that EPA has not identified and should be used in evaluating the risks presented by the land disposal of CCRs?

• The screening analysis conducted to estimate risks from fugitive CCR dust; data from any ambient air monitoring for particulate matter that has been conducted; where air monitoring stations are located near CCR landfills or surface impoundments; and information on any techniques, such as wetting, compaction, or daily cover that are or can be employed to reduce such exposures.

• Whether site-averaged porewater data used in model runs in EPA's risk analyses are representative of leachate from surface impoundments.

• Information and data regarding the existence of drinking water wells that are down-gradient of CCR disposal units, any monitoring data that exists on those monitoring wells and the potential of these wells to be intercepted by surface water bodies.

Liners

• Whether, in addition to the flexibility provided by section 3004(o)(2), regulations should also provide for alternative liner designs based on, for example, a specific performance standard, such as the performance standard in 40 CFR 258.40(a)(1), or a site specific risk assessment, or a standard that the alternative liner, such as a clay liner, was at least as effective as the composite liner.

• Whether clay liners designed to meet a 1×10^{-7} cm/sec hydraulic conductivity might perform differently in practice than modeled in the risk assessment, including specific data on the hydraulic conductivity of clay liners associated with CCR disposal units.

• The effectiveness of such additives as organosilanes, including any analyses that would reflect long-term performance of the additives, as well as the appropriateness of a performance standard that would allow the use of these additives in lieu of composite liners.

Beneficial Use

• The growth and maturation of state beneficial use programs and the growing recognition that the beneficial use of CCRs is a critical component in strategies to reduce GHG emissions taking into account the potentially changing composition of CCRs as a result of improved air pollution controls and the new science on metals leaching.

• Information and data on the extent to which states request and evaluate CCR characterization data prior to the beneficial use of unencapsulated CCRs.

• The appropriate means of characterizing beneficial uses that are both protective of human health and the environment and provide benefits. EPA is also requesting information and data demonstrating where the federal and state programs could improve on being environmentally protective and, where states have, or are developing, increasingly effective beneficial use programs.

• Whether certain uses of CCRs (*e.g.,* uses involving unencapsulated uses of CCRs) warrant tighter control and why such tighter control is necessary.

• If EPA determines that regulations are needed for the beneficial use of CCRs, should EPA consider removing the Bevill exemption for such uses and regulate these uses under RCRA subtitle C, develop regulations under RCRA subtitle D or some other statutory authority, such as under the Toxic Substances Control Act?

• Whether it is necessary to define beneficial use better or develop detailed guidance on the beneficial use of CCRs to ensure protection of human health and the environment, including whether certain unencapsulated beneficial uses should be prohibited.

• Whether the Agency should promulgate standards allowing uses on the land, on a site-specific basis, based on site specific risk assessments, taking into consideration the composition of CCRs, their leaching potential under the range of conditions under which the CCRs would be managed, and the context in which CCRs would be applied, such as location, volume, rate of application, and proximity to water.

• If materials characterization is required, what type of characterization is most appropriate? If the CCRs exceed the toxicity characteristic at pH levels different from the TCLP, should they be excluded from beneficial use? When are totals levels relevant?

• Whether EPA should fully develop a leaching assessment tool in combination with the Draft SW–846 leaching test methods described in Section I. F. 2 and other tools (*e.g.,* USEPA's *Industrial Waste Management Evaluation Model* (IWEM)) to aid prospective beneficial users in calculating potential release rates over a specified period of time for a range of management scenarios.

• Information and data relating to the agricultural use of FGD gypsum, including the submission of historical data, taking into account the impact of pH on leaching potential of metals, the variable and changing nature of CCRs, and variable site conditions.

• Historically, EPA has proposed or imposed conditions on other types of hazardous wastes used in a manner constituting disposal (*e.g.,* maximum application rates and risk-based concentration limits for cement kiln dust used as a liming agent in agricultural applications (*see* 64 FR 45639; August 20, 1999); maximum allowable total concentrations for non-nutritive and toxic metals in zinc fertilizers produced from recycled hazardous secondary materials (*see* 67 FR 48393; July 24, 2002). Should EPA establish standards, such as maximum/ minimum thresholds, or rely on implementing states to impose CCR site-specific limits based on front-end characterization that ensures individual beneficial uses remain protective?

• Whether additional beneficial uses of CCRs have been established, since the May 2000 Regulatory Determination, that have not been discussed elsewhere in today's preamble. The Agency solicits comment on any new uses of CCR, as well as the information and data which support that CCRs are beneficially used in an environmentally sound manner.

• Whether there are incentives that could be provided that would increase the amount of CCRs that are beneficially used and comment on specific incentives that EPA could adopt that would further encourage the beneficial use of CCRs.

• Information and data on the best means for estimating current and future quantities and changes in the beneficial use of CCRs, as well as on the price elasticity of CCR applications in the beneficial use market.

Stigma

• If EPA were to regulate CCRs as a "special waste" under subtitle C of RCRA, and stigma turns out to be an issue, suggestions on methods by which the Agency could reduce any stigmatic impact that might indirectly arise. We are seeking information on actual instances where "stigma" has adversely affected the beneficial use of CCRs and the causes of these adverse effects.

• The issue of "stigma" and its impact on beneficial uses of CCRs, including more specifics on the potential for procedural difficulties for state programs, and measures that EPA might adopt to try to mitigate these effects.

• For those commenters who argue that regulating CCRs under subtitle C of RCRA would raise liability issues, EPA requests that commenters describe the types of liability and the basis/data/information on which these claims are based.

• EPA furthermore welcomes ideas on how to best estimate these effects for purposes of conducting regulatory impact analysis, and requests any data or methods that would assist in this effort.

Today's Co-Proposed Regulations

General

• Some commenters have suggested that EPA not promulgate any standards, whether they be RCRA subtitle C or D, but continue to rely on the states to regulate CCRs under their existing or new state authorities. The Agency solicits comment on such an approach, including how such an approach would be protective of human health and the environment.

RCRA Subtitle C Regulations

• Whether EPA should modify the corrective action requirements for facility-wide corrective action under the subtitle C co-proposal under the authority of section 3004(x) of RCRA. If so, how such modification would be protective of human health and the environment.

• Pursuant to RCRA section 3010 and 40 CFR 270.1(b), facilities managing these special wastes subject to RCRA subtitle C must notify EPA of their waste management activities within 90 days after the wastes are identified or listed as a special waste. The Agency is proposing to waive this notification requirement for persons who handle CCRs and have already: (1) notified EPA that they manage hazardous wastes, and (2) received an EPA identification number. Should such persons be required to re-notify the Agency that they generate, transport, treat, store or dispose of CCRs?

• Representatives of the utility industry have stated their view that CCRs cannot be practically or cost effectively managed under the existing RCRA subtitle C storage standards, and that these standards impose significant costs without meaningful benefits when applied specifically to CCRs. Comments are solicited on the practicality of the proposed subtitle C storage requirements for CCRs, the workability of the existing variance process allowing alternatives to secondary containment, and the alternative requirements based, for example, on the mining and mineral processing waste storage requirements.

RCRA Subtitle D Regulations

• EPA broadly solicits comment on the approach of relying on certifications by independent registered professional hydrologists or engineers of the adequacy of actions taken at coal-fired utilities to design and operate safe waste management systems.

• The Agency does not have specific data showing the number of CCR landfills located in fault areas where movement along Holocene faults is common, and the distance between these units and the active faults and, thus, is unable to precisely estimate the number of these existing CCR landfills that would not meet today's proposed fault area restrictions. Additional information regarding the extent to which existing landfills are currently located in such locations is solicited.

• In general, EPA believes that a 200-foot buffer zone is necessary to protect engineered structures from seismic damages and also expects that the 200-foot buffer is appropriate for CCR surface impoundments. The Agency seeks comment and data on whether the buffer zone should be greater for surface impoundments.

• Additional information regarding the extent to which landfill capacity would be affected by applying the proposed subtitle D location restrictions to existing CCR landfills.

• The proposed location requirements do not reflect a complete prohibition on siting facilities in areas of concern, but provide a performance standard that facilities must meet in order to site a unit in such a location. Information on the extent to which facilities could comply with the proposed performance standards, and the necessary costs that would be incurred to retrofit CCR disposal units to meet these standards is solicited.

• The proposed definition of seismic impact zones and whether there are variants that could lessen the burden on the industry and the geographic areas covered by the proposed definition.

• Whether the subtitle D option, if promulgated, should allow facilities to use alternative designs for new disposal units, so long as the owner or operator of a unit could obtain certification from an independent registered professional engineer or hydrologist that the alternative design would ensure that the appropriate concentration values for a set of constituents typical of CCRs will not be exceeded in the uppermost aquifer at the relevant point of compliance (*i.e.,* 150 meters from the unit boundary down gradient from the unit, or the property boundary if the point of compliance is beyond the property boundary).

• Whether there could be homeland security implications with the requirement to post information on an internet site and whether posting certain information on the internet may duplicate information that is already available to the public through the State.

• Whether the subtitle "D prime" option is protective of human health and the environment.

• EPA is proposing that existing CCR landfills and surface impoundments that cannot make a showing that a CCR landfill or surface impoundment can be operated safely in a floodplain or unstable area must close within five years after the effective date of the rule. EPA solicits comment on the appropriate amount of time necessary to meet this requirement, as well as measures that could help to address the potential for inadequate disposal capacity.

• The effectiveness of annual surface impoundment assessments in ensuring the structural integrity of CCR surface impoundments over the long term.

Surface Impoundment Closeout

• Whether the Agency should provide for a variance process allowing some surface impoundments that manage wet-handled CCRs to remain in operation because they present minimal risk to groundwater (*e.g.,* because they have a composite liner) and minimal risk of a catastrophic release (*e.g.,* as indicated by a low or less than low potential hazard rating under the Federal Guidelines for Dam Safety established by the Federal Emergency Management Agency).

Surface Impoundment Stability

• The adequacy of EPA's proposals to address surface impoundment integrity under RCRA.

• Whether to address all CCR impoundments for stability, regardless of height and storage volume; whether to use the cut-offs in the MSHA regulations; or whether other regulations, approaches, or size cut-offs should be used. If commenters believe that other regulations or different size cut-offs should be adopted, we request that commenters provide the basis and technical support for their position.

• Whether surface impoundment integrity should be addressed under EPA's NPDES permit program, rather than the development of regulations under RCRA, whether it be RCRA subtitles C or D.

Financial Assurance

• EPA broadly solicits comments on whether financial assurance should be a key program element under a subtitle D approach, if the decision is made to promulgate regulations under RCRA subtitle D.

• Whether financial responsibility requirements under CERCLA § 108(b) should be a key Agency focus for ensuring that funds are available for addressing the mismanagement of CCRs.

• How the financial assurance requirements might apply to surface impoundments that cease receiving CCRs before the effective date of the rule.

• Whether a financial test similar to that in 40 CFR 258.74(f) in the Criteria for Municipal Solid Waste Landfills should be established for local governments that own and operate coal-fired power plants.

State Programs

• Detailed information on current and past individual state regulatory and non-regulatory approaches taken to ensure the safe management of CCRs, not only under State waste authorities, but under other authorities as well, including the implementation of those approaches.

• The potential of federal regulations to cause disruption to States' implementation of CCR regulatory programs under their own authorities, including more specifics on the potential for procedural difficulties for State programs, and measures that EPA might adopt to try to mitigate these effects.

Damage Cases

• EPRI's report and additional data regarding the proven damage cases identified by EPA, especially the degree to which there was off-site contamination.

• The report of additional damage cases submitted to EPA on February 24, 2010 by the Environmental Integrity Project and EarthJustice.

Regulatory Impact Analysis

• Data and findings presented in the RIA, as well as on the cost and benefit estimation uncertainty factors identified in the RIA.

• Data on the costs of converting coal fired power plants from wet handling to dry handling with respect to the various air pollution controls, transportation systems, disposal units, and other heterogeneous factors.

• Relevant RCRA corrective actions and related costs that would be useful in characterizing the potential costs for future actions.

• Information on other significant and catastrophic surface impoundment releases of CCRs or other similar materials and cleanup costs associated with these releases?

• Data on the costs of storage of CCRs in tanks or tank systems, on pads, or in buildings.

• EPA has also quantified and monetized the benefits of this rule to the extent possible based on available data and modeling tools, but welcomes additional data that may be available that would assist the Agency in expanding and refining our existing benefit estimates.

XV. Executive Orders and Laws Addressed in This Action

A. Executive Order 12866: Regulatory Planning and Review

Under section 3(f)(1) of Executive Order (EO) 12866 (58 FR 51735, October 4, 1993), this action is an "economically significant regulatory action" because it is likely to have an annual effect on the economy of $100 million or more (section 3(f)(1)). This determination is based on the regulatory cost estimates provided in EPA's "Regulatory Impact Analysis" (RIA) which is available in the docket for this proposal. The RIA estimated regulatory implementation and compliance costs, benefits and net benefits for a number of regulatory options, including a subtitle C "special waste" option, a subtitle D option and, a subtitle "D prime" option. The subtitle D prime option was briefly described in the Preamble and is more fully discussed in the RIA to the co-proposal. On an average annualized basis, the estimated regulatory compliance costs for the three options in today's proposed action are $1,474 million (subtitle C special waste), $587 million (subtitle D), and $236 million (subtitle "D prime") per year. On an average annualized basis, the estimated regulatory benefits for the three options in today's proposed action are $6,320 to $7,405 million (subtitle C special waste), $2,533 to $3,026 million (subtitle D), and $1,023 to $1,268 million (subtitle "D prime") per year. On an average annualized basis, the estimated regulatory net benefits for the three options in today's proposed action are $4,845 to $5,930 million (subtitle C special waste), $1,947 to $2,439 million (subtitle D), and $786 to $1,032 million (subtitle "D prime") per year. All options exceed $100 million in expected future annual effect. Accordingly, EPA submitted this action to the Office of Management and Budget (OMB) for review under EO 12866, and changes made in response to OMB recommendations are documented in the docket for this proposal.

B. Paperwork Reduction Act

The information collection requirements contained in this proposed rule has been submitted for approval to the Office of Management and Budget (OMB) under the *Paperwork Reduction Act,* 44 U.S.C. 3501 *et seq.* The Information Collection Request (ICR) document prepared by EPA has been assigned EPA ICR number 1189.22.

Today's action co-proposes two regulatory alternatives that would regulate the disposal of CCRs under RCRA. The regulatory options described in today's notice contain mandatory information collection requirements. One of the regulatory options (subtitle C special waste option) would also trigger mandatory emergency notification requirements for releases of hazardous substances to the environment under CERCLA and EPCRA. The labor hour burden and associated cost for these requirements are estimated in the ICR "Supporting Statement" for today's proposed action. The Supporting Statement identifies and estimates the burden for the following nine categories of information collection: (the proposed options also contain other regulatory requirements not listed here because they do not involve information collection).

1. Groundwater monitoring
2. Post-closure groundwater monitoring
3. RCRA manifest cost (for subtitle C only)
4. Added cost of RCRA subtitle C permits for all offsite CCR landfills
5. Structural integrity inspections
6. RCRA facility-wide investigation (for subtitle C only)
7. RCRA TSDF hazardous waste disposal permit (for subtitle C only)
8. RCRA enforcement inspection (for subtitle C only)
9. Recordkeeping requirements

Based on the same data and cost calculations applied in the "Regulatory Impact Analysis" (RIA) for today's action, but using the burden estimation methods for ICRs, the ICR "Supporting Statement" estimates an average annual labor hour burden of 2.88 million hours for the subtitle C "special waste" option and 1.38 million hours for both the subtitle D and "D prime" options at an average annual cost of $192.93 million for the subtitle C "special waste" option and $92.6 million for both the subtitle D options. One-time capital and hourly costs are included in these estimates based on a three-year annualization period. The estimated number of likely respondents (under the options) ranges from 90 to 495, depending on the information category enumerated above. Burden is defined at 5 CFR 1320.3(b). An Agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for EPA's regulations in 40 CFR are listed in 40 CFR part 9.

To comment on the Agency's need for this information, the accuracy of the provided burden estimates, and any suggested methods for minimizing respondent burden, EPA has established a public docket for this rule, which includes this ICR, under Docket ID number EPA–HQ–RCRA–2009–0640. Submit any comments related to the ICR to EPA and OMB. *See* **ADDRESSES** section at the beginning of this notice for where to submit comments to EPA. Send comments to OMB at the Office of Information and Regulatory Affairs, Office of Management and Budget, 725 17th Street, NW., Washington, DC 20503, Attention: Desk Office for EPA. Since OMB is required to make a decision concerning the ICR between 30 and 60 days after June 21, 2010, a comment to OMB is best assured of having its full effect if OMB receives it by July 21, 2010. The final rule will respond to any OMB or public comments on the information collection requirements contained in this proposal.

C. Regulatory Flexibility Act

The Regulatory Flexibility Act (RFA) generally requires an Agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the Agency certifies that the rule will not have a significant economic impact on a substantial number of small entities. Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impacts of today's rule on small entities in the electric utility industry, small entity is defined as: (1) A small fossil fuel electric utility plant as defined by NAICS code 221112 with a threshold of less than four million megawatt-hours of electricity output generated per year (based on Small Business Administration size standards); (2) a small governmental jurisdiction that is a government based on municipalities with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

EPA certifies that this action will not have a significant economic impact on a substantial number of small entities (*i.e.,* no SISNOSE). EPA nonetheless continues to be interested in the potential impacts of the proposed rule on small entities and welcomes comments on issues related to such impacts, including our estimated count of small entities that own the 495 electric utility plants covered by this rule. This certification is based on the small business analysis contained in the RIA for today's proposal, which contains the following findings and estimates.

- The RIA identifies 495 electric utility plants likely affected by the proposed rule, based on 2007 data. The RIA estimates these 495 plants are owned by 200 entities consisting of 121 companies, 18 cooperative organizations, 60 state or local governmental jurisdictions, and one Federal government Agency. The RIA estimates that 51 of these 200 owner entities (*i.e.,* 26%) may be classified as small entities, consisting of 33 small municipal governments, 11 small companies, 6 small cooperatives, plus 1 small county government.
- The RIA includes a set of higher cost estimates for the regulatory options and the RFA evaluation is based on these estimates and therefore overestimates potential impacts of our proposed regulations. The RIA estimated that (a) None of the 51 small entities may experience average annualized regulatory compliance costs of greater than three percent of annual revenues, (b) one to five of the 51 small entities (*i.e.,* 2% to 10%) may experience regulatory costs greater than one percent of annual revenues, and (c) 46 to 50 of the small entities (*i.e.,* 90% to 98%) may experience regulatory costs less than one percent of annual revenues. These percentages constitute the basis for today's no-SISNOSE certification.

As analyzed in the RIA, there are two electricity market factors which may be expected to reduce or eliminate these potential revenue impacts on small entities, as well as for the other owner entities for the 495 plants:

- Electric utility plants have a mechanism to cover operating cost increases via rate hike petitions to public utility commissions in states which regulate public utilities, and via market price increases in the 18 states (as of 2008) which have de-regulated electric utilities, and
- The residential, commercial, industrial, and transportation sector economic demand for (*i.e.,* consumption of) electricity is relatively price inelastic, which suggests that electric utility plants may succeed in passing through most or all regulatory costs to their electricity customers.

However, because the Agency is sensitive to any potential impacts its regulations may have on small entities, the Agency requests comment on its analysis, and its finding that this action is not expected to have a significant economic impact on a substantial number of small entities.

D. Unfunded Mandates Reform Act

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), 2 U.S.C. 1531–1538, requires Federal agencies, unless otherwise prohibited by law, to assess the effects of their regulatory actions on State, local, and tribal governments and the private sector. This co-proposal contains a Federal mandate that may result in expenditures of $100 million or more for State, local, and tribal governments, in the aggregate, or for the private sector, in any one year.

The RIA includes a set of higher cost estimates for the regulatory options and the UMRA evaluation is based on these estimates and therefore overestimates the potential impacts of this co-proposal. Accordingly, EPA has prepared under section 202 of the UMRA a "Written Statement" (an appendix to the RIA) which is summarized below. Today's co-proposal will likely affect 495 electric utility plants owned by an estimated 200 entities, of which 139 private sector electric utility companies and cooperatives may incur between $415 million to $1,999 million in future annual direct costs across the high-end options in the RIA, which exceed the $100 million UMRA direct cost threshold under each of the regulatory options. In addition, 60 entities are state or local governments which may incur between $56 million to $97 million in future annual direct costs across the regulatory options, the upper-end of which is slightly under the $100 million UMRA direct cost threshold. The remainder single entity is a Federal government Agency (*i.e.,* Tennessee Valley Authority).

Although the estimated annual direct cost on state or local governments is less than the $100 million UMRA threshold, (a) because the highest-cost regulatory option is only 3% less than the $100 million annual direct cost threshold, and (b) because there are a number of uncertainty factors (as identified in the RIA) which could result in regulatory costs being lower or higher than estimated, EPA consulted with small governments according to EPA's UMRA interim small government consultation plan developed pursuant to section 203 of the UMRA. EPA's interim plan provides for two types of possible small government input: technical input and administrative input. According to this plan, and consistent with section 204 of the UMRA, early in the process for developing today's co-proposal, the Agency implemented a small government consultation process consisting of two consultation components.

• A series of meetings in calendar year 2009 were held with the purpose of acquiring small government technical input, including: (1) A February 27 meeting with ASTSWMO's Coal Ash Workgroup (Washington, DC); (2) a March 22–24 meeting with ECOS at their Spring Meeting (Alexandria VA); (3) a April 15–16 meeting with ASTSWMO at their Mid-Year Meeting (Columbus OH), (4) a May 12–13 meeting at the EPA Region IV State Directors Meeting (Atlanta, GA), (5) a June 17–18 meeting at the ASTSWMO Solid Waste Managers Conference (New Orleans, LA), (6) a July 21–23 meeting at ASTSWMO's Board of Directors Meeting (Seattle, WA), and (7) an August 12 meeting at ASTSWMO's Hazardous Waste Subcommittee Meeting (Washington, DC). ASTSWMO is an organization with a mission to work closely with EPA to ensure that its state government members are aware of the most current developments related to their state waste management programs. ECOS is a national non-profit, non-partisan association of state and territorial environmental Agency leaders. As a result of these meetings, EPA received letters in mid-2009 from 22 state governments, as well as a letter from ASTSWMO expressing their stance on CCR disposal regulatory options.

Letters were mailed on August 24, 2009 to the following 10 organizations representing state and local elected officials, to inform them and seek their input for today's proposed rulemaking, as well as to invite them to a meeting held on September 16, 2009 in Washington, DC: (1) National Governors Association; (2) National Conference of State Legislatures, (3) Council of State Governments, (4) National League of Cities, (5) U.S. Conference of Mayors, (6) County Executives of America, (7) National Association of Counties, (8) International City/County Management Association, (9) National Association of Towns and Townships, and (10) ECOS. These 10 organizations of elected state and local officials are identified in EPA's November 2008 Federalism guidance as the "Big 10" organizations appropriate to contact for purpose of consultation with elected officials. EPA has received written comments from a number of these organizations and a copy of their comments has been placed in the docket for this rulemaking. The commenters express significant concerns with classifying CCRs as a hazardous waste. Their major concerns are that federal regulation could undercut or be duplicative of State regulations; that any federal regulation will have a great impact on already limited State resources; and that such a rule would have a negative effect on beneficial use. A number of commenters also raise the issue of the cost to their facilities of a subtitle C rule, particularly increased disposal costs and the potential shortage of hazardous waste disposal capacity.

Consistent with section 205 of UMRA, EPA identified and considered a reasonable number of regulatory alternatives. Today's proposed rule identifies a number of regulatory options, and EPA's RIA estimates that the average annual direct cost to industry across the three originally considered options (*e.g.* as reflected in the RIA in Exhibit 7L) may range between $415 million to $1,999 million. Section 205 of the UMRA requires Federal agencies to select the least costly or most cost-effective regulatory alternative unless the Agency publishes with the final rule an explanation of why such alternative was not adopted. We are co-proposing two regulatory options in today's notice involving RCRA subtitle C "special waste" and subtitle D. The justification for co-proposing the higher-cost options is that this provides for greater benefits and protection of public health and the environment by phasing out surface impoundments, compared to the lower cost subtitle D prime option.

E. Executive Order 13132: Federalism

Executive Order 13132, entitled "Federalism" (64 FR 43255, August 10, 1999), requires EPA to develop an accountable process to ensure "meaningful and timely input by State and local officials in the development of regulatory policies that have federalism implications." "Policies that have federalism implications" are defined in the Executive Order to include regulations that have "substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government."

Under Executive Order 13132, EPA may not issue a regulation that has federalism implications, that imposes substantial direct compliance costs, and that is not required by statute, unless the Federal government provides the funds necessary to pay the direct compliance costs incurred by State and local governments, or EPA consults with State and local officials early in the process of developing the proposed regulation.

EPA has concluded that this proposed rule may have federalism implications, because it may impose substantial direct compliance costs on State or local governments, and the Federal government may not provide the funds necessary to pay those costs. Accordingly, EPA provides the following federalism summary impact statement as required by section 6(b) of Executive Order 13132.

The RIA includes a set of higher cost estimates for the regulatory options and the Federalism evaluation is based on these estimates and, therefore, overestimates the potential impacts of our proposal.

Based on the estimates in EPA's RIA for today's action, the proposed regulatory options, if promulgated, may have federalism implications because the options may impose between $56 million to $97 million in annual direct compliance costs on 60 state or local governments. These 60 state and local governments consist of 33 small municipal government jurisdictions, 19 non-small municipal government jurisdictions, 7 state government jurisdictions, and one county government jurisdiction. In addition, the 48 state governments with RCRA-authorized programs for the proposed regulatory options may incur between $0.05 million to over $5.4 million in added annual administrative costs involving the 495 electric utility plants for reviewing and enforcing the various requirements. Based on these estimates, the expected annual cost to state and local governments for at least one of the regulatory options described in today's notice exceeds the $25 million per year "substantial compliance cost" threshold defined in section 1.2(A)(1) of EPA's November 2008 "Guidance on Executive Order 13132: Federalism." In developing the regulatory options described in today's notice, EPA consulted with 10 national organizations representing state and local elected officials to ensure meaningful and timely input by state/local governments, consisting of two consultation components, which is described under the UMRA Executive Order discussion.

In the spirit of Executive Order 13132, and consistent with EPA policy to promote communications between EPA and State and local governments, EPA specifically solicits comment on this co-proposal from elected State and local government officials.

F. Executive Order 13175: Consultation and Coordination With Indian Tribal Governments

Executive Order 13175 (65 FR 67249–67252, November 9, 2000) requires Federal agencies to provide funds to tribes, consult with tribes, and to conduct a tribal summary impact statement, for regulations and other actions which are expected to impose substantial direct compliance costs on one or more Indian tribal governments. Today's co-proposal, whether under subtitle C or subtitle D authority, is likely to impose direct compliance costs on an estimated 495 coal-fired electric utility plants. This estimated plant count is based on operating plants according to the most recent (2007) data available as of mid-2009 from the DOE's Energy Information Administration "Existing Generating Units in the United States by State, Company and Plant 2007." Based on information published by the Center for Media and Democracy,[171] three of the 495 plants are located on tribal lands, but are not owned by tribal governments: (1) Navajo Generating Station in Coconino County, Arizona owned by the Salt River Project; (2) Bonanza Power Plant in Uintah County, Utah owned by the Deseret Generation and Transmission Cooperative; and (3) Four Corners Power Plant in San Juan County, New Mexico owned by the Arizona Public Service Company. The Navajo Generating Station and the Four Corners Power Plant are on lands belonging to the Navajo Nation, while the Bonanza Power Plant is located on the Uintah and Ouray Reservation of the Ute Indian Tribe. According to this same information source, there is one additional coal-fired electric utility plant planned for construction on Navajo Nation tribal land near Farmington, New Mexico, but to be owned by a non-tribal entity (the Desert Rock Energy Facility to be owned by the Desert Rock Energy Company, a Sithe Global Power subsidiary). Because none of the 495 plants are owned by tribal governments, this action does not have tribal implications as specified in Executive Order 13175. Thus, Executive Order 13175 does not apply to this action. EPA solicits comment on the accuracy of the information used for this determination. EPA met with a Tribal President, whose Tribe owns a cement plant, and who was concerned about the adverse impact of designating coal combustion residuals as a hazardous waste and the effect that a hazardous waste designation would have on the plant's business. We assured the Tribal President that we are aware of the "stigma" concerns related to a hazardous waste listing and will be analyzing that issue throughout the rulemaking process.

G. Executive Order 13045: Protection of Children From Environmental Health & Safety Risks

Executive Order (EO) 13045 (62 FR 19885, April 23, 1997) establishes federal executive policy on children's health and safety risks. Its main provision directs federal agencies, to the greatest extent practicable and permitted by law, to make it a high priority to identify and assess environmental health risks and safety risks that may disproportionately affect children in the United States. EPA has conducted a risk assessment which includes evaluation of child exposure scenarios, as well as has evaluated Census child population data surrounding the 495 plants affected by today's co-proposal, because today's action meets both of the two criteria for "covered regulatory actions" defined by Section 2–202 of EO 13045: (a) today's co-proposal is expected to be an "economically significant" regulatory action as defined by EO 12866, and (b) based on the risk analysis discussed elsewhere in today's notice, the environmental and safety hazards addressed by this action may have a disproportionate effect on children.

For each covered regulatory action, such as today's action, Section 5 of EO 13045 requires federal agencies (a) to evaluate the environmental health or safety effects of the planned regulation on children, and (b) to explain why the planned regulation is preferable to other potentially effective and reasonably feasible alternatives considered by the Agency. The remainder of this section below addresses both of these requirements, as well as presents a summary of the human health risk assessment findings with respect to child exposure scenarios, and the results of the child demographic data evaluation.

G1. Evaluation of Environmental Health and Safety Effects on Children

EPA conducted a risk evaluation consisting of two steps, focusing on environmental and health effects to adults and to children that may occur due to groundwater contamination. The first step, conducted in 2002, was a screening effort targeting selected hazardous chemical constituents that appeared to be the most likely to pose risks. The second step, conducted between 2003 and 2009, consisted of more detailed "probabilistic" modeling for those constituents identified in the screening as needing further evaluation. Constituents that may cause either cancer or non-cancer effects in humans (*i.e.,* both adults and children) were evaluated under modeling scenarios where they migrate from a CCR landfill or surface impoundment toward a drinking water well or nearby surface water body, and where humans ingest the constituents either by drinking the contaminated groundwater or by eating fish caught in surface water bodies affected by the contaminated groundwater.

As described elsewhere in today's notice, EPA found that for the non-cancer health effects in the groundwater-to-drinking-water pathway and in the fish consumption pathways evaluated in the probabilistic modeling, children rather than adults had the higher exposures. This result stems from the fact that while at a given exposure point (*e.g.,* a drinking water well located a certain distance and direction down-gradient from the landfill or surface impoundment), the modeled groundwater concentration is the same regardless of whether the receptor is an adult or a child. Thus the other variables in the exposure equations (that relate drinking water intakes or fish consumption rates and body weight to a daily "dose" of the constituent) mean that, on a per-kilogram-body-weight basis, children are exposed to higher levels of constituents than adults.

G2. Evaluation of Children's Population Census Data Surrounding Affected Electric Utility Plants

The RIA for today's co-proposal contains an evaluation of whether children may disproportionately live near the 495 electric utility plants potentially affected by this rulemaking. This demographic data analysis is supplemental to and separate from the risk assessment summarized above. To make this determination, the RIA compares Census demographic data on child populations residing near each of the 495 affected plants, to statewide children population data. The results of that evaluation are summarized here.

- Of the 495 electric utility plants, 383 of the plants (77%) operate CCR disposal units on-site (*i.e.,* onsite landfills or onsite surface

[171] The Center for Media and Democracy (CMD) was founded in 1993 as an independent, non-profit, non-partisan, public interest organization. Information about electric utility plants located on tribal lands is from CMD's SourceWatch Encyclopedia at: *http://www.sourcewatch.org/index.php?title=Coal_and_Native_American_tribal_lands.*

impoundments), 84 electric utility plants solely transport CCRs to offsite disposal units operated by other companies (*e.g.,* commercial waste management companies), and 28 other electric utility plants generate CCRs that are solely beneficially used rather than disposed. Child demographic data is evaluated in the RIA for all 495 plants because some regulatory options could affect the future CCR management method (*i.e.,* disposal versus beneficial use) for some plants.

- The RIA provides three complementary approaches to comparison of child populations surrounding the 495 plants to statewide child population data: (a) Plant-by-plant comparison basis, (b) state-by-state aggregation comparison basis, and (c) nationwide total comparison basis. There are year 2000 Census data for 464 (94%) of the 495 electric utility plants which the RIA used for these comparisons and extrapolated to all 495 plants. Statewide children population benchmark percentages range from 21.5% (Maine) to 30.9% (Utah), with a nationwide average of 24.7%.
- For purpose of determining the relative degree by which children may exceed these statewide percentages, the percentages are not only compared in absolute terms, but also compared as a numerical ratio whereby a ratio of 1.00 indicates that the child population percentage living near an electric utility plant is equal to the statewide average, a ratio greater than 1.00 indicates the child population percentage near the electric utility plant is higher than the statewide population, and a ratio less than 1.00 indicates the child population is less than the respective statewide average.
- Using the plant-by-plant basis, 310 electric utility plants (63%) have surrounding child populations which exceed their statewide children benchmark percentages, whereas 185 of the electric utility plants (37%) have children populations below their statewide benchmarks, which represents a ratio of 1.68 (*i.e.,* 310/185). Since this ratio is much greater than 1.00, this finding indicates that a disproportionate number of electric utility plants have surrounding child population percentages which exceed their statewide benchmark. Using the state-by-state aggregation basis, 27 of the 47 states (57%) where the 495 electric utility plants are located have disproportionate percentages of children residing near the plants compared to the statewide averages, which also indicates a disproportionate surrounding child population. Using the nationwide aggregation basis across all 495 electric utility plants in all 47 states where the plants are located, 6.08 million people reside near these electric utility plants, including 1.54 million children (25.4%). Comparison of this percentage to the national aggregate benchmark across all states of 24.7% children yields a ratio of 1.03 (*i.e.,* 25.4%/24.7%). This ratio indicates a slightly higher disproportionate child population surrounding the 495 electric utility plants.

These three alternative comparisons indicate that the current (baseline) environmental and human health hazards and risks from electric utility CCR disposal units, and the expected future benefits of the regulatory options being considered in today's co-proposal may have a disproportionately higher effect on child populations.

The public is invited to submit comments or identify peer-reviewed studies and data that assess effects of early life exposure to CCRs managed in landfills and surface impoundments.

H. Executive Order 13211: Actions That Significantly Affect Energy Supply, Distribution, or Use

This co-proposal, if either of the options being considered is promulgated, is not expected to be a "significant energy action" as defined in Executive Order 13211 (66 FR 28355, May 22, 2001), because the regulatory options described in today's co-proposal are not expected to have a significant adverse effect on the supply, distribution, or use of energy. This determination is based on the energy price analysis presented in EPA's Regulatory Impact Analysis (RIA) for this proposed rule. The following is the basis for this conclusion.

The Office of Management and Budget's (OMB) July 13, 2001 Memorandum M–01–27 guidance for implementing this Executive Order identifies nine numerical indicators (thresholds) of potential adverse energy effects, three of which are relevant for evaluating potential energy effects of this proposed rule: (a) Increases in the cost of energy production in excess of 1%; (b) increases in the cost of energy distribution in excess of 1%; or (c) other similarly adverse outcomes.

Because EPA does not have data on energy production costs or energy distribution costs for the 495 electric utility plants likely affected by this rulemaking, EPA in its RIA for today's action evaluated the potential impact on electricity prices (for the regulatory options) as measured relative to the 1% numerical threshold of these two Executive Order indicators to represent an "other similarly adverse outcome."

The RIA calculated the potential increase in electricity prices of affected plants that the industry might induce under each regulatory option. Because the price analysis in the RIA is based only on the 495 coal-fired electric utility plants that would likely be affected by the co-proposal (with 333,500 megawatts nameplate capacity), rather than on all electric utility and independent electricity producer plants in each state using other fuels, such as natural gas, nuclear, hydroelectric, etc. (with 678,200 megawatts nameplate capacity), the price effects estimated in the RIA are higher than would be if the regulatory costs were averaged over the entire electric utility and independent electricity producer supply (totaling 1,011,700 megawatts, not counting an additional 76,100 megawatts of combined heat and electricity producers).

The price effect calculation in the RIA involved estimating plant-by-plant annual revenues, plant-by-plant average annualized regulatory compliance costs for each regulatory option, and comparison with statewide average electricity prices for the 495 electric utility plants. In its analysis, the Agency used the May 2009 statewide average retail prices for electricity published by DOE's, Energy Information Administration; these costs ranged from $0.0620 (Idaho & Wyoming) to $0.1892 (Hawaii) per kilowatt-hour, and the nationwide average for the 495 plants was $0.0884. Based on a 100% regulatory cost pass-thru scenario representing an upper-bound potential electricity price increase for each plant, the RIA estimated the potential target electricity sales revenue needed to cover these costs for each plant. The RIA then compared the higher target revenue to recent annual revenue estimates per plant, to calculate the potential price effect of this cost pass-thru scenario on electricity prices for each of the 495 electric utility plants, as well as on a state-by-state sub-total basis and on a nationwide basis across all 495 electric utility plants.

The RIA includes a set of higher cost estimates for the regulatory options and this Executive Order 13211 evaluation is based on the higher estimates and, therefore, overestimates the potential impacts of our proposal.

The RIA indicates that on a nationwide basis for all 495 electric utility plants, compared to the estimated average electricity price of $0.0884 per kilowatt-hour, the 100% regulatory cost pass-thru scenario may increase prices for the 495 electric utility plants by 0.172% to 0.795% across the original regulatory options; the high-end is the estimate associated with a regulatory cost pass-thru scenario increase for the 495 electric utility plants for the subtitle C "special waste" option. Based on this analysis, the Agency does not expect that either of the options being co-proposed today would have a significant adverse effect on the supply, distribution, or use of energy. However, the Agency solicits comments on our analysis and findings.

I. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 ("NTTAA"), Public Law No. 104–113, 12(d) (15 U.S.C. 272 note) directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (*e.g.,* materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use available and applicable voluntary consensus standards.

This proposed rulemaking does not involve technical standards. Therefore, EPA is not considering the use of any voluntary consensus standards.

J. Executive Order 12898: Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order (EO) 12898 (59 FR 7629, February 16, 1994) establishes federal executive policy on environmental justice. Its main provision directs federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income (*i.e.,* below poverty line) populations in the United States.

Furthermore, Section 3–302(b) of EO 12898 states that Federal agencies, whenever practicable and appropriate, shall collect, maintain and analyze information on minority and low-income populations for areas surrounding facilities or sites expected to have substantial environmental, human health, or economic effects on the surrounding populations, when such facilities or sites become the subject of a substantial Federal environmental administrative or judicial action. While EO 12898 does not establish quantitative thresholds for this "substantial effect" criterion, EPA has collected and analyzed population data for today's co-proposal because of the substantial hazards and adverse risks to the environment and human health described elsewhere in today's notice.

The RIA for today's action presents comparisons of minority and low-income population Census data for each of the 495 electric utility plant locations, to respective statewide population data, in order to identify whether these two demographic groups may disproportionately reside near electric utility plants. The result of these comparisons indicate (a) whether existing hazards associated with CCR disposal at electric utility plants to community safety, human health, and the environment may disproportionately affect minority and low-income populations surrounding the plants, and (b) whether the expected effects (*i.e.,* benefits and costs) of the regulatory action described in today's co-proposal rule may disproportionately affect minority and low-income populations.

Of the 495 electric utility plants, 383 of the plants (77%) operate CCR disposal units onsite (*i.e.,* onsite landfills or onsite surface impoundments), 84 electric utility plants solely transport CCRs to offsite disposal units operated by other companies (*e.g.,* commercial waste management companies), and 28 of the electric utility plants generate CCRs that are solely beneficially used rather than disposed. The minority and low-income Census data evaluation is conducted for all 495 plants because some regulatory options could affect the future CCR management method (*i.e.,* disposal versus beneficial use) for some plants.

In addition to this Census data evaluation, the RIA identifies three other possible affects of the co-proposal on (a) populations surrounding offsite CCR landfills, (b) populations surrounding the potential siting of new CCR landfills and (c) populations within the customer service areas of the 495 electric utility plants who may incur electricity price increases resulting from regulatory cost pass-thru. These three Census data evaluations are also summarized below.

J.1. Findings of Environmental Justice Analysis for Electric Utility Plants

For the first comparison, the RIA provides three complementary approaches to evaluating the Census data on minority and low-income populations: (a) Itemized plant-by-plant comparisons to statewide percentages, (b) state-by-state aggregation comparisons, and (c) nationwide aggregate comparisons. There are year 2000 Census data for 464 (94%) of the 495 electric utility plants which the RIA used for these comparisons and extrapolated to all 495 plants. Statewide minority population benchmark percentages range from 3.1% (Maine) to 75.7% (Hawaii), with a nationwide average of 24.9%, and statewide low-income population percentages range from 7.3% (Maryland) to 19.3% (New Mexico), with a nationwide average of 11.9%.

For purpose of determining the relative degree by which either group may exceed these statewide percentages, in addition to a comparison of absolute percentages, the percentages are compared as a numerical ratio whereby a ratio of 1.00 indicates that the group population percentage living near an electric utility plant is equal to the statewide average, a ratio greater than 1.00 indicates the group population percentage near the electric utility plant is higher than the statewide population, and a ratio less than 1.00 indicates the group population is less than the respective statewide average.

Using the plant-by-plant comparison, 138 electric utility plants (28%) have surrounding minority populations which exceed their statewide minority benchmark percentages, whereas 357 of the electric utility plants (72%) have minority populations below their statewide benchmarks, which represents a ratio of 0.39 (*i.e.,* 138/357). Because this ratio is less than 1.00, this finding indicates a relatively small number of the electric utility plants have surrounding minority population percentages which disproportionately exceed their statewide benchmarks. On a plant zip code tabulation area basis, 256 electric utility plants (52%) have surrounding low-income populations which exceed their respective statewide benchmarks, whereas 239 plants (48%) have surrounding low-income populations below their statewide benchmarks, which represents a ratio of 1.07 (*i.e.,* 256/239). Because this ratio is above 1.00, it indicates that a slightly disproportionate higher number of electric utility plants have surrounding low-income population percentages which exceed their statewide benchmarks.

Using the state-by-state aggregation comparison, the percentages of minority and low-income populations surrounding the plants were compared to their respective statewide population benchmarks. From this analysis, state ratios revealed that 24 of the 47 states

(51%) have higher minority percentages, and 29 of the 47 states (62%) have higher low-income percentages surrounding the 495 electric utility plants, suggesting a slightly disproportionate higher minority surrounding population and a higher disproportionate, higher low-income surrounding population. However, in comparison to the other two numerical comparisons—the plant-by-plant basis and the nationwide aggregation basis, this approach does not include numerically weighting of state plant counts or state surrounding populations, which explains why this comparison method yields a different numerical result.

Using the nationwide aggregation comparison across all 495 electric utility plants in all 47 states where the plants are located, 6.08 million people reside near these plants, including 1.32 million (21.7%) minority and 0.8 million (12.9%) low-income persons. A comparison of these percentages to the national benchmark of 24.9% minority and 11.9% low-income, represents a minority ratio of 0.87 (*i.e.,* 21.7%/24.9%) and a low-income ratio of 1.08 (*i.e.,* 12.9%/11.9%). These nationwide aggregate ratios indicate a disproportionately lower minority population surrounding the 495 electric utility plants, and a disproportionately higher low-income population surrounding these plants.

These demographic data comparisons indicate that the current (baseline) environmental and human health hazards and risks from electric utility CCR disposal units, and the expected future effects (*i.e.,* benefits and costs) of the regulatory options described in today's co-proposal may have a disproportionately lower effect on minority populations and may have a disproportionately higher effect on low-income populations.

J.2. Environmental Justice Analysis for Offsite Landfills, Siting of New Landfills, and Electricity Service Area Customers

There are three other potential differential effects of the regulatory options on three other population groups: (a) Populations surrounding offsite landfills, (b) populations surrounding the potential siting of new landfills and (c) populations within the customer service areas of the 495 electric utility plants. The RIA for today's notice does not quantify these potential effects so only a qualitative discussion appears below.

The potential effect on offsite landfills as evaluated in the RIA only involves the RCRA subtitle C "special waste" based regulatory option described in today's co-proposal, whereby electric utility plants may switch the management of CCRs, in whole or in part, from current onsite disposal to offsite commercial RCRA-permitted landfills. In addition, some or all of the CCRs which are currently disposed in offsite landfills that do not have RCRA operating permits may also switch to RCRA-permitted commercial landfills. Another fraction of annual CCR generation which could also switch to offsite commercial RCRA-permitted landfills are CCRs which are currently supplied for industrial beneficial use applications if such use is curtailed.

The future addition of any or all of these three fractions of CCR generation to offsite commercial hazardous waste landfills could exceed their capacity considering that a much smaller quantity of about 2 million tons per year of existing RCRA-regulated hazardous waste is currently disposed of in RCRA subtitle C permitted landfills in the U.S. As of 2009, there are 19 commercial landfills with RCRA hazardous waste permits to receive and dispose of RCRA-regulated hazardous wastes located in 15 states (AL, CA, CO, ID, IL, IN, LA, MI, NV, NY, OH, OK, OR, TX, UT). This potential shift could have a disproportionate effect on populations surrounding these locations, and in particular, minority and low-income populations surrounding commercial hazardous waste facilities, for the reason that a recent (2007) study determined that minority and low-income populations disproportionately live near commercial hazardous waste facilities. However, the study included other types of commercial hazardous waste treatment and disposal facilities in addition to commercial hazardous waste landfills.

The siting of new landfills is another potential effect due to possible changes in the management of CCRs, especially if the switch to offsite commercial hazardous waste landfills causes a capacity shortage (as described above) under subtitle C option. However, since it is unknown where these new landfills might possibly be sited, two possibilities were examined: (a) An expansion of existing commercial subtitle C landfills offsite from electric utility plants, and (b) an expansion of existing electric utility plant onsite landfills. If an expansion of existing commercial subtitle C landfills were to occur, this potential shift could have a disproportionate effect on populations surrounding these locations, as described previously.

The other possibility is the expansion of electric utility plant onsite landfills. That is, these landfills become permitted under RCRA subtitle C and expand existing onsite landfills or build new ones onsite. If this were to occur, the environmental justice impacts could be similar to the demographic comparison findings previously discussed, which indicates that the current environmental and human health hazards and risks from electric utility CCR disposal units, and the expected future effects (*i.e.,* benefits and costs) of the regulatory options, may have a disproportionately lower effect on minority populations, but may have a disproportionately higher effect on low-income populations.

A third potential effect of the regulatory options described in today's notice is the increase in price of electricity supplied by some or all of the affected 495 electric utility plants to cover the cost of regulatory compliance (as evaluated in a previous section of today's notice). Thus, customers in electric utility service areas could experience price increases, as described above in the Federalism sub-section of today's notice. The RIA for today's action did not evaluate the demographics of the customer service area populations for the 495 electric utility plants.

Appendix to the Preamble: Documented Damages From CCR Management Practices

EPA has gathered or received through comments on the 1999 Report to Congress and the May 2000 Regulatory Determination, and through allegations, 135 possible damage cases. Six cases involved minefills and, therefore, are outside the scope of today's proposed rule. Sixty-two cases have not been further assessed because there was little or no supporting information to assess the allegations.

Of the remaining 67 cases, EPA determined that 24 were proven damage cases. Sixteen were determined to be proven damage cases to ground water and eight were determined to be proven damages cases to surface water, as a result of elevated levels of contaminants from CCRs.[172] Four of the proven ground water damage cases were from unlined landfills, five were from unlined surface impoundments, one

[172] Of the 16 proven cases of damages to ground water, the Agency has been able to confirm that corrective action has been completed in seven cases and are ongoing in the remaining nine cases. Corrective action measures at these CCR management units vary depending on site specific circumstances and include formal closure of the unit, capping, re-grading of ash and the installation of liners over the ash, ground water treatment, groundwater monitoring, and combinations of these measures.

involved a surface impoundment for which it is not clear whether the unit was lined, and the remaining six were from unlined sand and gravel pits. Another 43 alleged cases were determined to be potential damage cases to ground water or surface water. However, four of these potential damage cases were attributable to oil combustion wastes, which are outside the scope of this notice. Therefore, we have determined that there were a total of 40 potential damage cases attributable to CCRs. (The concern with wastes from the combustion of oil involved unlined surface impoundments. Prior to the May 2000 Regulatory Determination, the unlined oil ash impoundments were closed, and thus EPA decided regulatory action to address oil ash was unnecessary.) These cases are discussed in more detail in the document "Coal Combustion Wastes Damage Case Assessments" available in the docket to the 2007 NODA at *http://www.regulations.gov/fdmspublic/component/main?main=DocumentDetail&d=EPA-HQ-RCRA-2006-0796-0015*. Three proven damage cases are sites that have been listed on EPA's National Priorities List (NPL). The sites, and links to additional information are: (1) Chisman Creek, Virginia (*http://www.epa.gov/reg3hwmd/npl/VAD980712913.htm*), (2) Salem Acres, Massachusetts (*http://yosemite.epa.gov/r1/npl_pad.nsf/f52fa5c31fa8f5c885256adc0050b631/C8A4A5BEC0121F048525691F0063F6F3?OpenDocument*), and (3) U.S. Department of Energy Oak Ridge Reservation, Tennessee (*http://www.epa.gov/region4/waste/npl/npltn/oakridtn.htm*). One potential damage case has also been listed on the NPL: Lemberger Landfill, Wisconsin (*http://www.epa.gov/region5/superfund/npl/wisconsin/WID980901243.htm*). Another site has undergone remediation under EPA enforcement action: Town of Pines (*http://cfpub.epa.gov/supercpad/cursites/cactinfo.cfm?id=0508071*).

In response to the 2007 NODA (*see* section II. A.), EPA received information on 21 alleged damage cases. Of these, 18 pertain to alleged violations of state solid waste permits, and 3 to alleged violations of NPDES permits. Upon review of this information, we conclude that 13 of the alleged RCRA violations are new, and one of the alleged NPDES violations is new; the other damage cases have previously been submitted to EPA and evaluated. In addition, five new alleged damage cases have been brought to EPA's attention since February 2005 (the closure date of damage cases assessed by the NODA's companion documents). For the most part, these cases involve activities that are different from the prior damage cases and the focus of the regulatory determination on groundwater contamination from landfills and surface impoundments. Specifically:

- Two of the new alleged cases involve the structural failure of surface impoundments; *i.e.,* dam safety and structural integrity issues, which were not a consideration at the time of the May 2000 Regulatory Determination. In both cases, there were Clean Water Act violations.
- One other alleged case involves the failure of an old discharge pipe, and is clearly a regulated NPDES permit issue.
- Two other alleged cases involve the use of coal ash in large scale structural fill operations, one of which involves an unlined sand and gravel pit. The Agency is considering whether to regulate this method of disposal as a landfill or whether to address the issue separately as part of its rulemaking to address minefilling. EPA is soliciting comments on those alternatives.

The Agency has classified three of the five new cases as proven damage cases (BBBS Sand and Gravel Quarries, Martins Creek Power Plant, TVA Kingston Power Plant), one as a potential damage case (Battlefield Golf Course), and the other as not being a damage case under RCRA (TVA Widows Creek). Several of the recently submitted damage cases are discussed briefly below. The following descriptions further illustrate that there are additional risk concerns (dam safety, and fill operations) which EPA did not evaluate when it completed its the May 2000 Regulatory Determination, in which EPA primarily was concerned with groundwater contamination associated with landfills and surface impoundments and the beneficial use of CCRs. Additional information on these damage cases is included in the docket.

Recent Cases

BBBS Sand and Gravel Quarries—Gambrills, Maryland

On October 1, 2007, the Maryland Department of the Environment (MDE) filed a consent order in Anne Arundel County, Maryland Circuit Court to settle an environmental enforcement action that was taken against the owner of a sand and gravel quarry and the owner of coal fired power plants (defendants) for contamination of public drinking water wells in the vicinity of the sand and gravel quarry.

Specifically, beginning in 1995, the defendants used fly ash and bottom ash from two Maryland power plants to fill excavated portions of two sand and gravel quarries. Ground water samples collected in 2006 and 2007 from residential drinking water wells near the site indicated that, in certain locations, contaminants, including heavy metals and sulfates were present at or above ground water quality standards. The Anne Arundel County, Maryland Department of Health tested private wells in 83 homes and businesses in areas around the disposal site. MCLs were exceeded in 34 wells [arsenic (1), beryllium (1), cadmium (6), lead (20),[173] and thallium (6)]. The actual number of wells affected by fly ash and bottom ash is undetermined since some of the sample results may reflect natural minerals in the area. SMCLs were exceeded in 63 wells [aluminum (44), manganese (14), and sulfate (5)]. MDE concluded that leachate from the placement of CCRs at the site resulted in the discharge of pollutants to waters of the state. Based on these findings, as well as an MDE consent order, EPA has concluded that the Gambrills site is a proven case of damage to ground water resulting from the placement of CCRs in unlined sand and gravel quarries.

Under the terms of the consent order, the defendants are required to pay a fine, remediate the ground water in the area and provide replacement water supplies for 40 properties. A retail development is now planned for the site with a cap over the fill designed to reduce infiltration and subsequent leaching from the site. An MDE fact sheet on this site is available at *http://www.mde.state.md.us/assets/document/AA_Fly_Ash_QA.pdf*.

Battlefield Golf Course—Chesapeake, Virginia

On July 16, 2008, the City of Chesapeake, Virginia sent a letter to the EPA Region III Regional Administrator requesting assistance to perform an assessment of the Battlefield Golf Course. The 216 acre site was contoured with 1.5 million cubic yards of fly ash, amended with 1.7% to 2.3% cement kiln dust to develop the golf course. Virginia's Administrative Code allowed the use of fly ash as fill material (considered a beneficial use under Virginia's Administrative Code) without a liner as long as the fly ash was placed at least two feet above groundwater and covered by an 18-inch soil cap.

Because of ground water contamination discovered at another site where fly ash was used, the City of

[173] It is uncertain whether lead exceedances were due to CCRs or lead in plumbing and water holding tanks.

Chesapeake initiated a drinking water well sampling assessment at residences surrounding the golf course. Additionally, 13 monitoring points were installed around the site. No monitoring points were installed through the fly ash area to avoid creating an additional path of contaminant migration. EPA conducted a site investigation by reviewing analytical data from fly ash, soil, surface water, sediment, and groundwater sampling events completed in 2001, 2008 and 2009. The sampling results of the City of Chesapeake ground water and surface water sampling [174] indicated that the highest detections of metals occurred in monitoring wells located on the golf course property. The concentrations of arsenic, boron, chromium, copper, lead and vanadium detected in groundwater collected from on-site monitoring wells were considered to be significantly above background concentrations. Of these compounds, only boron has been detected in approximately 25 drinking water wells.

Although not a primary contaminant of concern, boron is suspected to be the leading indicator of fly ash migration. The highest level of boron reported in a residential well was 596 µg/L which was significantly below the health-based regional screening level for boron in tap water of 7,300 µg/L. Additionally, the secondary drinking water standard for manganese (0.05 mg/L) was exceeded in nine residential wells; however, the natural levels of both manganese and iron in the area's shallow aquifer are very high and, thus, it could not be ruled out that the elevated levels of manganese and iron are a result of the natural background levels of these two contaminants.

Metal contaminants were below MCLs and Safe Drinking Water Act (SDWA) action levels in all residential wells that EPA tested, except for lead. Lead has been detected during EPA sampling events above the action level of 15 µg/L in six residential wells. The lead in these wells, however, does not appear to come from the fly ash. Lead concentrations are lower in groundwater collected from monitoring wells on the golf course (1.1 to 1.6 µg/L) than in these residential wells; and lead concentrations in the fly ash are not higher than background concentrations of lead in soil.

The recently issued EPA Final Site Inspection Report [175] concluded that (i) Metal contaminants were below MCLs and Safe Drinking Water Act (SDWA) action levels in all residential wells that EPA tested; (2) the residential well data indicate that metals are not migrating from the fly ash to residential wells; and (iii) there are no adverse health effects expected from human exposure to surface water or sediments on the Battlefield Golf Course site as the metal concentrations were below the ATSDR standards for drinking water and soil. Additionally, the sediment samples in the ponds were below EPA Biological Technical Assistance Group screening levels and are not expected to pose a threat to ecological receptors. Based on these findings, EPA has categorized the Battlefield Golf Club site as a potential damage case, as there is a possibility that leaching could cause levels of toxic constituents to increase over time and that groundwater could become contaminated at off-site locations if due diligence is not practiced.

Martins Creek Power Plant—Martins Creek, Pennsylvania

In August 2005, a dam confining a 40 acre CCR surface impoundment in eastern Pennsylvania failed. The dam failure, a violation of the State's solid waste disposal permit, resulted in the discharge of 0.5 million cubic yards of coal-ash and contaminated water into the Oughoughton Creek and the Delaware River.

Ground-water monitoring results from approximately 20 on-site monitoring wells found selenium concentrations exceeding Pennsylvania's Statewide Health Standards and Federal primary drinking water standards. There was also one exceedance of the primary MCL for chromium and two exceedances of the secondary MCL for iron.

Surface water samples were also taken from a number of locations along the Delaware River upstream and downstream of the spill. Sampling began soon after the spill in August 2005 and continued through November 2005. Several samples exceeded the Federal Water Quality Criteria (WQC) for aluminum, copper, iron, manganese, and silver (*see http://www.epa.gov/waterscience/criteria/wqctable/index.html*). Four samples also exceeded the WQC for arsenic—three of which were taken near the outfall to the river. Lead, nickel and zinc were also detected above the WQC in samples taken near the outfall to the river. Sampling results are available from the Pennsylvania Department of Environmental Protection (PADEP) at *http://www.depweb.state.pa.us/northeastro/cwp/view.asp?a=1226&q=478264&northeastroNav=|*.

As a result of the exceedances of primary and secondary MCLs in on-site ground water, and exceedances of federal water quality criteria in off-site surface water, in addition to a PADEP consent order for clean up, the Agency considers this site to be a proven damage case.

TVA Kingston—Harriman, Tennessee

On December 22, 2008, a failure of the northeastern dike used to contain fly ash occurred at the dewatering area of the Tennessee Valley Authority's (TVA's) Kingston Fossil Plant in Harriman, Tennessee. Subsequently, approximately 5.4 million cubic yards of fly ash sludge was released over an approximately 300 acre area and into a branch of the Emory River. The ash slide disrupted power, ruptured a gas line, knocked one home off its foundation and damaged others. The state-issued NPDES permit requires that TVA properly operate and maintain all facilities and systems for collection and treatment, and expressly prohibits overflows of wastes to land or water from any portion of the collection, transmission, or treatment system other than through permitted outfalls. Therefore, the release was a violation of the NPDES permit. A root-cause analysis report developed for TVA, accessible at *http://www.tva.gov/kingston/rca/index.htm,* established that the dike failed because it was expanded by successive vertical additions, to a point where a thin, weak layer of fly ash ('slime') on which it had been founded, failed by sliding. Additional information on the TVA Kingston incident is available at *http://www.epa.gov/region4/kingston/index.html* and *http://www.tva.gov/kingston/*.

EPA joined TVA, the Tennessee Department of Environment and Conservation (TDEC), and other state and local agencies in a coordinated response. EPA provided oversight and technical advice to TVA, and conducted independent water sampling and air monitoring to evaluate public health and environmental threats.

Following the incident, EPA sampled the coal ash and residential soil to determine if the release posed an immediate threat to human health. Sampling results for the contaminated residential soil showed arsenic, cobalt, iron, and thallium levels above the residential Superfund soil screening levels.[176] Sampling results also showed

[174] *Available at http://cityofchesapeake.net/services/citizen_info/battlefieldgolfclub/index.shtml.*

[175] *http://www.epa.gov/reg3hwmd/CurrentIssues/finalr-battlefield_golf_club_site/redacted_DTN_0978_Final_Battlefield_SI_Report.pdf.*

[176] Soil screening levels (SSLs) for contaminants in soil are used to identify sites needing further

average arsenic levels above the EPA Region 4 Residential Removal Action Level (RAL)[177] of 39 mg/L, but below EPA Region 4's Industrial RAL of 177 mg/L. All residential soil results were below the Residential RAL.

Shortly after the release, samples were also collected of untreated river water, which showed elevated levels of suspended ash and heavy metals known to be associated with coal ash. Nearly 800 surface water samples were taken by TVA and TDEC, ranging from two miles upstream of the release on the Emory River to approximately eight miles downstream on the Clinch River. Sampling results of untreated river water showed elevated levels of arsenic, cadmium, chromium, and lead just after the incident. This was also observed again after a heavy rainfall. In early January 2009, the Tennessee Wildlife Resources Agency (TWRA) issued a fish advisory stating that until further notice, fishing should be avoided in the lower section of the Emory River. TWRA plans to resample fish tissue on a semiannual basis and expects that the assessment of the impact of this release on wildlife resources and habitat will require repeated sampling and evaluation over the next three to five years.

Constituent concentrations measured in drinking water on December 23, 2008, near the intake of the Kingston Water Treatment Plant, located downstream of the release, were below federal MCLs for drinking water, with the exception of elevated thallium levels. Subsequent EPA testing on December 30, 2008, of samples at the same intake found that concentration levels for thallium had fallen below the MCL. Subsequent testing of treated drinking water from the Kingston Water Treatment Plant showed that the drinking water from the treatment plant met all federal drinking water standards.

Additionally, EPA and TDEC identified and sampled potentially impacted private wells that are used as a source for drinking water. More than 100 wells have been tested to date and all have met drinking water standards.

To address potential risks from windblown ash, TVA, under EPA oversight, began air monitoring for coarse and fine particles. EPA also conducted independent monitoring to validate TVA's findings. To date, all of the more than 25,000 air samples from this area have measured levels below the NAAQS for particulates.

On January 12, 2009, TDEC issued an order to TVA to, among other things, continue to implement measures to prevent the movement of contaminated materials into waters of the state and, where feasible, minimize further downstream migration of contaminated sediments.

Than on May 11, 2009, TVA agreed to clean up more than 5 million tons of coal ash spilled from its Kingston Fossil Fuel Plant under an administrative order and agreement on consent. TVA and EPA entered into the agreement under CERCLA. The order requires TVA to perform a thorough cleanup of coal ash from the Emory River and surrounding areas and EPA will oversee the removal. Based on the consent order, EPA has identified this site as a proven damage case.

TVA Widows Creek—Stevenson, Alabama

On Friday, January 9, 2009, a cap in an unused discharge pipe became dislodged, resulting in a discharge from an FGD pond at a Tennessee Valley Authority (TVA) coal-burning power plant in Stevenson, Alabama. FGD is a residual of a process that reduces sulfur dioxide emissions from coal-fired boilers Some 5,000 cubic yards of FGD material containing water and a mixture of predominantly gypsum and some fly ash, was released from the pond into Widows Creek which flows into the Tennessee River.[178] Information on the TVA Widows Creek incident is available at *http://www.epa.gov/region4/stevenson/index.html*.

EPA joined TVA and the Alabama Department of Environmental Management (ADEM) in a coordinated response. EPA is supporting the response by coordinating environmental sampling and monitoring response operations by TVA. EPA has also collected surface water samples from both Widows Creek and the Tennessee River to determine if there have been any environmental impacts. Samples have also been taken from the FGD pond to characterize the material that was released into the creek fully. The drinking water intake for Scottsboro, Alabama, about 20 miles downstream, has also been sampled.

EPA Region 4 has received final results of its independent environmental sampling activities for the TVA Widows Creek Fossil Plant FGD pond release. Specifically, the concentrations of metals, solids and nutrients detected in samples drawn from the drinking water intake for Scottsboro, Alabama, along with samples collected from two locations in Widows Creek and three other locations in the Tennessee River, are all below national primary drinking water standards and/or other health-based levels. The pH of all these samples also fell within the standard range and no oil or grease was detected in any of the samples.

Four waste samples and one water sample collected from the bank along the ditch connecting TVA's permitted discharge outfall and the Tennessee River, and from TVA's permitted discharge outfall showed elevated pH and elevated concentrations of metals, nutrients, and suspended and dissolved solids. However, because samples drawn downstream at the drinking water intake and from locations where individuals would likely come into contact with the water were below the primary drinking water standards, EPA does not expect the release to pose a threat to the public. On July 7, 2009, TVA issued a finding of no significant impact and final environmental assessment for the Gypsum Removal Project from Widows Creek.[179] Therefore, EPA has not classified the TVA Widows Creek fly ash release as a damage case.

Summary

In summary, as discussed above, the Agency has documented evidence of proven damages to ground water or surface water in 27 cases[180]—17 cases of damage to ground water, and ten cases of damage to surface water, including ecological damages in seven of the ten. Sixteen of the 17 proven damages to ground water involved disposal in unlined units (for the remaining unit, it is unclear whether a liner was present). We have also identified 40 cases of potential damage to ground water or surface water.[181] Another two cases were determined to be potential ecological damage cases. Finally, the more recently documented damage cases also provide evidence that current management practices can pose additional risks that EPA had not

investigation. SSLs alone do not trigger the need for a response action or define "unacceptable" levels of contaminants in soil. Generally, at sites where contaminant concentrations fall below the SSLs, no further action or study is warranted under CERCLA. However, where contaminant concentrations equal or exceed the SSLs, further study or investigation, but not necessarily cleanup, is warranted.

[177] RALs are used to trigger time-critical removal actions.

[178] *http://www.tva.gov/emergency/wc_1-29-09.htm*.

[179] *http://www.tva.gov/environment/reports/widows_creek/wcf_gypsum_removal_fonsi.pdf*.

[180] The 24 cases identified in the Damage Cases Assessment report, plus Martin Creek, PA; Gambrills, MD; and Kingston/TVA, TN.

[181] The 39 cases of potential damages from CCR identified in the Damage Cases Assessment report (excludes the 4 damage cases from oil combustion wastes), plus the Battlefield Golf Course, Chesapeake, Virginia.

previously studied—that is, from catastrophic releases due to the structural failure of CCR surface impoundments.

TABLE OF EPA'S PROVEN DAMAGE CASES

Damage case, State	Affected media	Constituents of concern	Brief description	Basis for consideration as a proven damage case
Alliant Nelson Dewey Ash Landfill, WI.	Groundwater	Arsenic, Selenium, Sulfate, Boron, Flourine.	The LF [182] was originally constructed in the early 1960's as a series of settling basins for sluiced ash and permitted by the State in 1979.	*Scientific*—Although the boron standard was not health-based at the time of the exceedances, the boron levels reported for the facility would have exceeded the State's recently promulgated health-based ES for boron, and *Administrative*—The State required a groundwater investigation, and the facility took action to remediate groundwater contamination and prevent further contamination.
Dairyland Power E.J. Stoneman, WI.	Groundwater	Cadmium, Chromium, Sulfate, Manganese, Iron, Zinc.	Unlined SI [183], on permeable substrate, that managed ash, demineralizer regenerant, and sand filter backwash between the 1950'and 1987.	*Scientific*—Cadmium and chromium exceeded (health-based) primary MCLs, and contamination migrated to nearby, private drinking water wells, and *Administrative*—The State required closure of the facility.
WEPCO Cedar Sauk Ash Landfill/WEPCO, WI.	Groundwater	Selenium, Boron, Sulfate.	An abandoned sand and gravel pit that received CCW from the WEPCO Port Washington Power Plant from 1969 to 1979.	*Scientific*—Selenium in groundwater exceeded the (health-based) primary MCL, and there was clear evidence of vegetative damage, and *Administrative*—The State required remedial action.
WEPCO Highway 59 Landfill/We Energies 59, WI.	Groundwater	Arsenic, Boron, Chlorides, Iron, Manganese, Sulfate.	Located in an old sand and gravel pit that received fly ash and bottom ash between 1969 and 1978.	*Scientific*—Although the boron standard was not health-based at the time of the exceedances, the boron levels reported for the facility would have exceeded the State's recently promulgated health-based ES for boron; and contamination from the facility appears to have migrated to off-site private wells, and *Administrative*—As a result of the various PAL [184] and ES [185] exceedances, the State required a groundwater investigation.
WEPCO Port Washington Facility/ Druecker Quarry Fly Ash Site, WI.	Groundwater	Boron, Selenium	The power company placed 40–60 feet deep column of fly ash in a sand & gravel pit from 1948–1971. A well located ~250′ south of the old quarry was impacted.	*Scientific*—The off-site exceedance of a health-based standard for selenium.
SC Electric & Gas Canadys Plant, SC.	Groundwater	Arsenic, Nickel	Ash from the Canadys power plant was mixed with water and managed in a SI. The facility operated an unlined, 80-acre SI from 1974 to 1989.	*Scientific*—There are exceedances of the health-based standard for arsenic at this site. While there are no known human exposure points nearby, some recent exceedances have been detected outside an established regulatory boundary.
PEPCO Morgantown Generating Station Faulkner Off-site Disposal Facility, MD.	Groundwater	Iron, pH	LFs at this shallow groundwater site manage fly ash, bottom ash, and pyrites from the Morgantown Generating Station starting in 1970. Unlined settling ponds also are used at the site to manage stormwater runoff and leachate from the ash disposal area.	*Scientific*—Ground water contamination migrated off-site, and *Administrative*—The State required remedial action.

TABLE OF EPA'S PROVEN DAMAGE CASES—Continued

Damage case, State	Affected media	Constituents of concern	Brief description	Basis for consideration as a proven damage case
Don Frame Trucking, Inc., Fly Ash Landfill, NY.	Groundwater	Lead, Manganese	This LF has been used for disposal of fly ash, bottom ash, and other material including yard sweepings generated by the Niagara Mohawk Power Corporation's Dunkirk Steam Station. The age of the facility is unknown.	*Scientific*—The lead levels found in down-gradient wells exceed the primary MCL Action Level. *Administrative*—The State has required remedial action as a result of the contamination, and the owner was directed, by the Supreme Court of the State of New York County of Chautauqua (July 22, 1988), to cease receiving the aforementioned wastes at the facility no later than October 15, 1988.
Salem Acres, MA	Groundwater	Antimony, Arsenic, Manganese.	Fly ash disposal occurred at this site—a LF and SI, from at least 1952 to 1969.	*Scientific*—Arsenic and chromium exceeded (health-based) primary MCLs, and *Administrative*—The site was placed on the NPL list, and EPA signed a Consent Order with the owner to clean up the lagoons.
Vitale Fly Ash Pit, MA ...	Groundwater	Aluminum, Arsenic, Iron, Manganese, Selenium.	An abandoned gravel and sand pit that was used as an unpermitted LF between the 1950s and the mid-1970s. The Vitale Brothers, the site owners until 1980, accepted and disposed saltwater-quenched fly ash from New England Power Company along with other wastes.	This case was not counted as a proven damage case in the 1999 RTC[186] because it was a case of illegal disposal not representative of historical or current disposal practices. However, it otherwise meets the criteria for a proven damage case for the following reasons: *Scientific*—(i) Selenium and arsenic exceeded (health-based) primary MCLs, and (ii) there is evidence of contamination of nearby wetlands and surface waters, and *Administrative*—the facility was the subject of several citations and the State has enforced remedial actions.
Town of Pines, IN	Groundwater	Boron, Molybdenum ...	NIPSCO's Bailly and Michigan City power plants have deposited ~1 million tons of fly ash in the Town of Pines since 1983. Fly ash was buried in the LF and used as construction fill in the town. The ash is pervasive on site, visible in roads and driveways.	*Scientific*—Evidence for boron, molybdenum, arsenic and lead exceeding health-based standards in water wells away from the Pines Yard 520 Landfill site, and *Administrative*—Orders of consent signed between the EPA and IDEM with responsible parties for continued work at the site.
North Lansing Landfill, MI.	Groundwater	Lithium, Selenium	The North Lansing Landfill (NLL), an unlined, former gravel quarry pit with an elevated groundwater table, was licensed in 1974 for disposal of inert fill materials including soil, concrete, and brick. From 1980 to 1997, the NLL was used for disposal of coal ash from the Lansing Board of Water and Light electric and steam generating plants.	*Scientific*—Observation of off-site exceedances of the State's health-based standard for lithium.
Basin Electric, W.J. Neal Plant, ND.	Groundwater	Aluminum, Arsenic, Barium, Copper, Manganese, Zinc.	An unlined, 44-acre SI that received fly ash and scrubber sludge from a coal-fired power plant, along with other wastes (including ash from the combustion of sunflower seed hulls), between the 1950s and the late 1980s.	*Scientific*—Several constituents have exceeded their (health-based) primary MCLs in down-gradient groundwater, and the site inspection found documentation of releases to ground water and surface water from the site, and *Administrative*—The State required closure of the facility.

TABLE OF EPA'S PROVEN DAMAGE CASES—Continued

Damage case, State	Affected media	Constituents of concern	Brief description	Basis for consideration as a proven damage case
Great River Energy (GRE)—(formerly Co-operative Power Association/United Power) Coal Creek Station, ND.	Groundwater	Arsenic, Selenium	This site includes a number of evaporation ponds and SIs that were constructed in 1978 and 1979. Both the SIs and the evaporation ponds leaked significantly upon plant start-up. A ND DOH regulator was uncertain as to whether a liner was initially installed, although the plant may have thought they were placing some sort of liner. The surficial soils were mostly sandy materials with a high water table.	*Scientific*—Arsenic and selenium exceeded (health-based) primary MCLs, and *Administrative*—The State required remedial action.
VEPCO Chisman Creek, VA.	Groundwater	Selenium, Sulfate, Vanadium.	Between 1957 and 1974, abandoned sand and gravel pits at the site received fly ash from the combustion of coal and petroleum coke at the Yorktown Power Station. Disposal at the site ended in 1974 when Virginia Power began burning oil at the Yorktown plant. In 1980, nearby shallow residential wells became contaminated with vanadium and selenium.	Designated as a proven damage case in the 1999 RTC. *Scientific*—(i) Drinking water wells contained selenium above the (health-based) primary MCL and (ii) There is evidence of surface water and sediment contamination, and *Administrative*—The site was remediated under CERCLA.
VEPCO Possum Point, VA.	Groundwater	Cadmium, Nickel	At this site, oil ash, pyrites, boiler chemical cleaning wastes, coal fly ash, and coal bottom ash were co-managed in an unlined SI, with solids dredged to a second pond.	Damage case described in the 1999 RTC. *Administrative*—Action pursued by the State based on evidence on exceedances of cadmium and nickel, by requiring the removal of the waste.
BBBS Sand and Gravel Quarries, Gambrills, MD.	Groundwater	Aluminum, Arsenic, Beryllium, Cadmium, Lead, Manganese, Sulfate, Thallium.	As of 1995, the defendants used fly ash and bottom ash from two Maryland power plants to fill excavated portions of two unlined sand and gravel quarries. GW samples collected in 2006/07 from residential drinking water wells near the site indicated contaminants at or above GW quality standards. Testing of private wells in 83 homes and businesses in areas around the disposal site revealed MCL exceedances in 34 wells, and SMCLs exceedances in 63 wells.	*Scientific*—Documented exceedances of MCLs in numerous off-site drinking water wells. *Administrative*—On October 1, 2007, the Maryland Department of the Environment (MDE) filed a consent order in Anne Arundel County, Maryland Circuit Court to settle an environmental enforcement action against the owner of a sand and gravel quarry and the owner of coal fired power plants for contamination of public drinking water wells in the vicinity of the sand and gravel quarry.

TABLE OF EPA'S PROVEN DAMAGE CASES—Continued

Damage case, State	Affected media	Constituents of concern	Brief description	Basis for consideration as a proven damage case
Hyco Lake, Roxboro, NC.	Surface Water ...	Selenium	Hyco Lake was constructed in 1964 as a cooling water source for the Electric Plant. The lake received discharges from the plant's ash-settling ponds containing high levels of selenium. The selenium accumulated in the fish in the lake, affecting reproduction and causing declines in fish populations in the late 1970s and 1980s.	*Scientific*—Declines in fish populations were observed (1970s & 1980s). *Administrative*—The State concluded that the impacts were attributable to the ash ponds, and issued a fish consumption advisory as a result of the contamination.
Georgia Power Company, Plant Bowen, Cartersville, GA.	Surface Water ...	Ash Slurry	This unlined SI was put in service in 1968. On July 28, 2002, a sinkhole developed in the SI that ultimately reached four acres in area. An estimated 2.25 million gallons of ash/water mixture was released to a tributary of the Euharlee Creek, containing 281 tons of ash.	*Scientific*—Unpermitted discharge of water containing ash slurry into the Euharlee Creek resulting in a temporary degradation of public waters. *Administrative*—Georgia Department of Natural Resources issued a consent order requiring, among others, a fine and corrective action.
Department of Energy—Oak Ridge Y–12 Plant Chestnut Ridge Operable Unit 2, DOE Oak Ridge Reservation, Oak Ridge, TN.	Surface Water ...	Aluminum, Arsenic, Iron, Manganese.	The Filled Coal Ash Pond (FCAP) is an ash retention SI used to dispose of coal ash slurry from the Y–12 steam plant. It was constructed in 1955 by building an earthen dam across a northern tributary of Upper McCoy Branch. After the SI was filled to capacity, the slurry was released directly into Upper McCoy Branch. Erosion of both the spillway and the ash itself resulted in releases of ash into Upper McCoy Branch.	*Scientific*—Exceedances of primary and secondary MCLs were detected in onsite monitoring locations. *Administrative*—Federal RCRA and the Tennessee Department of Environmental Conservation (TDEC) requirements, including placement of the entire Oak Ridge Reservation on the NPL.
Belews Lake, NC	Surface Water ...	Selenium	This Lake was impounded in the early 1970s to serve as a cooling reservoir for a large coal-fired power plant. Fly ash was disposed in a settling basin, which released selenium-laden effluent in return flows to the Lake. Sixteen of the 20 fish species originally present in the reservoir were entirely eliminated.	*Scientific*—Evidence of extensive impacts on fish populations due to direct discharge to a surface water body. *Administrative*—The State required changes in operating practices to mitigate the contamination.

TABLE OF EPA'S PROVEN DAMAGE CASES—Continued

Damage case, State	Affected media	Constituents of concern	Brief description	Basis for consideration as a proven damage case
U.S. Department of Energy Savannah River Project, SC.	Surface Water ...	Not cited	A coal-fired power plant sluices fly ash to a series of open settling basins. A continuous flow of sluice water exits the basins, overflows, and enters a swamp that in turn discharges to Beaver Dam Creek. Bullfrog tadpoles inhabiting the site have oral deformities and impaired swimming and predator avoidance abilities, and there also is evidence of metabolic impacts on water snakes inhabiting the site.	*Scientific*—Evidence of impacts on several species in a nearby wetland caused by releases from the ash settling ponds.
Brandy Branch Reservoir, TX.	Surface Water ...	Selenium	A power plant cooling reservoir built in 1983 for Southwestern Electric Power Company's Pirkey Power Plant. The cooling reservoir received discharges from SIs containing elevated levels of selenium.	*Scientific*—Observations of impacts on fish populations were confirmed by scientific study, based on which the State concluded that the impacts were attributable to the ash ponds. *Administrative*—The State issued a fish consumption advisory as a result of the contamination.
Southwestern Electric Power Company Welsh Reservoir, TX.	Surface Water ...	Selenium	This Lake was constructed in 1976 to serve as a cooling reservoir for a power plant and receives discharges from an open SI. The Texas Parks and Wildlife Department's monitoring documents elevated levels of selenium and other metals in fish.	*Scientific*—Selenium accumulation in fish may be attributable to the ash settling ponds. *Administrative*—The State has issued a fish consumption advisory as a result of the contamination.
Texas Utilities Electric Martin Lake Reservoir, TX.	Surface Water ...	Selenium	This Lake was constructed in 1974 to serve as a cooling reservoir for a power plant and was the site of a series of major fish kills in 1978 and 1979. Investigations determined that unpermitted discharges from ash settling ponds resulted in elevated levels of selenium in the water and fish.	*Scientific*—Evidence of adverse effects on wildlife—impacts on fish populations were observed, and the State concluded that the impacts were attributable to the ash setting ponds. *Administrative*—The State has issued a fish consumption advisory as a result of the contamination.
Martins Creek Power Plant, Martins Creek, PA.	Groundwater and Surface Water.	Aluminum, Arsenic, Chromium, Copper, Iron, Lead, Manganese, Nickel, Selenium, Silver, Zinc.	In August 2005, a dam confining a 40 acre CCR SI failed. The dam failure, a violation of the State's solid waste disposal permit, resulted in the discharge of 100 million gallons of coal-ash and contaminated water into the Oughoughton Creek and the Delaware River. Ground-water monitoring found Se and Cr concentrations exceeding Pennsylvania's Statewide Health Standards and Federal primary drinking water standards, and there were also exceedances of the secondary MCL for iron.	*Scientific*—Exceedances of primary and secondary MCLs in on-site ground water, and exceedances of federal water quality criteria in off-site surface water, and *Administrative*—PA DEP issued a consent order for cleanup.

TABLE OF EPA'S PROVEN DAMAGE CASES—Continued

Damage case, State	Affected media	Constituents of concern	Brief description	Basis for consideration as a proven damage case
TVA Kingston, Harriman, TN.	Surface Water ...	Arsenic, Cobalt, Iron, Thallium.	On December 22, 2008, the northeastern dike of a SI failed. About 5.4 million cubic yards of fly ash sludge was released over about a 300 acre area and into a branch of the Emory River, disrupting power, rupturing a gas line, and destroying or damaging scores of homes. Sampling results for the contaminated residential soil showed arsenic, cobalt, iron, and thallium levels above the residential Superfund soil screening levels.	*Administrative*—On May 11, 2009, TVA agreed to clean up more than 5 million tons of spilled coal ash under an administrative order and agreement on consent under CERCLA issued by the USEPA, and In early January 2009, the Tennessee Wildlife Resources Agency (TWRA) issued a fish advisory stating that until further notice, fishing should be avoided in the lower section of the Emory River.

Abbreviations key:
1 LF—Landfill
2 SI—Surface Impoundment
3 PAL—Prevention Action Level
4 ES—Enforcement Standard
5 RTC—Report to Congress

List of Subjects

40 CFR Part 257

Environmental Protection, coal combustion products, coal combustion residuals, coal combustion waste, beneficial use, disposal, hazardous waste, landfill, surface impoundment.

40 CFR Part 261

Hazardous waste, Recycling, Reporting and recordkeeping requirements.

40 CFR Part 264

Air pollution control, Hazardous waste, Insurance, Packaging and containers, Reporting and recordkeeping requirements, Security measures, Surety bonds.

40 CFR Part 268

Hazardous waste, Reporting and recordkeeping requirements.

40 CFR Part 271

Administrative practice and procedure, Confidential business information, Hazardous materials transportation, Hazardous waste, Indians-lands, Intergovernmental relations, Penalties, Reporting and recordkeeping requirements, Water pollution control, Water supply.

40 CFR Part 302

Air pollution control, Chemicals, Hazardous substances, Hazardous waste, Intergovernmental relations, Natural resources, Reporting and recordkeeping requirements, Superfund, Water pollution control, Water supply.

Dated: May 4, 2010.

Lisa P. Jackson,

Administrator.

For the reasons set out in the preamble, title 40, chapter I of the Code of Federal Regulations is proposed to be amended as follows:

Alternative 1: Co-Proposal Under Authority of Subtitle D

PART 257—CRITERIA FOR CLASSIFICATION OF SOLID WASTE DISPOSAL FACILITIES AND PRACTICES

1. The authority citation for part 257 continues to read as follows:

Authority: 42 U.S.C., 6907(a)(3), 6912(a)(1), 6944(a), and 6949a(c); 33 U.S.C. 1345(d) and (e).

2. Section 257.1 is amended by revising the last sentence of paragraph (a) introductory text, revising paragraphs (a)(1) and (a)(2), and adding new paragraph (c)(12) to read as follows:

§ 257.1 Scope and purpose.

(a) * * * Unless otherwise provided, the criteria §§ 257.51 through 257.101 are adopted for determining which CCR Landfills and CCR Surface impoundments pose a reasonable probability of adverse effects on health or the environment under sections 1008(a)(3) and 4004(a) of the Act.

(1) Facilities failing to satisfy either the criteria in §§ 257.1 through 257.4 or §§ 257.5 through 257.30 or §§ 257.51 through 257.101 are considered open dumps, which are prohibited under section 4005 of the Act.

(2) Practices failing to satisfy either the criteria in §§ 257.1 through 257.4 or §§ 257.5 through 257.30 or §§ 257.51 through 257.101 constitute open dumping, which is prohibited under section 4005 of the Act.

* * * * *

(c) * * *

(12) Except as otherwise provided in subpart C, the criteria in subpart A of this part do not apply to CCR landfills and CCR surface impoundments subject to subpart C of this part.

3. Section 257.2 is amended by adding definitions of "CCR landfill " and "CCR surface impoundment or impoundment" to read as follows:

§ 257.2 Definitions.

* * * * *

CCR landfill means a disposal facility or part of a facility where CCRs are placed in or on land and which is not a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit. For purposes of this part, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills.

CCR surface impoundment or *impoundment* means a facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), which is designed to hold an accumulation of CCRs containing free liquids, and which is not an injection well. Examples of CCR surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons. CCR surface impoundments are used to receive CCRs that have been sluiced (flushed or mixed with water to facilitate movement), or wastes from wet air pollution control devices, often in addition to other solid wastes.

* * * * *

Subpart C—[Added and Reserved]

4. Part 257 is amended by adding and reserving Subpart C.

5. Part 257 is amended by adding Subpart D to part 257 to read as follows:

Subpart D—Standards for the Receipt of Coal Combustion Residuals in Landfills and Surface Impoundments

Subpart D—Standards for the Receipt of Coal Combustion Residuals in Landfills and Surface Impoundments

General Provisions

§ 257.40 Disposal standards for owners/operators of CCR landfills and CCR surface impoundments.

(a) *Applicability.* (1) The requirements of this subpart apply to owners or operators of CCR landfills and CCR surface impoundments. Any CCR landfill and surface impoundment continues to be subject to the requirements in §§ 257.3–1, 257.3–2, and 257.3–3.

(2) Except as otherwise specified in this Subpart, all of the requirements in this Subpart are applicable [date 180 days after the effective date of the final rule].

(b) *Definitions.* As used in this subpart:

Acre-foot means the volume of one acre of surface area to a depth of one foot.

Active life means the period of operation beginning with the initial placement of CCRs in the landfill or surface impoundment and ending at completion of closure activities in accordance with § 257.110.

Aquifer means a geological formation, group of formations, or portion of a formation capable of yielding significant quantities of groundwater to wells.

Area-capacity curves means graphic curves which readily show the reservoir water surface area, in acres, at different elevations from the bottom of the reservoir to the maximum water surface, and the capacity or volume, in acre-feet, of the water contained in the reservoir at various elevations.

Coal Combustion Residuals (CCRs) means fly ash, bottom ash, boiler slag, and flue gas desulfurization materials. CCRs are also known as coal combustion wastes (CCWs) and fossil fuel combustion (FFC) wastes.

CCR landfill means a disposal facility or part of a facility where CCRs are placed in or on land and which is not a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit. For purposes of this subpart, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills.

CCR surface impoundment or *impoundment* means a facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), which is designed to hold an accumulation of CCRs containing free liquids, and which is not an injection well. Examples of CCR surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons. CCR surface impoundments are used to receive CCRs that have been sluiced (flushed or mixed with water to facilitate movement), or wastes from wet air pollution control devices, often in addition to other solid wastes.

Existing CCR landfill means a CCR landfill which was in operation on, or for which construction commenced prior to [the effective date of the final rule]. A CCR landfill has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either:

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill to be completed within a reasonable time.

Existing CCR surface impoundment means a surface impoundment which was in operation on, or for which construction commenced prior to [the effective date of the final rule]. A CCR surface impoundment has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which can not be cancelled or modified without substantial loss—for physical construction of the CCR surface impoundment to be completed within a reasonable time.

Facility means all contiguous land and structures, other appurtenances, and improvements on the land used for the disposal of CCRs.

Factor of safety (Safety factor) means the ratio of the forces tending to resist the failure of a structure to the forces tending to cause such failure as determined by accepted engineering practice.

Freeboard means the vertical distance between the slurry or liquid elevation in an impoundment and the lowest point on the crest of the impoundment embankment.

Groundwater means water below the land surface in a zone of saturation.

Hazard potential classification means the possible adverse incremental consequences that result from the release of water or stored contents due to failure of a dam (or impoundment) or mis-operation of the dam or appurtenances. (Note: The Hazard Potential Classification System for Dams was developed by the U.S. Army Corps of Engineers for the National Inventory of Dams.)

(1) *High hazard potential surface impoundment* means a surface impoundment where failure or mis-operation will probably cause loss of human life.

(2) *Significant hazard potential surface impoundment* means a surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.

(3) *Low hazard potential surface impoundment* means a surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Independent registered professional engineer or hydrologist means a scientist or engineer who is not an employee of the owner or operator of a CCR landfill or surface impoundment who has received a baccalaureate or post-graduate degree in the natural sciences or engineering and has sufficient training and experience in groundwater hydrology and related fields as may be demonstrated by state registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgments regarding the technical information for which a certification under this subpart is necessary.

Lateral expansion means a horizontal expansion of the waste boundaries of an existing CCR landfill, or existing CCR surface impoundment made after [the effective date of the final rule].

New CCR landfill means a CCR landfill in which there is placement of CCRs without the presence of free liquids, which began operation, or for which the construction commenced after [the effective date of the final rule].

New CCR surface impoundment means a CCR surface impoundment from which there is placement of CCRs with the presence of free liquids, which began operation, or for which the construction commenced after [the effective date of the final rule].

Operator means the person(s) responsible for the overall operation of a facility.

Owner means the person(s) who owns a facility or part of a facility.

Probable maximum precipitation means the value for a particular area which represents an envelopment of depth-duration-area rainfall relations for all storm types affecting that area adjusted meteorologically to maximum conditions.

Recognized and generally accepted good engineering practices means engineering maintenance or operation activities based on established codes, standards, published technical reports, recommended practice, or similar document. Such practices detail generally approved ways to perform specific engineering, inspection, or mechanical integrity activities.

Representative sample means a sample of a universe or whole (*e.g.,* waste pile, lagoon, groundwater) which can be expected to exhibit the average properties of the universe or whole.

Run-off means any rainwater, leachate, or other liquid that drains over land from any part of a CCR landfill or surface impoundment.

Run-on means any rainwater, leachate, or other liquid that drains over land onto any part of a CCR landfill or surface impoundment.

Sand and gravel pit or quarry means an excavation for the commercial extraction of aggregate for use in construction projects.

State means any of the several States, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands.

Surface water means all water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.).

Uppermost aquifer means the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary.

Waste boundary means a vertical surface located at the hydraulically downgradient limit of the CCR landfill or CCR surface impoundment, or lateral expansion. The vertical surface extends down into the uppermost aquifer.

§§ 257.42–257.49 [Reserved]

General Requirements

§ 257.50 Applicability of other regulations.

(a) The owner or operator of a CCR landfill or CCR surface impoundment must comply with any other applicable federal, state, tribal, or local laws or other requirements.

§§ 257.51–257.59 [Reserved]

Location Restrictions

§ 257.60 Placement above the natural water table.

(a) New CCR landfills and new CCR surface impoundments and lateral expansions must be constructed with a base that is located a minimum of two feet above the upper limit of the natural water table.

(b) For purposes of this section, natural water table means the natural level at which water stands in a shallow well open along its length and penetrating the surficial deposits just deeply enough to encounter standing water at the bottom. This level is uninfluenced by groundwater pumping or other engineered activities.

§ 257.61 Wetlands.

(a) New CCR landfills, new CCR surface impoundments, and lateral expansions shall not be located in wetlands, unless the owner or operator can make the following demonstrations, certified by an independent registered professional engineer or hydrologist. The owner or operator must place the demonstrations in the operating record and the owner's or operator's publicly accessible internet site, and notify the state of this action.

(1) Where applicable under section 404 of the Clean Water Act or applicable state wetlands laws, the presumption that a practicable alternative to the proposed landfill, surface impoundment, or lateral expansion is available which does not involve wetlands is clearly rebutted; and

(2) The construction and operation of the new CCR landfill, new CCR surface impoundment, or lateral expansion will not:

(i) Cause or contribute to violations of any applicable state water quality standard,

(ii) Violate any applicable toxic effluent standard or prohibition under Section 307 of the Clean Water Act;

(iii) Jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modification of a critical habitat, protected under the Endangered Species Act of 1973; and

(iv) Violate any requirement under the Marine Protection, Research, and Sanctuaries Act of 1972 for the protection of a marine sanctuary; and

(3) The new CCR landfill, new CCR surface impoundment, or lateral expansion will not cause or contribute to significant degradation of wetlands. The owner or operator must demonstrate the integrity of the new CCR landfill, new CCR surface impoundment, or lateral expansion and its ability to protect ecological resources by addressing the following factors:

(i) Erosion, stability, and migration potential of native wetland soils, muds and deposits used to support the new CCR landfill, new CCR surface impoundment, or lateral expansion;

(ii) Erosion, stability, and migration potential of dredged and fill materials used to support the landfill or surface impoundment.

(iii) The volume and chemical nature of the CCRs.

(iv) Impacts on fish, wildlife, and other aquatic resources and their habitat from release of CCRs.

(v) The potential effects of catastrophic release of CCRs to the wetland and the resulting impacts on the environment; and

(vi) Any additional factors, as necessary, to demonstrate that ecological resources in the wetland are sufficiently protected; and

(4) To the extent required under section 404 of the Clean Water Act or applicable state wetlands laws, steps have been taken to attempt to achieve no net loss of wetlands (as defined by acreage and function) by first avoiding impacts to wetlands to the maximum extent practicable as required by paragraph (a)(1) of this section, then minimizing unavoidable impacts to the maximum extent practicable, and finally offsetting remaining unavoidable wetland impacts through all appropriate and practicable compensatory mitigation actions (*e.g.,* restoration of existing degraded wetlands or creation of man-made wetlands); and

(5) Sufficient information is available to make a reasonable determination with respect to these demonstrations.

(b) For purposes of this section, *wetlands* means those areas defined in 40 CFR 232.2.

§ 257.62 Fault areas.

(a) New CCR landfills, new CCR surface impoundments and lateral expansions shall not be located within 200 feet (60 meters) of a fault that has had displacement in Holocene time unless the owner or operator demonstrates that an alternative setback distance of less than 200 feet (60 meters) will prevent damage to the structural integrity of the new CCR landfill, new CCR surface impoundment and lateral expansion and will be protective of human health and the environment. The demonstration must be certified by an independent registered professional engineer and the owner or operator must notify the state that the demonstration has been placed in the operating record and on the owner's or operator's publicly accessible Internet site.

(b) For the purposes of this section:

(1) *Fault* means a fracture or a zone of fractures in any material along which strata on one side have been displaced with respect to that on the other side.

(2) *Displacement* means the relative movement of any two sides of a fault measured in any direction.

(3) *Holocene* means the most recent epoch of the Quaternary period, extending from the end of the Pleistocene Epoch to the present.

§ 257.63 Seismic impact zones.

(a) New CCR landfills, new CCR surface impoundments and lateral expansions shall not be located in seismic impact zones, unless the owner or operator demonstrates that all containment structures, including liners, leachate collection systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site. The demonstration must be certified by an independent registered professional engineer and the owner or operator must notify the state that the demonstration has been placed in the operating record and on the owner's or operator' publicly accessible internet site.

(b) For the purposes of this section:

(1) *Seismic impact zone* means an area with a ten percent or greater probability that the maximum horizontal acceleration in lithified earth material, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10g in 250 years.

(2) *Maximum horizontal acceleration in lithified earth material* means the maximum expected horizontal acceleration depicted on a seismic hazard map, with a 98 percent or greater probability that the acceleration will not be exceeded in 50 years, or the maximum expected horizontal acceleration based on a site-specific seismic risk assessment.

(3) *Lithified earth material* means all rock, including all naturally occurring and naturally formed aggregates or masses of minerals or small particles of older rock that formed by crystallization of magma or by induration of loose sediments. This term does not include man-made materials, such as fill, concrete, and asphalt, or unconsolidated earth materials, soil, or regolith lying at or near the earth surface.

§ 257.64 Unstable areas.

(a) Owners or operators of new or existing CCR landfills, new or existing CCR surface impoundments and lateral expansions located in an unstable area must demonstrate that engineering measures have been incorporated into the landfill, surface impoundment, or lateral expansion design to ensure that the integrity of the structural components of the landfill or surface impoundment will not be disrupted. The demonstration must be certified by an independent registered professional engineer. The owner or operator must notify the state that the demonstration has been placed in the operating record and on the owner's or operator's publicly accessible internet site. The owner or operator must consider the following factors, at a minimum, when determining whether an area is unstable:

(1) On-site or local soil conditions that may result in significant differential settling;

(2) On-site or local geologic or geomorphologic features; and

(3) On-site or local human-made features or events (both surface and subsurface).

(b) For purposes of this section:

(1) *Unstable area* means a location that is susceptible to natural or human-induced events or forces capable of impairing the integrity of some or all of the CCR landfill or CCR surface impoundment or lateral expansion structural components responsible for preventing releases from a landfill or surface impoundment. Unstable areas can include poor foundation conditions, areas susceptible to mass movements, and Karst terrains.

(2) *Structural components* means liners, leachate collection systems, final covers, run-on/run-off systems, and any other component used in the construction and operation of the CCR landfill or CCR surface impoundment or lateral expansion that is necessary for protection of human health and the environment.

(3) *Poor foundation conditions* means those areas where features exist which indicate that a natural or man-induced event may result in inadequate foundation support for the structural components of a CCR landfill, CCR surface impoundment, or lateral expansion.

(4) *Areas susceptible to mass movement* means those areas of

influence (*i.e.,* areas characterized as having an active or substantial possibility of mass movement) where the movement of earth material at, beneath, or adjacent to the CCR landfill, CCR surface impoundment, or lateral expansion, because of natural or man-induced events, results in the downslope transport of soil and rock material by means of gravitational influence. Areas of mass movement include, but are not limited to, landslides, avalanches, debris slides and flows, soil fluction, block sliding, and rock fall.

(5) *Karst terranes* means areas where karst topography, with its characteristic surface and subterranean features, has developed as a result of dissolution of limestone, dolomite, or other soluble rock. Characteristic physiographic features present in karst terranes include, but are not limited to, sinkholes, sinking streams, caves, large springs, and blind valleys.

§ 257.65 Closure of existing CCR landfills and surface impoundments.

(a) Existing CCR landfills and surface impoundments that cannot make the demonstration specified in § 257.64 (a) pertaining to unstable areas, must close by [date five years after the effective date of the final rule], in accordance with § 257.100 and conduct post-closure activities in accordance with § 257.101.

(b) The deadline for closure required by paragraph (a) of this section may be extended up to two years if the owner or operator can demonstrate that:

(1) There is no available alternative disposal capacity;

(2) There is no immediate threat to human health and the environment.

(c) The demonstration in paragraph (b) of this section must be certified by an independent registered professional engineer or hydrologist.

(d) The owner or operator must place the demonstration in paragraph (b) of this section in the operating record and on the owner's or operator's publicly accessible internet site and notify the state that this action was taken.

§§ 257.66–257.69 [Reserved]

Design Criteria

§ 257.70 Design criteria for new CCR landfills and lateral expansions.

(a) New CCR landfills and lateral expansions of CCR landfills shall be constructed:

(1) With a composite liner, as defined in paragraph (a)(2) of this section and a leachate collection system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner. The design of the composite liner and leachate collection system must be prepared by, or under the direction of, and certified by an independent registered, professional engineer.

(2) For purposes of this section, *composite liner* means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

(3) For purpose of this section, *hydraulic conductivity* means the rate at which water can move through a permeable medium. (*i.e.,* the coefficient of permeability).

(b) [Reserved]

§ 257.71 Design criteria for existing CCR surface impoundments.

(a) No later than [five years after effective date of final rule] existing CCR surface impoundments shall be constructed:

(1) With a composite liner, as defined in paragraph (a)(2) of this section and a leachate collection system between the upper and lower components of the composite liner. The design shall be in accordance with a design prepared by, or under the direction of, and certified by an independent registered professional engineer.

(2) For purposes of this section, *composite liner* means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane line (FML), and the lower component must consist of at least two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

(3) For purposes of this section, *hydraulic conductivity* means the rate at which water can move through a permeable medium (*i.e.,* the coefficient of permeability).

(b) The owner or operator of an existing CCR surface impoundment shall place in the operating record and on the owner's or operator's publicly accessible internet site, and provide to the state a history of construction, and any record or knowledge of structural instability if the existing surface impoundment can:

(1) Impound CCRs to an elevation of five feet or more above the upstream toe of the structure and can have a storage volume of 20 acre-feet or more; or

(2) Impound CCRs to an elevation of 20 feet or more above the upstream toe of the structure.

(c) For purposes of this subpart, *upstream toe* means, for an embankment dam, the junction of the upstream slope of the dam with the ground surface. (Federal Guidelines for Dam Safety, Glossary of Terms, Federal Emergency Management Agency, April 2004.)

(d) The history of construction specified in paragraph (b) of this section shall contain, at a minimum, the following information as may be available:

(1) The name and address of the persons owning or operating the CCR surface impoundment; the name associated with the CCR surface impoundment; and the identification number of the CCR surface impoundment if one has been assigned by the state.

(2) The location of the CCR surface impoundment indicated on the most recent USGS 7½ minute or 15 minute topographic quadrangle map, or a topographic map of equivalent scale if a USGS map is not available.

(3) A statement of the purpose for which the CCR surface impoundment is being used.

(4) The name and size in acres of the watershed affecting the CCR surface impoundment.

(5) A description of the physical and engineering properties of the foundation materials on which the CCR surface impoundment is constructed.

(6) A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR surface impoundment; the method of site preparation and construction of each zone of the CCR surface impoundment; and the approximate dates of construction, and each successive stage of construction of the CCR surface impoundment.

(7) At a scale not to exceed 1 inch = 100 feet, detailed dimensional drawings of the CCR surface impoundment, including a plan view and cross sections of the length and width of the CCR surface impoundment, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the measurement of the minimum vertical distance between the crest of the CCR surface impoundment

and the reservoir surface at present and under design storm conditions, CCR slurry level and CCR waste water level, and any identifiable natural or manmade features which could affect operation of the CCR surface impoundment.

(8) A description of the type and purpose of existing or proposed instrumentation.

(9) Graphs showing area-capacity curves.

(10) The hazard potential classification for which the facility is designed and a detailed explanation of the basis for this classification.

(11) A description of the spillway and diversion design features and capacities and calculations used in their determination.

(12) The computed minimum factor of safety for slope stability of the CCR retaining structure(s) and the analyses used in their determinations.

(13) A certification by an independent registered professional engineer that the design of the CCR surface impoundment is in accordance with current, prudent engineering practices for the maximum volume of CCR slurry and CCR waste water which can be impounded therein and for the passage of runoff from the design storm which exceeds the capacity of the CCR surface impoundment; or, in lieu of the certification, a report indicating what additional investigations, analyses, or improvement work are necessary before such a certification can be made by an independent registered professional engineer, including what provisions have been made to carry out such work in addition to a schedule for completion of such work. Upon completion of such work, the owner or operator shall place the certification in the operating record and on the owner's or operator's publicly accessible internet site and provide to the state notice of such certification.

(14) The construction specifications and provisions for surveillance, maintenance, and repair of the CCR surface impoundment.

(15) General provisions for closure.

(e) A permanent identification marker, at least six feet high and showing the identification number of the existing CCR surface impoundment, if one has been assigned by the state, the name associated with the CCR surface impoundment and the name of the person owning or operating the structure, shall be located on or immediately adjacent to each existing CCR surface impoundment. This requirement becomes effective [date 60 days after the effective date of the final rule].

(f) For existing CCR surface impoundments classified as having a high or significant hazard potential, as certified by an independent registered professional engineer, the owner or operator shall develop and maintain in the operating record, and on the owner's or operator' publicly accessible internet site, an Emergency Action Plan which: defines responsible persons and the actions to be taken in the event of a dam-safety emergency; provides contact information for emergency responders; includes a map which delineates the downstream area which would be affected in the event of a dam failure; and includes provisions for an annual face-to-face meeting or exercise between representatives of the facility owner and the local emergency responders.

(g) CCR surface impoundments shall be dredged of CCRs and lined with a composite liner system, as defined in paragraph (d)(2) of this section, by [date five years after the effective date of the final rule] or closed in accordance with § 257.100.

§ 257.72 Design criteria for new CCR surface impoundments and lateral expansions.

(a) New CCR surface impoundments and lateral expansions of CCR landfills or surface impoundments shall be constructed:

(1) With a composite liner, as defined in paragraph (a)(2) of this section and a leachate collection system between the upper and lower components of the composite liner. The design of the composite liner and leachate collection system must be prepared by, or under the direction of, and certified by an independent registered, professional engineer.

(2) For purposes of this section, *composite liner* means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

(3) For purpose of this section, *hydraulic conductivity* means the rate at which water can move through a permeable medium (*i.e.,* the coefficient of permeability).

(b) Plans for the design, construction, and maintenance of new CCR surface impoundments and lateral expansions shall be placed in the operating record and be submitted to the state upon certification by an independent registered professional engineer, and a notice shall be placed on the owner's or operator's publicly accessible internet site that such plans have been placed in the operating record and submitted to the state, if such proposed surface impoundment or lateral expansion can:

(1) Impound CCRs to an elevation of five feet or more above the upstream toe of the structure and can have a storage volume of 20 acre-feet or more; or

(2) Impound CCRs to an elevation of 20 feet or more above the upstream toe of the structure.

(c) A permanent identification marker, at least six feet high and showing the identification number of the CCR surface impoundment, if one has been assigned by the state, the name associated with the CCR surface impoundment and the name of the person owning or operating the structure, shall be located on or immediately adjacent to each CCR surface impoundment. This requirement becomes effective [date 60 days after the effective date of the final rule].

(d) The plan specified in paragraph (b) of this section, shall contain at a minimum the following information:

(1) The name and address of the persons owning or operating the CCR surface impoundment; the name associated with the CCR surface impoundment; and the identification number of the CCR surface impoundment if one has been assigned by the state.

(2) The location of the CCR surface impoundment indicated on the most recent USGS 7½ minute or 15 minute topographic quadrangle map, or a topographic map of equivalent scale if a USGS map is not available.

(3) A statement of the purpose for which the CCR surface impoundment is being used.

(4) The name and size in acres of the watershed affecting the CCR surface impoundment.

(5) A description of the physical and engineering properties of the foundation materials on which the CCR surface impoundment is constructed.

(6) A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR surface impoundment; the method of site preparation and construction of each zone of the CCR surface impoundment; and the approximate dates of construction, and each successive stage of construction of the CCR surface impoundment.

(7) At a scale not to exceed 1 inch = 100 feet, detailed dimensional drawings

of the CCR surface impoundment, including a plan view and cross sections of the length and width of the CCR surface impoundment, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the measurement of the minimum vertical distance between the crest of the CCR surface impoundment and the reservoir surface at present and under design storm conditions, CCR slurry level and CCR waste water level, and any identifiable natural or manmade features which could affect operation of the CCR surface impoundment.

(8) A description of the type and purpose of existing or proposed instrumentation.

(9) Graphs showing area-capacity curves.

(10) The hazard potential classification for which the facility is designed and a detailed explanation of the basis for this classification.

(11) A description of the spillway and diversion design features and capacities and calculations used in their determination.

(12) The computed minimum factor of safety for slope stability of the CCR retaining structure(s) and the analyses used in their determinations.

(13) The construction specifications and provisions for surveillance, maintenance, and repair of the CCR surface impoundment.

(14) General provisions for closure.

(15) A certification by an independent registered professional engineer that the design of the CCR surface impoundment is in accordance with generally accepted engineering standards for the maximum volume of CCR slurry and CCR waste water which can be impounded therein and for the passage of runoff from the design storm which exceeds the capacity of the CCR surface impoundment. The owner or operator shall place the certification in the operating record and on the owner's or operator's publicly accessible internet site and notify the state that these actions have been taken.

(e) Any changes or modifications to the plans for CCR surface impoundments shall be certified by an independent registered professional engineer and provided to the state prior to the initiation of such changes or modifications. The certification required in this paragraph shall be placed on the owner's or operator's publicly accessible internet site.

(f) For CCR surface impoundments classified by as having a high or significant hazard potential, as certified by an independent registered professional engineer, the owner or operator shall develop and maintain in the operating record and on the owner's or operator's publicly accessible internet site, an Emergency Action Plan which: Defines responsible persons and the actions to be taken in the event of a dam-safety emergency; provides contact information for emergency responders; includes a map which delineates the downstream area which would be affected in the event of a dam failure; and includes provisions for an annual face-to-face meeting or exercise between representatives of the facility owner and the local emergency responders.

§§ 257.73–257.79 [Reserved]

Operating Criteria

§ 257.80 Air criteria.

(a) CCR surface impoundments and CCR landfills must be managed in a manner that fugitive dusts do not exceed 35 $\mu g/m^3$, unless some alternative standard has been established pursuant to applicable requirements developed under a State Implementation Plan (SIP) approved or promulgated by the Administrator pursuant to section 110 of the Clean Air Act, as amended.

(b) CCR surface impoundments must be managed to control wind dispersal of dusts, consistent with the standard in paragraph (a) of this section.

(c) CCR landfills must be managed to control wind dispersal of dusts, consistent with the standard in paragraph (a). CCRs must be emplaced as conditioned CCRs as defied in paragraph (d) of this section.

(d) For purposes of this section, conditioning means wetting CCRs with water to a moisture content that will prevent wind dispersal, but will not result in free liquids.

(e) Documentation of the measures taken to comply with the requirements of this section must be certified by an independent registered professional engineer and notification provided to the state that the documentation has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

§ 257.81 Run-on and run-off controls.

(a) Owners or operators of all CCR landfills and surface impoundments must design, construct, and maintain:

(1) A run-on control system to prevent flow onto the active portion of the CCR landfill or surface impoundment during the peak discharge from a 24-hour, 25-year storm;

(2) A run-off control system from the active portion of the CCR landfill or surface impoundment to collect and control at least the water volume resulting from a 24-hour, 25-year storm.

(b) The design required in paragraph (a) of this section must be certified by an independent registered professional engineer that the design meets the requirements of this section. The owner or operator must notify the state that the design has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(c) The owner or operator must prepare a report, certified by an independent registered professional engineer, that documents how relevant calculations were made, and how the control systems meet the requirements of this subpart and notify the state that the report has been placed in the operating record and made available to the public on the owner's or operator's publicly accessible internet site.

(d) Run-off from the active portion of the CCR landfill or surface impoundment must be handled in accordance with § 257.3–3.

§ 257.82 Surface water requirements.

(a) CCR landfills and surface impoundments shall not:

(1) Cause a discharge of pollutants into waters of the United States, including wetlands, that violates any requirements of the Clean Water Act, including, but not limited to, the National Pollutant Discharge Elimination System (NPDES) requirements, pursuant to section 402 of the Clean Water Act.

(2) Cause the discharge of a nonpoint source of pollution to waters of the United States, including wetlands, that violates any requirement of an area-wide or State-wide water quality management plan that has been approved under section 208 or 319 of the Clean Water Act, as amended.

(b) [Reserved]

§ 257.83 Surface impoundment inspection requirements.

(a) All existing CCR surface impoundments shall be examined as follows:

(1) At intervals not exceeding 7 days for appearances of structural weakness and other hazardous conditions.

(2) At intervals not exceeding 7 days all instruments shall be monitored.

(3) All inspections required by paragraphs (a)(1) and (2) of this section shall be performed by a qualified person, as defined in paragraph (e) of this section, designated by the person owning or operating the CCR surface impoundment.

(4) All existing CCR surface impoundments shall be inspected

annually by an independent registered professional engineer to assure that the design, operation, and maintenance of the surface impoundment is in accordance with generally accepted engineering standards. The owner or operator must notify the state that a certification by the independent registered professional engineer that the design, operation, and maintenance of the surface impoundment is in accordance with generally accepted engineering standards has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(b) When a potentially hazardous condition develops, the person owning or operating the CCR surface impoundment shall immediately:

(1) Take action to eliminate the potentially hazardous condition;

(2) Notify potentially affected persons and state and local first responders;

(3) Notify and prepare to evacuate, if necessary, all personnel from the owner or operator's property which may be affected by the potentially hazardous conditions; and

(4) Direct a qualified person to monitor all instruments and examine the structure at least once every eight hours, or more often as required by an authorized representative of the state.

(c) After each inspection and instrumentation monitoring referred to in paragraphs (a) and (b) of this section, each qualified person who conducted all or any part of the inspection or instrumentation monitoring shall promptly record the results of such inspection or instrumentation monitoring in a book which shall be available in the operating record and such qualified person shall also promptly report the results of the inspection or monitoring to the state. A report of each inspection and instrumentation monitoring shall also be placed on the owner's or operator's publicly accessible internet site.

(d) All inspection and instrumentation monitoring reports recorded in accordance with paragraph (c) of this section shall include a report of the action taken to abate hazardous conditions and shall be promptly signed by the person designated by the owner or operator as responsible for health and safety at the owner or operator's facility.

(e) The qualified person or persons referred to in this section shall be trained to recognize specific signs of structural instability and other hazardous conditions by visual observation and, if applicable, to monitor instrumentation.

§ 257.84 Recordkeeping requirements.

(a) The owner or operator of a CCR landfill or surface impoundment must record and retain near the facility in an operating record and on the owner's or operator's publicly accessible internet site, all records, reports, studies or other documentation required to demonstrate compliance with §§ 257.60 through 257.83 and 257.90 through 257.101.

(b) Except as provided in paragraph (c) of this section, every twelfth month following [the effective date of the final rule] for CCR surface impoundments addressed under § 257.71, and every twelfth month following the date of the initial plan for the design (including lateral expansions), construction, and maintenance of the surface impoundments addressed under § 257.72(b), the owner or operator of such CCR surface impoundments that have not been closed in accordance with § 257.100 shall place in the operating record and on the owner's or operator's publicly accessible internet site, a report containing the following information. The owner or operator shall notify the state that the report has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(1) Changes in the geometry of the impounding structure for the reporting period.

(2) Location and type of installed instruments and the maximum and minimum recorded readings of each instrument for the reporting period.

(3) The minimum, maximum, and present depth and elevation of the impounded water, sediment, or slurry for the reporting period.

(4) Storage capacity of the impounding structure.

(5) The volume of the impounded water, sediment, or slurry at the end of the reporting period.

(6) Any other change which may have affected the stability or operation of the impounding structure that has occurred during the reporting period.

(7) A certification by an independent registered professional engineer that all construction, operation, and maintenance were in accordance with the approved plan.

(c) A report is not required under this section when the owner or operator provides the state with a certification by an independent registered professional engineer that there have been no changes under paragraphs (b)(1) through (b)(6) of this section to the surface impoundment. However, a report containing the information set out in paragraph (b) of this section shall be placed in the operating record and on the owner's or operator's publicly accessible internet site and notification submitted to the state at least every 5 years.

§§ 257.85–257.89 [Reserved]

Groundwater Monitoring and Corrective Action

§ 257.90 Applicability.

(a) Owners and operators of all CCR landfills, surface impoundments subject to this subpart must comply with the groundwater monitoring requirements according to the following schedule:

(1) Existing CCR landfills and surface impoundments must comply with the groundwater monitoring requirements specified in §§ 257.91 through 257.95 within [one year after the effective date of the final rule];

(2) New CCR landfills and surface impoundments must comply with the groundwater monitoring requirements specified in §§ 257.91 through 257.95 before CCR can be disposed of in the CCR landfill or surface impoundment.

(b) The owner or operator must notify the state once each year throughout the active life and post-closure care period that the CCR landfill or surface impoundment is in compliance with the groundwater monitoring and corrective action provisions of this subpart.

(c) Once established at a CCR landfill or surface impoundment, groundwater monitoring shall be conducted throughout the active life and post-closure care period of that CCR landfill or surface impoundment as specified in § 257.101.

§ 257.91 Groundwater monitoring systems.

(a) A groundwater monitoring system must be installed that consists of a sufficient number of wells, installed at appropriate locations and depths, to yield groundwater samples from the uppermost aquifer (as defined in § 257.41) that:

(1) Represent the quality of background groundwater that has not been affected by leakage from a CCR landfill or surface impoundment. A determination of background quality may include sampling of wells that are not hydraulically upgradient of the CCR management area where:

(i) Hydrogeologic conditions do not allow the owner or operator to determine what wells are hydraulically upgradient; or

(ii) Sampling at other wells will provide an indication of background groundwater quality that is as representative or more representative than that provided by the upgradient wells; and

(2) Represent the quality of groundwater passing the waste

boundary. The downgradient monitoring system must be installed at the waste boundary that ensures detection of groundwater contamination in the uppermost aquifer.

(b) The groundwater monitoring system must include at a minimum one up gradient and three downgradient wells.

(c) A multiunit groundwater monitoring system may be installed instead of separate groundwater monitoring systems for each CCR landfill or surface impoundment when the facility has several units, provided the multi-unit groundwater monitoring system meets the requirement of § 257.91(a) and will be as protective of human health and the environment as individual monitoring systems for each CCR landfill or surface impoundment, based on the following factors:

(1) Number, spacing, and orientation of the CCR landfill or surface impoundment;

(2) Hydrogeologic setting;

(3) Site history;

(4) Engineering design of the CCR landfill or surface impoundment; and

(d) Monitoring wells must be cased in a manner that maintains the integrity of the monitoring well bore hole. This casing must be screened or perforated and packed with gravel or sand, where necessary, to enable collection of groundwater samples. The annular space (*i.e.,* the space between the bore hole and well casing) above the sampling depth must be sealed to prevent contamination of samples and the groundwater.

(1) The owner or operator of the CCR landfill or surface impoundment must notify the state that the design, installation, development, and decommission of any monitoring wells, piezometers and other measurement, sampling, and analytical devices documentation has been placed in the operating record and on the owner's or operator's publicly accessible internet site; and

(2) The monitoring wells, piezometers, and other measurement, sampling, and analytical devices must be operated and maintained so that they perform to design specifications throughout the life of the monitoring program.

(e) The number, spacing, and depths of monitoring systems shall be:

(1) Determined based upon site-specific technical information that must include thorough characterization of:

(i) Aquifer thickness, groundwater flow rate, groundwater flow direction including seasonal and temporal fluctuations in groundwater flow; and

(ii) Saturated and unsaturated geologic units and fill materials overlying the uppermost aquifer, materials comprising the uppermost aquifer, and materials comprising the confining unit defining the lower boundary of the uppermost aquifer; including, but not limited to: thicknesses, stratigraphy, lithology, hydraulic conductivities, porosities and effective porosities.

(2) Certified by an independent registered professional engineer or hydrologist. Within 14 days of this certification, the owner or operator must notify the state that the certification has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

§ 257.92 [Reserved]

§ 257.93 Groundwater sampling and analysis requirements.

(a) The groundwater monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide an accurate representation of groundwater quality at the background and downgradient wells installed in compliance with § 257.91. The owner or operator of the CCR landfill or surface impoundment must notify the State that the sampling and analysis program documentation has been placed in the operating record and on the owner's or operator's publicly accessible internet site and the program must include procedures and techniques for:

(1) Sample collection;

(2) Sample preservation and shipment;

(3) Analytical procedures;

(4) Chain of custody control; and

(5) Quality assurance and quality control.

(b) The groundwater monitoring program must include sampling and analytical methods that are appropriate for groundwater sampling and that accurately measure hazardous constituents and other monitoring parameters in groundwater samples. Groundwater samples shall not be field-filtered prior to laboratory analysis.

(c) The sampling procedures and frequency must be protective of human health and the environment.

(d) Groundwater elevations must be measured in each well immediately prior to purging, each time groundwater is sampled. The owner or operator of the CCR landfill or surface impoundment must determine the rate and direction of groundwater flow each time groundwater is sampled. Groundwater elevations in wells which monitor the same CCR management area must be measured within a period of time short enough to avoid temporal variations in groundwater flow which could preclude accurate determination of groundwater flow rate and direction.

(e) The owner or operator of the CCR landfill or surface impoundment must establish background groundwater quality in a hydraulically upgradient or background well(s) for each of the monitoring parameters or constituents required in the particular groundwater monitoring program that applies to the CCR landfill or surface impoundment, as determined under § 257.94(a) or § 257.95(a). Background groundwater quality may be established at wells that are not located hydraulically upgradient from the CCR landfill or surface impoundment if it meets the requirements of § 257.91(a)(1).

(f) The number of samples collected to establish groundwater quality data must be consistent with the appropriate statistical procedures determined pursuant to paragraph (g) of this section. The sampling procedures shall be those specified under § 257.94(b) for detection monitoring, § 257.95(b) and (c) for assessment monitoring, and § 257.96(b) for corrective action.

(g) The owner or operator of the CCR landfill or surface impoundment must specify in the operating record and on the owner's or operator's publicly accessible Internet site, one of the following statistical methods to be used in evaluating groundwater monitoring data for each hazardous constituent. The statistical test chosen shall be conducted separately for each hazardous constituent in each well.

(1) A parametric analysis of variance (ANOVA) followed by multiple comparison procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent.

(2) An analysis of variance (ANOVA) based on ranks followed by multiple comparison procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's median and the background median levels for each constituent.

(3) A tolerance or prediction interval procedure in which an interval for each constituent is established from the distribution of the background data, and the level of each constituent in each compliance well is compared to the upper tolerance or prediction limit.

(4) A control chart approach that gives control limits for each constituent.

(5) Another statistical test method that meets the performance standards of paragraph (h) of this section. The owner or operator of the CCR landfill or surface impoundment must place a justification for this alternative in the operating record and on the owner's or operator's publicly accessible internet site and notify the state of the use of this alternative test. The justification must demonstrate that the alternative method meets the performance standards of paragraph (h) of this section.

(h) Any statistical method chosen under paragraph (g) of this section shall comply with the following performance standards, as appropriate:

(1) The statistical method used to evaluate groundwater monitoring data shall be appropriate for the distribution of chemical parameters or hazardous constituents. If the distribution of the chemical parameters or hazardous constituents is shown by the owner or operator of the CCR landfill or surface impoundment to be inappropriate for a normal theory test, then the data should be transformed or a distribution-free theory test should be used. If the distributions for the constituents differ, more than one statistical method may be needed.

(2) If an individual well comparison procedure is used to compare an individual compliance well constituent concentration with background constituent concentrations or a groundwater protection standard, the test shall be done at a Type I error level no less than 0.01 for each testing period. If a multiple comparison procedure is used, the Type I experiment wise error rate for each testing period shall be no less than 0.05; however, the Type I error of no less than 0.01 for individual well comparisons must be maintained. This performance standard does not apply to tolerance intervals, prediction intervals, or control charts.

(3) If a control chart approach is used to evaluate groundwater monitoring data, the specific type of control chart and its associated parameter values shall be protective of human health and the environment. The parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(4) If a tolerance interval or a predictional interval is used to evaluate groundwater monitoring data, the levels of confidence and, for tolerance intervals, the percentage of the population that the interval must contain, shall be protective of human health and the environment. These parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(5) The statistical method shall account for data below the limit of detection with one or more statistical procedures that are protective of human health and the environment. Any practical quantitation limit (pql) that is used in the statistical method shall be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions that are available to the facility.

(6) If necessary, the statistical method shall include procedures to control or correct for seasonal and spatial variability as well as temporal correlation in the data.

(i) The owner or operator of the CCR landfill or surface impoundment must determine whether or not there is a statistically significant increase over background values for each parameter or constituent required in the particular groundwater monitoring program that applies to the CCR landfill or surface impoundment, as determined under §§ 257.94(a) or 257.95(a).

(1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the groundwater quality of each parameter or constituent at each monitoring well designated pursuant to § 257.91(a)(2) to the background value of that constituent, according to the statistical procedures and performance standards specified under paragraphs (g) and (h) of this section.

(2) Within a reasonable period of time after completing sampling and analysis, the owner or operator of the CCR landfill or surface impoundment must determine whether there has been a statistically significant increase over background at each monitoring well.

§ 257.94 Detection monitoring program.

(a) Detection monitoring is required at CCR landfills and surface impoundments at all groundwater monitoring wells. At a minimum, a detection monitoring program must include monitoring for the parameters listed in Appendix III to this part.

(b) The monitoring frequency for all parameters listed in Appendix III to this part shall be at least semiannual during the active life of the CCR landfill or surface impoundment (including closure) and the post-closure period. A minimum of four independent samples from each background and downgradient well must be collected and analyzed for the Appendix III parameters during the first semiannual sampling event.

(c) At least one sample from each background and downgradient well must be collected and analyzed during subsequent semiannual sampling events.

(d) If the owner or operator of the CCR landfill or surface impoundment determines, pursuant to § 257.93(g) that there is a statistically significant increase over background for one or more of the parameters listed in Appendix III to this part at any monitoring well at the waste boundary specified under § 257.91(a)(2), the owner or operator:

(1) Must, within 14 days of this finding, place a notice in the operating record and on the owner's or operator's publicly accessible internet site indicating which parameters have shown statistically significant changes from background levels, and notify the state that this notice was placed in the operating record and on the owner's or operator's publicly accessible internet site; and

(2) Must establish an assessment monitoring program meeting the requirements of § 257.95 of this part within 90 days except as provided for in paragraph (c)(3) of this section.

(3) The owner/operator may demonstrate that a source other than the CCR landfill or surface impoundment caused the statistically significant increase or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. A report documenting this demonstration must be certified by an independent registered professional engineer or hydrologist and be placed in the operating record and on the owner's or operator's publicly accessible internet site and the state notified of this finding. If a successful demonstration is made and documented, the owner or operator of the CCR landfill or surface impoundment may continue detection monitoring as specified in this section. If, after 90 days, a successful demonstration is not made, the owner or operator of the CCR landfill or surface impoundment must initiate an assessment monitoring program as required in § 257.95.

§ 257.95 Assessment monitoring program.

(a) Assessment monitoring is required whenever a statistically significant increase over background has been detected for one or more of the constituents listed in the Appendix III to this part.

(b) Within 90 days of triggering an assessment monitoring program, and annually thereafter, the owner or operator of the CCR landfill or surface impoundment must sample and analyze the groundwater for all constituents identified in Appendix IV to this part. A minimum of one sample from each downgradient well must be collected and analyzed during each sampling event. For any constituent detected in the downgradient wells as a result of the complete Appendix IV analysis, a minimum of four independent samples from each well (background and downgradient) must be collected and analyzed to establish background for the constituents.

(c) After obtaining the results from the initial or subsequent sampling events required in paragraph (b) of this section, the owner or operator of the CCR landfill or surface impoundment must:

(1) Within 14 days, place a notice in the operating record and on the owner's or operator's publicly accessible internet site identifying the Appendix IV constituents that have been detected and notify the state that this notice has been placed in the operating record and on the owner's or operator's publicly accessible internet site;

(2) Within 90 days, and on at least a semiannual basis thereafter, resample all wells specified by § 257.91(a), conduct analyses for all parameters in Appendix III to this part and for those constituents in Appendix IV to this part that are detected in response to paragraph (b) of this section, and record their concentrations in the facility operating record and place the results on the owner's or operator's publicly accessible internet site. At least one sample from each well (background and downgradient) must be collected and analyzed during these sampling events.

(3) Establish background concentrations for any constituents detected pursuant to paragraph (b) or (c)(2) of this section; and

(4) Establish groundwater protection standards for all constituents detected pursuant to paragraph (b) or (c) of this section. The groundwater protection standards shall be established in accordance with paragraphs (g) or (h) of this section.

(d) If the concentrations of all Appendix IV constituents are shown to be at or below background values, using the statistical procedures in § 257.93(g), for two consecutive sampling events, the owner or operator of the CCR landfill or surface impoundment must place that information in the operating record and on the owner's or operator's publicly accessible internet site and notify the state of this finding and may return to detection monitoring.

(e) If the concentrations of any Appendix IV constituents are above background values, but all concentrations are below the groundwater protection standard established under paragraphs (g) or (h) of this section, using the statistical procedures in § 257.93(g), the owner or operator must continue assessment monitoring in accordance with this section.

(f) If one or more Appendix IV constituents are detected at statistically significant levels above the groundwater protection standard established under paragraphs (g) or (h) of this section in any sampling event, the owner or operator must, within 14 days of this finding, place a notice in the operating record and on the owner's or operator's publicly accessible internet site identifying the Appendix IV constituents that have exceeded the groundwater protection standard and notify the state and all appropriate local government officials that the notice has been placed in the operating record and on the owner's or operator's publicly accessible internet site. The owner or operator of the CCR landfill or surface impoundment also must:

(1)(i) Characterize the nature and extent of the release by installing additional monitoring wells as necessary;

(ii) Install at least one additional monitoring well at the facility boundary in the direction of contaminant migration and sample this well in accordance with paragraph (c)(2) of this section;

(iii) Notify all persons who own the land or reside on the land that directly overlies any part of the plume of contamination if contaminants have migrated off-site if indicated by sampling of wells in accordance with paragraph (f)(1) of this section; and

(iv) Initiate an assessment of corrective measures as required by § 257.96 of this part within 90 days; or

(2) May demonstrate that a source other than the CCR landfill or surface impoundment caused the contamination, or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. A report documenting this demonstration must be certified by an independent registered professional engineer or hydrologist and placed in the operating record and on the owner's or operator's publicly accessible internet site, and the state notified of this action. If a successful demonstration is made the owner or operator of the CCR landfill or surface impoundment must continue monitoring in accordance with the assessment monitoring program pursuant to this section, and may return to detection monitoring if the Appendix IV constituents are at or below background as specified in paragraph (d) of this section. Until a successful demonstration is made, the owner or operator of the CCR landfill or surface impoundment must comply with paragraph (f) of this section including initiating an assessment of corrective measures.

(g) The owner or operator of the CCR landfill or surface impoundment must establish a groundwater protection standard for each Appendix IV constituent detected in the groundwater. The groundwater protection standard shall be:

(1) For constituents for which a maximum contaminant level (MCL) has been promulgated under section 1412 of the Safe Drinking Water Act (codified) under 40 CFR part 141, the MCL for that constituent;

(2) For constituents for which MCLs have not been promulgated, the background concentration for the constituent established from wells in accordance with § 257.91(a)(1); or

(3) For constituents for which the background level is higher than the MCL identified under paragraph (g)(1) of this section or health based levels identified under paragraph (h)(1) of this section, the background concentration.

(h) The owner or operator may establish an alternative groundwater protection standard for constituents for which MCLs have not been established provided that the alternative groundwater protection standard has been certified by an independent registered professional engineer and the state has been notified that the alternative groundwater protection standard has been placed in the operating record and on the owner's or operator's publicly accessible internet site. These groundwater protection standards shall be appropriate health based levels that satisfy the following criteria:

(1) The level is derived in a manner consistent with Agency guidelines for assessing the health risks of environmental pollutants;

(2) The level is based on scientifically valid studies conducted in accordance with the Toxic Substances Control Act Good Laboratory Practice Standards (40 CFR part 792) or equivalent;

(3) For carcinogens, the level represents a concentration associated with an excess lifetime cancer risk level

(due to continuous lifetime exposure) within the 1×10^{-4} to 1×10^{-6} range; and

(4) For systemic toxicants, the level represents a concentration to which the human population (including sensitive subgroups) could be exposed to on a daily basis that is likely to be without appreciable risk of deleterious effects during a lifetime. For purposes of this subpart, *systemic toxicants* include toxic chemicals that cause effects other than cancer or mutation.

(i) In establishing groundwater protection standards under paragraph (h) of this section, the owner or operator of the CCR landfill or surface impoundment may consider the following:

(1) Multiple contaminants in the groundwater;

(2) Exposure threats to sensitive environmental receptors; and

(3) Other site-specific exposure or potential exposure to groundwater.

§ 257.96 Assessment of corrective measures.

(a) Within 90 days of finding that any of the constituents listed in Appendix IV to this part have been detected at a statistically significant level exceeding the groundwater protection standards defined under § 257.95 (g) or (h) of this part, the owner or operator of the CCR landfill or surface impoundment must initiate an assessment of corrective measures. Such an assessment must be completed within 90 days.

(b) The owner or operator of the CCR landfill or surface impoundment must continue to monitor in accordance with the assessment monitoring program as specified in § 257.95.

(c) The assessment shall include an analysis of the effectiveness of potential corrective measures in meeting all of the requirements and objectives of the remedy as described under § 257.97, addressing at least the following:

(1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;

(2) The time required to begin and complete the remedy;

(3) The costs of remedy implementation; and

(4) The institutional requirements such as state or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

(d) The owner or operator of the CCR landfill or surface impoundment must provide notification of the corrective measures assessment to the state and the public.

(e) The owner or operator must discuss the results of the corrective measures assessment, prior to the selection of remedy, in a public meeting with interested and affected parties.

§ 257.97 Selection of remedy.

(a) Based on the results of the corrective measures assessment conducted under § 257.96, the owner or operator of the CCR landfill or surface impoundment must select a remedy that, at a minimum, meets the standards listed in paragraph (b) of this section. The owner or operator of the CCR landfill or surface impoundment must notify the state and the public within 14 days of selecting a remedy, that a report certified by an independent registered professional engineer or hydrologist describing the selected remedy, has been placed in the operating record and on the owner's or operator's publicly accessible internet site, and how it meets the standards in paragraph (b) of this section.

(b) Remedies must:

(1) Be protective of human health and the environment;

(2) Attain the groundwater protection standard as specified pursuant to §§ 257.95 (g) or (h);

(3) Control the source(s) of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of Appendix IV of this part constituents into the environment that may pose a threat to human health or the environment; and

(4) Comply with standards for management of wastes as specified in § 257.98(d).

(c) In selecting a remedy that meets the standards of paragraph (b) of this section, the owner or operator of the CCR landfill or surface impoundment shall consider the following evaluation factors:

(1) The long- and short-term effectiveness and protectiveness of the potential remedy(s), along with the degree of certainty that the remedy will prove successful based on consideration of the following:

(i) Magnitude of reduction of existing risks;

(ii) Magnitude of residual risks in terms of likelihood of further releases due to CCRs remaining following implementation of a remedy;

(iii) The type and degree of long-term management required, including monitoring, operation, and maintenance;

(iv) Short-term risks that might be posed to the community, workers, or the environment during implementation of such a remedy, including potential threats to human health and the environment associated with excavation, transportation, and redisposal of containment;

(v) Time until full protection is achieved;

(vi) Potential for exposure of humans and environmental receptors to remaining wastes, considering the potential threat to human health and the environment associated with excavation, transportation, redisposal, or containment;

(vii) Long-term reliability of the engineering and institutional controls; and

(viii) Potential need for replacement of the remedy.

(2) The effectiveness of the remedy in controlling the source to reduce further releases based on consideration of the following factors:

(i) The extent to which containment practices will reduce further releases;

(ii) The extent to which treatment technologies may be used.

(3) The ease or difficulty of implementing a potential remedy(s) based on consideration of the following types of factors:

(i) Degree of difficulty associated with constructing the technology;

(ii) Expected operational reliability of the technologies;

(iii) Need to coordinate with and obtain necessary approvals and permits from other agencies;

(iv) Availability of necessary equipment and specialists; and

(v) Available capacity and location of needed treatment, storage, and disposal services.

(4) The degree to which community concerns are addressed by a potential remedy(s).

(d) The owner or operator of the CCR landfill or surface impoundment shall specify as part of the selected remedy a schedule(s) for initiating and completing remedial activities. Such a schedule must require the initiation of remedial activities within a reasonable period of time taking into consideration the factors set forth in paragraphs (d) (1) through (8) of this section. The owner or operator of the CCR landfill or surface impoundment must consider the following factors in determining the schedule of remedial activities:

(1) Extent and nature of contamination;

(2) Reasonable probabilities of remedial technologies in achieving compliance with the groundwater protection standards established under § 257.95 (f) or (g) and other objectives of the remedy;

(3) Availability of treatment or disposal capacity for CCRs managed during implementation of the remedy;

(4) Desirability of utilizing technologies that are not currently available, but which may offer significant advantages over already available technologies in terms of effectiveness, reliability, safety, or ability to achieve remedial objectives;

(5) Potential risks to human health and the environment from exposure to contamination prior to completion of the remedy;

(6) Resource value of the aquifer including:

(i) Current and future uses;

(ii) Proximity and withdrawal rate of users;

(iii) Groundwater quantity and quality;

(iv) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to CCR constituents;

(v) The hydrogeologic characteristic of the facility and surrounding land;

(vi) Groundwater removal and treatment costs; and

(vii) The cost and availability of alternative water supplies.

(7) Other relevant factors.

(e) The owner or operator of the CCR landfill or surface impoundment may determine that remediation of a release of an Appendix IV constituent from a CCR landfill or surface impoundment is not necessary if the owner or operator of the CCR landfill or surface impoundment demonstrates the following, and notifies the state that the demonstration, certified by an independent registered professional engineer or hydrologist, has been placed in the operating record and on the owner's or operator's publicly accessible internet site:

(1) The groundwater is additionally contaminated by substances that have originated from a source other than a CCR landfill or surface impoundment and those substances are present in concentrations such that cleanup of the release from the CCR landfill or surface impoundment would provide no significant reduction in risk to actual or potential receptors; or

(2) The constituent(s) is present in groundwater that:

(i) Is not currently or reasonably expected to be a source of drinking water; and

(ii) Is not hydraulically connected with waters to which the hazardous constituents are migrating or are likely to migrate in a concentration(s) that would exceed the ground-water protection standards established under § 257.95 (g) or (h); or

(3) Remediation of the release(s) is technically impracticable; or

(4) Remediation results in unacceptable cross-media impacts.

(f) A determination by the owner or operator pursuant to paragraph (e) of this section shall not affect the obligation of the owner or operator to undertake source control measures or other measures that may be necessary to eliminate or minimize further releases to the groundwater, to prevent exposure to the groundwater, or to remediate the groundwater to concentrations that are reasonable and significantly reduce threats to human health or the environment.

§ 257.98 Implementation of the corrective action program.

(a) Based on the schedule established under § 257.97(d) for initiation and completion of remedial activities the owner or operator must:

(1) Establish and implement a corrective action groundwater monitoring program that:

(i) At a minimum, meets the requirements of an assessment monitoring program under § 257.95;

(ii) Indicates the effectiveness of the corrective action remedy; and

(iii) Demonstrates compliance with ground-water protection standard pursuant to paragraph (e) of this section.

(2) Implement the corrective action remedy selected under § 257.97; and

(3) Take any interim measures necessary to ensure the protection of human health and the environment. Interim measures should, to the greatest extent practicable, be consistent with the objectives of and contribute to the performance of any remedy that may be required pursuant to § 257.97. The following factors must be considered by an owner or operator in determining whether interim measures are necessary:

(i) Time required to develop and implement a final remedy;

(ii) Actual or potential exposure of nearby populations or environmental receptors to any of the Appendix IV constituents;

(iii) Actual or potential contamination of drinking water supplies or sensitive ecosystems;

(iv) Further degradation of the groundwater that may occur if remedial action is not initiated expeditiously;

(v) Weather conditions that may cause any of the Appendix IV of this part constituents to migrate or be released;

(vi) Potential for exposure to any of the Appendix IV of this part constituents as a result of an accident or failure of a container or handling system; and

(vii) Other situations that may pose threats to human health and the environment.

(b) An owner or operator of the CCR landfill or surface impoundment may determine, based on information developed after implementation of the remedy has begun or other information, that compliance with requirements of § 257.97(b) are not being achieved through the remedy selected. In such cases, the owner or operator of the CCR landfill or surface impoundment must implement other methods or techniques that could reasonably achieve compliance with the requirements, unless the owner or operator makes the determination under paragraph (c) of this section.

(c) If the owner or operator determines that compliance with requirements under § 257.97(b) cannot be reasonably achieved with any currently available methods, the owner or operator of the CCR landfill or surface impoundment must:

(1) Obtain certification of an independent registered professional engineer or hydrologist that compliance with requirements under § 257.97(b) cannot be reasonably achieved with any currently available methods;

(2) Implement alternate measures to control exposure of humans or the environment to residual contamination, as necessary to protect human health and the environment; and

(3) Implement alternate measures for control of the sources of contamination or for removal or decontamination of equipment, units, devices, or structures that are consistent with the overall objective of the remedy.

(4) Notify the state within 14 days that a report, including the certification required in paragraph (c)(1) of this section, justifying the alternative measures prior to implementing the alternative measures has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(d) All CCRs that are managed pursuant to a remedy required under § 257.97, or an interim measure required under paragraph (a)(3) of this section, shall be managed in a manner:

(1) That is protective of human health and the environment; and

(2) That complies with applicable RCRA requirements.

(e) Remedies selected pursuant to § 257.97 shall be considered complete when:

(1) The owner or operator of the CCR landfill or surface impoundment complies with the groundwater protection standards established under §§ 257.95 (h) or (i) at all points within the plume of contamination that lie beyond the groundwater monitoring well system established under § 257.91(a).

(2) Compliance with the groundwater protection standards established under §§ 257.95 (h) or (h) has been achieved by demonstrating that concentrations of Appendix IV constituents have not exceeded the groundwater protection standard(s) for a period of three consecutive years using the statistical procedures and performance standards in § 257.93 (g) and (h).

(3) All actions required to complete the remedy have been satisfied.

(f) Upon completion of the remedy, the owner or operator of the CCR landfill or surface impoundment must notify the state within 14 days that a certification that the remedy has been completed in compliance with the requirements of paragraph (e) of this section has been placed in the operating record and on the owner's or operator's publicly accessible internet site. The certification must be signed by the owner or operator and by an independent registered professional engineer or hydrologist.

§ 257.99 [Reserved]

Closure and Post-Closure Care

§ 257.100 Closure criteria.

(a) Prior to closure of any CCR landfill or surface impoundment covered by this subpart, the owner or operator shall submit to the state, a plan for closure of the unit based on recognized and generally accepted good engineering practices and certified by an independent registered professional engineer. The closure plan shall be consistent with paragraph (g) of this section and provide for major slope stability, include a schedule for the plan's implementation and contain provisions to preclude the probability of future impoundment of water, sediment, or slurry. The closure plan shall be placed in the operating record and on the owner's or operator's publicly accessible internet site.

(b) Closure of a CCR landfill or surface impoundment may be accomplished with CCRs in place or through CCR removal and decontamination of all areas affected by releases from the CCR landfill or surface impoundment. CCR removal and decontamination are complete when constituent concentrations throughout the CCR landfill or surface impoundment and any areas affected by releases from the CCR landfill or surface impoundment do not exceed numeric cleanup levels for those constituents found in the CCRs established by the state in which the CCR landfill or surface impoundment is located.

(c) At closure, the owner or operator of a surface impoundment must:

(1) Eliminate free liquids by removing liquid wastes or solidifying the remaining wastes and waste residues;

(2) Stabilize remaining wastes to a bearing capacity sufficient to support the final cover; and

(3) Cover the surface impoundment with a final cover designed and constructed to:

(i) Provide long-term minimization of the migration of liquids through the closed impoundment;

(ii) Function with minimum maintenance; and

(iii) Promote drainage and minimize erosion or abrasion of the cover;

(iv) Accommodate settling and subsidence so that the cover's integrity is maintained; and

(v) Have a final cover system that meets the requirements of subsection (d).

(d) For closure with CCRs in place, a final cover system must be installed at all CCR landfills and surface impoundments that is designed to minimize infiltration and erosion. The final cover system must be designed and constructed to:

(1) Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-5} cm/sec, whichever is less, and

(2) Minimize infiltration through the closed CCR landfill or surface impoundment by the use of an infiltration layer that contains a minimum 18-inches of earthen material, and

(3) Minimize erosion of the final cover by the use of an erosion layer that contains a minimum 6-inches of earthen material that is capable of sustaining native plant growth, and

(4) Minimize the disruption of the final cover through a design that accommodates settling and subsidence.

(e) The owner or operator of the CCR landfill or surface impoundment may select an alternative final cover design, provided the alternative cover design is certified by an independent registered professional engineer and notification is provided to the state and the EPA Regional Administrator that the alternative cover design has been placed in the operating record and on the owner's or operator's publicly accessible internet site. The alternative final cover design must include:

(1) An infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer specified in paragraphs (d)(1) and (d)(2) of this section, and

(2) An erosion layer that provides equivalent protection from wind and water erosion as the erosion layer specified in paragraph (d)(3) of this section.

(f) The design of the final cover system shall be placed on the owner's or operator's publicly accessible internet site.

(g) The owner or operator of the CCR landfill or surface impoundment must prepare a written closure plan that describes the steps necessary to close the CCR landfill or surface impoundment at any point during the active life in accordance with the cover design requirements in paragraph (d) or (e) of this section, as applicable. The closure plan, at a minimum, must include the following information:

(1) A description of the final cover, designed in accordance with paragraph (d) or (e) of this section and the methods and procedures to be used to install the cover;

(2) An estimate of the largest area of the CCR landfill or surface impoundment ever requiring a final cover as required under paragraph (d) or (e) of this section at any time during the active life;

(3) An estimate of the maximum inventory of CCRs ever on-site over the active life of the CCR landfill or surface impoundment; and

(4) A schedule for completing all activities necessary to satisfy the closure criteria in this section.

(h) The owner or operator of the CCR landfill or surface impoundment must notify the state that a closure plan, certified by an independent registered professional engineer, has been prepared and placed in the operating record and on the owner's or operator's publicly accessible internet site no later than the effective date of this part, or by the initial receipt of CCRs, whichever is later.

(i) Prior to beginning closure of each CCR landfill or surface impoundment as specified in paragraph (j) of this section, an owner or operator of a CCR landfill or surface impoundment must notify the state that a notice of the intent to close the unit has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(j) The owner or operator of the CCR landfill or surface impoundment must begin closure activities no later than 30 days after the date on which the CCR landfill or surface impoundment receives the known final receipt of CCR or, if the CCR landfill or surface impoundment has remaining capacity and there is a reasonable likelihood that the CCR landfill or surface impoundment will receive additional CCRs, no later than one year after the most recent receipt of CCRs.

(k) The owner or operator of the CCR landfill or surface impoundment must complete closure activities in accordance with the closure plan within 180 days following the beginning of closure as specified in paragraph (j) of this section.

(l) Following closure of each CCR landfill or surface impoundment, the owner or operator of the CCR landfill or surface impoundment must notify the state that a certification, signed by an independent registered professional engineer, verifying that closure has been completed in accordance with the closure plan and the requirements of this subpart that has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(m)(1) Following closure of all CCR landfills or surface impoundments, the owner or operator of the CCR landfill or surface impoundment must record a notation on the deed to the property, or some other instrument that is normally examined during title search, and notify the state that the notation has been recorded and a copy has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(2) The notation on the deed must in perpetuity notify any potential purchaser of the property that:

(i) The land has been used as a CCR landfill or surface impoundment; and

(ii) Its use is restricted under § 257.101(c)(3).

§ 257.101 Post-closure care requirements.

(a) Following closure of each CCR landfill or surface impoundment, the owner or operator must conduct post-closure care. Post-closure care must be conducted for 30 years, except as provided under paragraph (b) of this section, and consist of at least the following:

(1) Maintaining the integrity and effectiveness of any final cover, including making repairs to the cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover;

(2) Maintaining the integrity and effectiveness of the leachate collection and removal system and operating the leachate collection and removal system in accordance with the requirements of §§ 257.70, 257.71, and 257.72.

(3) Maintaining the groundwater monitoring system and monitoring the groundwater in accordance with the requirements of §§ 257.91 through 257.98 of this part.

(b) The length of the post-closure care period may be:

(1) Decreased if the owner or operator of the CCR landfill or surface impoundment demonstrates that the reduced period is sufficient to protect human health and the environment and this demonstration is certified by an independent registered professional engineer and notice is provided to the state that the demonstration has been placed in the operating record and on the owner's or operator's publicly accessible Internet site; or

(2) Increased if the owner or operator of the CCR landfill or surface impoundment determines that a lengthened period is necessary to protect human health and the environment.

(c) The owner or operator of the CCR landfill or surface impoundment must prepare a written post-closure plan, certified by an independent registered professional engineer that includes, at a minimum, the following information:

(1) A description of the monitoring and maintenance activities required in paragraph (a) of this section for each CCR landfill or surface impoundment, and the frequency at which these activities will be performed;

(2) Name, address, and telephone number of the person or office to contact about the facility during the post-closure period; and

(3) A description of the planned uses of the property during the post-closure period. Post-closure use of the property shall not disturb the integrity of the final cover, liner(s), or any other components of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements in this subpart. Any other disturbance is allowed if the owner or operator of the CCR landfill or surface impoundment demonstrates that disturbance of the final cover, liner or other component of the containment system, including any removal of CCRs, will not increase the potential threat to human health or the environment. The demonstration must be certified by an independent registered professional engineer, and notification shall be provided to the state that the demonstration has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

(d) The owner or operator of the CCR landfill or surface impoundment must notify the state that a post-closure plan has been prepared and placed in the operating record and on the owner's or operator's publicly accessible internet site no later than the effective date of this rule, or by the initial receipt of CCRs, whichever is later.

(e) Following completion of the post-closure care period for the CCR landfill or surface impoundment, the owner or operator of the CCR landfill or surface impoundment must notify the state that a certification, signed by an independent registered professional engineer, verifying that post-closure care has been completed in accordance with the post-closure plan has been placed in the operating record and on the owner's or operator's publicly accessible internet site.

§§ 257.102–257.109 [Reserved]

6. Add Appendixes III and IV to Part 257 to read as follows:

Appendix III to Part 257—Constituents for Detection Monitoring

Common Name [1]
Boron
Chloride
Conductivity
Fluoride
pH
Sulphate
Sulfide
Total Dissolved Solids

[1] Common names are those widely used in government regulations, scientific publications, and commerce; synonyms exist for many chemicals.

Appendix IV to Part 257—Constituents for Assessment Monitoring

Common Name [1]
Aluminum
Antimony
Arsenic
Barium
Beryllium
Boron
Cadmium
Chloride
Chromium (total)
Copper
Fluoride
Iron
Lead
Manganese
Mercury
Molybdenum
pH
Selenium
Sulphate
Sulfide
Thallium
Total Dissolved Solids

[1] Common names are those widely used in government regulations, scientific publications, and commerce; synonyms exist for many chemicals.

Alternative 2: Co-Proposal Under Authority of Subtitle C

PART 261—IDENTIFICATION AND LISTING OF HAZARDOUS WASTE

6a. The authority citation for part 261 continues to read as follows:

Authority: 42 U.S.C. 6905, 6912(a), 6921, 6922, 6924(y), and 6938.

7. Section 261.4 is amended by revising paragraph (b)(4) to read as follows.

§ 261.4 Exclusions.

* * * * *

(b) * * *

(4)(i) Fly ash, bottom ash, boiler slag, and flue gas emission control wastes, generated primarily from the combustion of coal for the purpose of generating electricity by the electric power sector if the fly ash, bottom ash, boiler slag, and flue gas emission control wastes are beneficially used or placed in minefilling operations. Beneficial Use of Coal Combustion Products (CCPs) means the use of CCPs that provides a functional benefit; replaces the use of an alternative material, conserving natural resources that would otherwise need to be obtained through practices such as extraction; and meets relevant product specifications and regulatory standards (where these are available). CCPs that are used in excess quantities, placed as fill in sand and gravel pits, or used in large scale fill projects, such as for restructuring the landscape, are not considered beneficial uses.

(ii) Fly ash, bottom ash, boiler slag, and flue gas emission control wastes generated primarily from the combustion of coal for the purpose of generating electricity by facilities outside of the electric power sector (*i.e.,* not included in NAICS code 221112).

(iii) Fly ash, bottom ash, boiler slag, and flue gas emission control wastes, generated primarily from the combustion of fossil fuels other than coal, for the purpose of generating electricity, except as provided by § 266.112 of this chapter for facilities that burn or process hazardous waste.

* * * * *

8. Part 261 is amended by adding Subpart F to read as follows.

Subpart F—Special Wastes Subject to Subtitle C Regulations

§ 261.50 General.

(a) The following solid wastes are special wastes subject to regulation under parts 262 through 268, and parts 270, 271, and 124 of this chapter, and to the notification requirements of section 3010 of RCRA,

Industry and EPA special waste No.	Special waste	Hazard code
Coal Combustion Residuals:		
S001	Coal combustion residuals generated by the electric power sector (Electric Utilities and Independent Power Producers).	(T)

(b) For the purposes of the S001 listing, the electric power sector is defined as electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public; *i.e.,* NAICS code 221112 plants. Coal combustion residuals are defined to include fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated by the electric utility industry. This listing does not apply to coal combustion residuals that are:

(1) Uniquely associated wastes as defined in paragraph (c) of this section;

(2) Beneficially used as defined in paragraph (d) of this section;

(3) Placed in minefilling operations;

(4) Generated by facilities outside the electric power sector (*i.e.,* not included in NAICS code 22112); or

(5) Generated from clean-up activities that are conducted as part of a state or federally required clean-up that commenced prior to the effective date of this rule.

(c) Uniquely associated wastes are low-volume wastes other than those defined as coal combustion residuals in paragraph (a) of this section that are related to the coal combustion process. Examples of uniquely associated wastes are precipitation runoff from coal storage piles at the facility, waste coal or coal mill rejects that are not of sufficient quality to burn as fuel, and wastes from cleaning the boilers used to generate steam.

(d) Beneficial Use of Coal Combustion Products (CCPs) means the use of CCPs that provides a functional benefit; replaces the use of an alternative material, conserving natural resources that would otherwise need to be obtained through practices such as extraction; and meets relevant product specifications and regulatory standards (where these are available). CCPs that are used in excess quantities, placed as fill in sand and gravel pits, or used in large scale fill projects, such as for restructuring the landscape, are not considered beneficial uses.

9. Part 261 is amended by adding Appendix X to read as follows.

Appendix X to Part 261—Basis for Listing Special Wastes

EPA special waste No.	Hazardous constituents for which listed
S001	Antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, thallium.

PART 264—STANDARDS FOR OWNERS AND OPERATORS OF HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

10. The authority citation for part 264 continues to read as follows:

Authority: 42 U.S.C. 6905, 6912(a), 6924, and 6925.

11. Section 264.1 is amended by adding paragraph (k) to read as follows:

§ 264.1 Purpose, scope and applicability.

* * * * *

(k) Owners or operators who treat, store or dispose of EPA Special Waste Number S001, also referred to as coal combustion residuals are subject to the requirements of this part, except as specifically provided otherwise in this part. In addition, subpart FF of this part includes additional requirements for the treatment, storage or disposal of EPA Special Waste Number S001.

12. Section 264.140 is amended by revising paragraph (a) to read as follows:

§ 264.140 Applicability.

(a) The requirements of §§ 264.142, 264.143, and 264.147 through 264.151 apply to owners and operators of all hazardous waste facilities and facilities that treat, store or dispose of special wastes, except as provided otherwise in this section, or in § 264.1.

* * * * *

13. Part 264 is amended by adding subpart FF to read as follows:

Subpart FF—Special Requirements for Coal Combustion Residual (S001) Wastes

Subpart FF—Special Requirements for Coal Combustion Residual (S001) Wastes

§ 264.1300 Applicability.

(a) The regulations in this subpart apply to owners or operators of facilities that treat, store or dispose of EPA Special Waste Number S001.

(b) Owners or operators of surface impoundments that cease receiving EPA Special Waste Number S001, must comply with the closure requirements in 40 CFR 265.111 and 40 CFR 265.228. Facilities that have not met these closure requirements by the effective date of this regulation would be subject to the requirements in Parts 260 through 268, and 270 through 272, of this chapter.

§ 264.1301 Definitions.

This section contains definitions for terms that appear throughout this subpart; additional definitions appear in 40 CFR 260.10 or the specific sections to which they apply.

Area-capacity curves means graphic curves which readily show the reservoir water surface area, in acres, at different elevations from the bottom of the reservoir to the maximum water surface, and the capacity or volume, in acre-feet, of the water contained in the reservoir at various elevations.

CCR landfill means a disposal facility or part of a facility where CCRs are placed in or on land and which is not a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit. For purposes of this subpart, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills.

CCR surface impoundment or *impoundment* means a facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), which is designed to hold an accumulation of CCRs containing free liquids, and which is not an injection well. Examples of CCR surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons. CCR surface impoundments are used to receive CCRs that have been sluiced (flushed or mixed with water to facilitate movement), or wastes from wet air pollution control devices, often in addition to other solid wastes.

Coal Combustion Residuals (CCRs) means fly ash, bottom ash, boiler slag, and flue gas desulfurization materials, destined for disposal. CCRs are also known as coal combustion wastes (CCWs) and fossil fuel combustion (FFC) wastes, when destined for disposal.

Existing CCR landfill means a landfill which was in operation or for which construction commenced prior to the effective date of the final rule. A CCR landfill has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill to be completed within a reasonable time.

Existing CCR surface impoundment means a surface impoundment which was in operation or for which construction commenced prior to the effective date of the final rule. A CCR surface impoundment has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which can not be cancelled or modified without substantial loss—for physical construction of the CCR surface impoundment to be completed within a reasonable time.

Factor of safety (Safety factor) means the ratio of the forces tending to resist the failure of a structure to the forces tending to cause such failure as determined by recognized and generally accepted good engineering practices.

Hazard potential means the possible adverse incremental consequences that result from the release of water or stored contents due to failure of a dam (or impoundment) or mis-operation of the dam or appurtenances.

(1) *High hazard potential surface impoundment* means a surface impoundment where failure or mis-operation will probably cause loss of human life.

(2) *Significant hazard potential surface impoundment* means a surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environment damage, disruption of lifeline facilities, or impact other concerns.

(3) *Low hazard potential surface impoundment* means a surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

(4) *Less than low hazard potential surface impoundment* means a surface impoundment not meeting the definitions for High, Significant, or Low Hazard Potential.

Lateral expansion means a horizontal expansion of the waste boundaries of an existing CCR landfill, or CCR surface impoundment made after the effective date of the final rule.

New CCR landfill means a landfill, including lateral expansions, or installation from which there is or may be placement of CCRs without the presence of free liquids, which began operation, or for which the construction commenced after the effective date of the final rule.

New CCR surface impoundment means a surface impoundment, including lateral expansions, or installation from which there is or may be placement of CCRs with the presence of free liquids, which began operation, or for which the construction commenced after the effective date of the final rule.

Probable maximum precipitation means the value for a particular area which represents an envelopment of depth-duration-area rainfall relations for all storm types affecting that area adjusted meteorologically to maximum conditions.

Recognized and generally accepted good engineering practices (RAGAGEPs) means engineering, operation, or maintenance activities based on established codes, standards, published technical reports or recommended practices (RP) or a similar document. RAGAGEPs detail generally approved ways to perform specific engineering, inspection or mechanical integrity activities.

§ 264.1302 Reporting.

(a) Except as provided in paragraph (b) of this section, every twelfth month following the date of the initial plan approval required in § 264.1303, the person owning or operating a CCR surface impoundment that has not been properly closed in accordance with an approved plan shall submit to the Regional Administrator a report containing the following information:

(1) Changes in the geometry of the CCR surface impoundment for the reporting period.

(2) Location and type of installed instruments and the maximum and minimum recorded readings of each instrument for the reporting period.

(3) The minimum, maximum, and present depth and elevation of the CCR slurry and CCR wastewater in the CCR surface impoundment for the reporting period.

(4) The storage capacity of the CCR surface impoundment.

(5) The volume of the CCR slurry and CCR wastewater in the CCR surface impoundment at the end of the reporting period.

(6) Any other change which may have affected the stability or operation of the CCR surface impoundment that has occurred during the reporting period.

(7) A certification by an independent registered professional engineer that all construction, operation, and maintenance are in accordance with the approved plan prepared in accordance with § 264.1303.

(b) A report is not required under this section when the person owning or operating the CCR surface impoundment provides the Regional Administrator with a certification by an independent registered professional engineer that there have been no changes in the operation of the CCR surface impoundment or to any of the parameters previously reported under paragraphs (a)(1) through (a)(6) of this section. However, a report containing the information set out in paragraph (a) of this section shall be submitted to the Regional Administrator at least every 5 years.

§ 264.1303 Surface impoundments.

(a) In addition to the requirements in subpart K of this part, EPA Special Waste No. S001 is subject to the requirements in this section.

(b) Plans for the design, construction, and maintenance of existing CCR surface impoundments shall be required if such a unit can:

(1) Impound CCRs to an elevation of five feet or more above the upstream toe of the structure and can have a storage volume of 20 acre-feet or more; or

(2) Impound CCRs to an elevation of 20 feet or more above the upstream toe of the structure.

(c) Plans required under paragraph (b) of this section shall be submitted in triplicate to the Regional Administrator on or before [date one year after the effective date of the final rule].

(d) A permanent identification marker, at least six feet high and showing the identification number of the CCR surface impoundment as assigned by the Regional Administrator, the name associated with the CCR surface impoundment and the name of the person owning or operating the structure, shall be located on or immediately adjacent to each CCR surface impoundment by [date 60 days after the effective date of the final rule].

(e) The plan specified in paragraph (b) of this section, shall contain at a minimum the following information:

(1) The name and address of the persons owning or operating the CCR surface impoundment; the name associated with the CCR surface impoundment; and the identification number of the CCR surface impoundment as assigned by the Regional Administrator.

(2) The location of the CCR surface impoundment indicated on the most recent USGS 7½ minute or 15 minute topographic quadrangle map, or a topographic map of equivalent scale if a USGS map is not available.

(3) A statement of the purpose for which the CCR surface impoundment is being used.

(4) The name and size in acres of the watershed affecting the CCR surface impoundment.

(5) A description of the physical and engineering properties of the foundation materials on which the CCR surface impoundment is constructed.

(6) A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR surface impoundment; the method of site preparation and construction of each zone of the CCR surface impoundment; the approximate dates of construction, and each successive stage of construction of the CCR surface impoundment; and for existing CCR surface impoundments, such history of construction as may be available, and any record or knowledge of structural instability.

(7) At a scale not to exceed 1 inch = 100 feet, detailed dimensional drawings of the CCR surface impoundment, including a plan view and cross sections of the length and width of the CCR surface impoundment, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the measurement of the minimum vertical distance between the crest of the CCR surface impoundment and the reservoir surface at present and under design storm conditions, CCR slurry level and CCR wastewater level, and other information pertinent to the CCR surface impoundment itself, including any identifiable natural or manmade features which could affect operation of the CCR surface impoundment.

(8) A description of the type and purpose of existing or proposed instrumentation.

(9) Graphs showing area-capacity curves.

(10) The hazard potential classification for which the facility is designed and a detailed explanation of the basis for this classification.

(11) A statement of the runoff attributable to the storm for which the CCR surface impoundment is designed and the calculations used in determining such runoff and the minimum freeboard during the design storm.

(12) A description of the spillway and diversion design features and capacities and calculations used in their determination.

(13) The computed minimum factor of safety for slope stability of the CCR retaining structure(s) and the analyses used in their determinations.

(14) The construction specifications and provisions for surveillance, maintenance, and repair of the CCR surface impoundment.

(15) General provisions for closure.

(16) Such other information pertaining to the CCR surface impoundment which may be requested by the Regional Administrator.

(17) A certification by an independent registered professional engineer that the design of the CCR surface impoundment is in accordance with recognized and generally accepted good engineering practices for the maximum volume of CCR slurry and CCR wastewater which can be impounded therein and for the passage of runoff from the design storm which exceeds the capacity of the CCR surface impoundment; or, in lieu of the

certification, a report indicating what additional investigations, analyses, or improvement work are necessary before such a certification can be made by an independent registered professional engineer, including what provisions have been made to carry out such work in addition to a schedule for completion of such work.

(f) Any changes or modifications to the plans for CCR surface impoundments shall be approved by the Regional Administrator prior to the initiation of such changes or modifications.

(g) Effective [date two years after the effective date of the final rule], all existing CCR surface impoundments that receive CCRs shall be operated and maintained with:

(1) A run-on control system to prevent flow onto the active portion of the CCR surface impoundment during the peak discharge from a 24-hour, 25-year storm;

(2) A run-off control system from the active portion of the CCR surface impoundment to collect and control at least the water volume resulting from a 24-hour, 25-year storm. Run-off from the active portion of the CCR surface impoundment must be handled in accordance with § 264.1307.

(h) For CCR surface impoundments classified as having high or significant hazard potential, the owner or operator shall develop and maintain in the operating record an Emergency Action Plan which: defines responsible persons and the actions to be taken in the event of a dam-safety emergency; provides contact information for emergency responders; includes a map which delineates the downstream area which would be affected in the event of a dam failure; and includes provisions for an annual face-to-face meeting or exercise between representatives of the facility owner and the local emergency responders.

§ 264.1304 Inspection requirements for surface impoundments.

(a) In addition to the inspection requirements in § 264.226 of this part, all CCR surface impoundments that meet the requirements of § 264.1303(b) of this subpart shall be inspected by the owner or operator as follows:

(1) At intervals not exceeding 7 days, or as otherwise approved by the Regional Administrator, for appearances of structural weakness and other hazardous conditions.

(2) At intervals not exceeding 7 days, or as otherwise approved by the Regional Administrator, all instruments shall be monitored.

(3) Longer inspection or monitoring intervals approved under this paragraph shall be justified by the owner or operator of the CCR surface impoundment based on the hazard potential and performance of the CCR surface impoundment, and shall include a requirement for inspection immediately after a specified event approved by the Regional Administrator.

(4) All inspections required by paragraphs (a)(1) and (2) shall be performed by a qualified person, as defined in paragraph (e) of this section, designated by the person owning or operating the CCR surface impoundment.

(5) All CCR surface impoundments that meet the requirements of § 264.1303(b) of this subpart shall be inspected annually by an independent registered professional engineer to assure that the design, operation, and maintenance of the surface impoundment is in accordance with recognized and generally accepted good engineering standards. The owner or operator must notify the state and the EPA Regional Administrator that a certification by the registered professional engineer that the design, operation, and maintenance of the surface impoundment is in accordance with recognized and generally accepted good engineering standards has been placed in the operating record.

(b) When a potentially hazardous condition develops, the person owning or operating the CCR surface impoundment shall immediately:

(1) Take action to eliminate the potentially hazardous condition;

(2) Notify the Regional Administrator and State and local first responders;

(3) Notify and prepare to evacuate, if necessary, all personnel from the owner or operator's property which may be affected by the potentially hazardous conditions; and

(4) Direct a qualified person to monitor all instruments and examine the structure at least once every eight hours, or more often as required by an authorized representative of the Regional Administrator.

(c) After each inspection and instrumentation monitoring referred to in paragraphs (a) and (b) of this section, each qualified person who conducted all or any part of the inspection or instrumentation monitoring shall promptly record the results of such inspection or instrumentation monitoring in a book which shall be available in the operating record for inspection by an authorized representative of the Regional Administrator and such qualified person shall also promptly report the results of the inspection or monitoring to one of the persons specified in paragraph (d) of this section.

(d) All inspection and instrumentation monitoring reports recorded in accordance with paragraph (c) of this section shall include a report of the action taken to abate hazardous conditions and shall be promptly signed or countersigned by the person designated by the owner or operator as responsible for health and safety at the owner or operator's facility.

(e) The qualified person or persons referred to in this section shall be trained to recognize specific signs of structural instability and other hazardous conditions by visual observation and, if applicable, to monitor instrumentation.

§ 264.1305 Requirements for surface impoundment closure.

Prior to the closure of any CCR surface impoundment which meets the requirements of § 264.1303(b) of this subpart, the person owning or operating such CCR surface impoundment shall submit to and obtain approval from the Regional Administrator, a plan for closure in accordance with the requirements of § 264.228 and subpart G of this part. This plan shall provide for major slope stability, include a schedule for the plan's implementation and, contain provisions to preclude the probability of future impoundment of water.

§ 264.1306 Landfills.

(a) Owners or operators of new CCR landfills and lateral expansions of existing landfills are exempt from the double liner and leachate collection system requirements of § 264.301(c), and the requirements of § 264.302, provided the owner or operator is in compliance with the requirements of paragraph (b) of this section. Owners or operators of existing landfills are also exempt from the liner requirements of paragraph (b)(1) of this section, provided they comply with the requirements of paragraph (c) of this section and the requirements at 40 CFR part 264 subparts F, G, H, and N.

(b) Prior to placement of CCRs in new landfills and lateral expansions of new and existing landfills, new landfills and lateral expansions shall be constructed:

(1) With a composite liner, as defined in paragraph (b)(2) of this section, and a leachate collection and removal system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner.

(2) For purposes of this subpart, composite liner means a system consisting of two components; the upper component must consist of a

minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

(3) For purpose of this subpart, hydraulic conductivity means the rate at which water can move through a permeable medium (*i.e.,* the coefficient of permeability).

(c) Effective [date two years after the effective date of the final rule], all existing landfills that receive CCRs shall be operated and maintained with:

(1) A run-on control system to prevent flow onto the active portion of the CCR landfill during the peak discharge from a 24-hour, 25-year storm;

(2) A run-off control system from the active portion of the CCR landfill to collect and control at least the water volume resulting from a 24-hour, 25-year storm. Run-off from the active portion of the CCR landfill must be handled in accordance with § 264.1307 of this subpart.

§ 264.1307 Surface water requirements.

(a) Permits for CCR surface impoundments and CCR landfills shall include conditions to ensure that:

(1) The operation of the unit will not cause any violation of any requirements of the Clean Water Act, including, but not limited to, the National Pollutant Discharge Elimination System (NPDES) requirements, pursuant to section 402 of the Clean Water Act.

(2) The operation of the unit will not cause any violation of any requirement of an area-wide or state-wide water quality management plan that has been approved under section 208 or 319 of the Clean Water Act, as amended.

(b) [Reserved]

§ 264.1308 Air requirements.

(a) CCR surface impoundments and CCR landfills must be managed in a manner that fugitive dusts do not exceed 35 μg/m^3, unless an alternative standard has been established by the Regional Administrator.

(b) CCR surface impoundments must be managed to control wind dispersal of dusts consistent with the standard in paragraph (a) of this section unless an alternative standard has been established by the Regional Administrator.

(c) CCR landfills must be managed to control wind dispersal of dusts consistent with the standard in paragraph (a) of this section unless an alternative standard has been established by the Regional Administrator. CCRs placed in landfills as wet conditioned CCRs shall not result in the formation of free liquids.

(d) Tanks, containers, buildings and pads used for the storage must be managed to control the dispersal of dust. Pads must have wind protection that will ensure comparable levels of control.

(e) CCRs transported in trucks or other vehicles must be covered or otherwise managed to control the wind dispersal of dust consistent with the standard in paragraph (a) of this section unless an alternative standard has been established by the Regional Administrator.

PART 265—INTERIM STATUS STANDARDS FOR OWNERS AND OPERATORS OF HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

14. The authority citation for part 265 continues to read as follows:

Authority: 42 U.S.C. 6905, 6906, 6912, 6922, 6923, 6924, 6925, 6935, 6936, and 6937.

15. Section 265.1 is amended by adding paragraph (g) to read as follows:

§ 265.1 Purpose, scope, and applicability.

* * * * *

(g) Owners or operators who treat, store or dispose of EPA Special Waste Number S001, also referred to as coal combustion residuals (CCRs) are subject to the requirements of this part, except as specifically provided otherwise in this part. In addition, subpart FF of this part includes additional requirements for the treatment storage or disposal of EPA Special Waste No. S001.

* * * * *

16. Section 265.140 is amended by revising paragraph (a) to read as follows:

§ 265.140 Applicability.

(a) The requirements of §§ 265.142, 265.143 and 265.147 through 265.150 apply to owners or operators of all hazardous and special waste facilities, except as provided otherwise in this section, or in § 265.1.

* * * * *

17. Part 265 is amended by adding Subpart FF to read as follows:

Subpart FF—Special Requirements for S001 Wastes

Sec.

Subpart FF—Special Requirements for S001 Wastes

§ 265.1300 Applicability.

(a) The regulations in this subpart apply to owners or operators of hazardous waste facilities that treat, store or dispose of EPA Hazardous Waste Number S001.

(b) Owners or operators of surface impoundments that cease receiving EPA Special Waste Number S001,must comply with the closure requirements in 40 CFR Part 265.111 and 40 CFR 265.228. Facilities that have not met these closure requirements by the effective date of this regulation would be subject to the requirements in Parts 260 through 268, and 270 through 272, of this chapter.

§ 265.1301 Definitions.

This section contains definitions for terms that appear throughout this subpart; additional definitions appear in 40 CFR 260.10 or the specific sections to which they apply.

Area-capacity curves means graphic curves which readily show the reservoir water surface area, in acres, at different elevations from the bottom of the reservoir to the maximum water surface, and the capacity or volume, in acre-feet, of the water contained in the reservoir at various elevations.

Coal Combustion Residuals (CCRs) means fly ash, bottom ash, boiler slag, and flue gas desulfurization materials, destined for disposal. CCRs are also known as coal combustion wastes (CCWs) and fossil fuel combustion (FFC) wastes, when destined for disposal, and as coal combustion products (CCPs) when beneficially used.

CCR landfill means a disposal facility or part of a facility where CCRs are placed in or on land and which is not a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit. For purposes of this subpart, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills.

CCR surface impoundment or *impoundment* means a facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), which is designed to hold an accumulation of CCRs containing free liquids, and which is not an injection well. Examples of CCR surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons. CCR surface impoundments are used to receive CCRs that have been sluiced (flushed or mixed with water to facilitate movement), or wastes from wet air pollution control devices, often in addition to other solid wastes.

Existing CCR landfill means a landfill which was in operation or for which construction commenced prior to the effective date of the final rule A CCR landfill has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill to be completed within a reasonable time.

Existing CCR surface impoundment means a surface impoundment which was in operation or for which construction commenced prior to the effective date of the final rule. A CCR surface impoundment has commenced construction if the owner or operator has obtained the Federal, State and local approvals or permits necessary to begin physical construction; and either

(1) A continuous on-site, physical construction program has begun; or

(2) The owner or operator has entered into contractual obligations—which can not be cancelled or modified without substantial loss—for physical construction of the CCR surface impoundment to be completed within a reasonable time.

Factor of safety (Safety factor) means the ratio of the forces tending to resist the failure of a structure to the forces tending to cause such failure as determined by recognized and accepted good engineering practices.

Hazard potential means the possible adverse incremental consequences that result from the release of water or stored contents due to failure of a dam (or impoundment) or mis-operation of the dam or appurtenances.

(1) *High hazard potential surface impoundment* means a surface impoundment where failure or mis-operation will probably cause loss of human life.

(2) *Significant hazard potential surface impoundment* means a surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environment damage, disruption of lifeline facilities, or impact other concerns.

(3) *Low hazard potential surface impoundment* means a surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

(4) *Less than low hazard potential surface impoundment* means a surface impoundment not meeting the definitions for High, Significant, or Low Hazard Potential.

Lateral expansion means a horizontal expansion of the waste boundaries of an existing CCR landfill, or CCR surface impoundment made after the effective date of the final rule.

New CCR landfill means a landfill, including lateral expansions, or installation from which there is or may be placement of CCRs without the presence of free liquids, which began operation, or for which the construction commenced after the effective date of the final rule.

New CCR surface impoundment means a surface impoundment, including lateral expansion, or installation from which there is or may be placement of CCRs with the presence of free liquids, which began operation, or for which the construction commenced after the effective date of the final rule.

Probable maximum precipitation means the value for a particular area which represents an envelopment of depth-duration-area rainfall relations for all storm types affecting that area adjusted meteorologically to maximum conditions.

Recognized and generally accepted good engineering practices (RAGAGEPs) means engineering, operation, or maintenance activities based on established codes, standards, published technical reports or recommended practices (RP) or a similar document. RAGAGEPs detail generally approved ways to perform specific engineering, inspection or mechanical integrity activities.

§ 265.1302 Reporting.

(a) Except as provided in paragraph (b) of this section, every twelfth month following the date of the initial plan approval required in § 265.1303 of this subpart, the person owning or operating a CCR surface impoundment that has not been properly closed in accordance with an approved plan shall submit to the Regional Administrator a report containing the following information:

(1) Changes in the geometry of the CCR surface impoundment for the reporting period.

(2) Location and type of installed instruments and the maximum and minimum recorded readings of each instrument for the reporting period.

(3) The minimum, maximum, and present depth and elevation of the CCR slurry and CCR waste water in the CCR surface impoundment for the reporting period.

(4) The storage capacity of the CCR surface impoundment.

(5) The volume of the CCR slurry and CCR waste water in the CCR surface impoundment at the end of the reporting period.

(6) Any other change which may have affected the stability or operation of the CCR surface impoundment that has occurred during the reporting period.

(7) A certification by an independent registered professional engineer that all construction, operation, and maintenance are in accordance with the approved plan prepared in accordance with § 265.1303.

(b) A report is not required under this section when the person owning or operating the CCR surface impoundment provides the Regional Administrator with a certification by an independent registered professional engineer that there have been no changes in the operation of the CCR surface impoundment or to any of the parameters previously reported under paragraphs (a)(1) through (a)(6) of this section. However, a report containing the information set out in paragraph (a) of this section shall be submitted to the Regional Administrator at least every 5 years.

§ 265.1303 Surface impoundments.

(a) In addition to the requirements in subpart K of this part, EPA Special Waste No. S001 is subject to the requirements in this section.

(b) Plans for the design, construction, and maintenance of existing CCR surface impoundments shall be required if such a unit can:

(1) Impound CCRs to an elevation of five feet or more above the upstream toe of the structure and can have a storage volume of 20 acre-feet or more; or

(2) Impound CCRs to an elevation of 20 feet or more above the upstream toe of the structure.

(c) Plans required under paragraph (b) of this section shall be submitted in triplicate to the Regional Administrator on or before [date one year after the effective date of the final rule].

(d) A marker, at least six feet high and showing the identification number of the CCR surface impoundment as assigned by the Regional Administrator, the name associated with the CCR surface impoundment and the name of the person owning or operating the structure, shall be located on or immediately adjacent to each CCR surface impoundment permanent identification by [date 60 days after the effective date of the final rule].

(e) The plan specified in paragraph (b) of this section, shall contain at a minimum the following information:

(1) The name and address of the persons owning or operating the CCR surface impoundment; the name associated with the CCR surface impoundment; and the identification number of the CCR surface impoundment as assigned by the Regional Administrator.

(2) The location of the CCR surface impoundment indicated on the most recent USGS 7½ minute or 15 minute topographic quadrangle map, or a topographic map of equivalent scale if a USGS map is not available.

(3) A statement of the purpose for which the CCR surface impoundment is being used.

(4) The name and size in acres of the watershed affecting the CCR surface impoundment.

(5) A description of the physical and engineering properties of the foundation materials on which the CCR surface impoundment is constructed.

(6) A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR surface impoundment; the method of site preparation and construction of each zone of the CCR surface impoundment; the approximate dates of construction, and each successive stage of construction of the CCR surface impoundment; and for existing CCR surface impoundments, such history of construction as may be available, and any record or knowledge of structural instability.

(7) At a scale not to exceed 1 inch = 100 feet, detailed dimensional drawings of the CCR surface impoundment, including a plan view and cross sections of the length and width of the CCR surface impoundment, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the measurement of the minimum vertical distance between the crest of the CCR surface impoundment and the reservoir surface at present and under design storm conditions, CCR slurry level or CCR waste water level, and other information pertinent to the CCR surface impoundment itself, including any identifiable natural or manmade features which could affect operation of the CCR surface impoundment.

(8) A description of the type and purpose of existing or proposed instrumentation.

(9) Graphs showing area-capacity curves.

(10) The hazard potential classification for which the facility is designed and a detailed explanation of the basis for this classification.

(11) A statement of the runoff attributable to the storm for which the CCR surface impoundment is designed and the calculations used in determining such runoff and the minimum freeboard during the design storm.

(12) A description of the spillway and diversion design features and capacities and calculations used in their determination.

(13) The computed minimum factor of safety for slope stability of the CCR retaining structure(s) and the analyses used in their determinations.

(14) The construction specifications and provisions for surveillance, maintenance, and repair of the CCR surface impoundment.

(15) General provisions for closure.

(16) Such other information pertaining to the stability of the CCR surface impoundment which may be requested by the Regional Administrator.

(17) A certification by an independent registered professional engineer that the design of the CCR surface impoundment is in accordance with recognized and generally accepted good engineering practices for the maximum volume of CCR slurry and CCR waste water which can be impounded therein and for the passage of runoff from the design storm which exceeds the capacity of the CCR surface impoundment; or, in lieu of the certification, a report indicating what additional investigations, analyses, or improvement work are necessary before such a certification can be made by an independent registered professional engineer, including what provisions have been made to carry out such work in addition to a schedule for completion of such work.

(f) Any changes or modifications to the plans for CCR surface impoundments shall be approved by the Regional Administrator prior to the initiation of such changes or modifications.

(g) Effective [date two years after the effective date of the final rule], all existing surface impoundments that receive CCRs shall be operated and maintained with:

(1) A run-on control system to prevent flow onto the active portion of the CCR surface impoundment during the peak discharge from a 24-hour, 25-year storm;

(2) A run-off control system from the active portion of the CCR surface impoundment to collect and control at least the water volume resulting from a 24-hour, 25-year storm. Run-off from the active portion of the CCR surface impoundment must be handled in accordance with § 265.1307 of this subpart.

(h) For CCR surface impoundments classified as having high or significant hazard potential, the owner or operator shall develop and maintain in the operating record an Emergency Action Plan which: defines responsible persons and the actions to be taken in the event of a dam-safety emergency; provides contact information for emergency responders; includes a map which delineates the downstream area which would be affected in the event of a dam failure; and includes provisions for an annual face-to-face meeting or exercise between representatives of the facility owner and the local emergency responders.

§ 265.1304 Inspection requirements for surface impoundments.

(a) In addition to the inspection requirements in § 265.226, all CCR surface impoundments that meet the requirements of § 265.1303(b) of this subpart shall be inspected by the owner or operator as follows:

(1) At intervals not exceeding 7 days, or as otherwise approved by the Regional Administrator, for appearances of structural weakness and other hazardous conditions.

(2) At intervals not exceeding 7 days, or as otherwise approved by the Regional Administrator, all instruments shall be monitored.

(3) Longer inspection or monitoring intervals approved under this paragraph shall be justified by the owner or operator of the CCR surface impoundment based on the hazard potential and performance of the CCR surface impoundment, and shall include a requirement for inspection immediately after a specified event approved by the Regional Administrator.

(4) All inspections required by paragraphs (a)(1) and (2) of this section shall be performed by a qualified person, as defined in paragraph (e) of this section, designated by the person owning or operating the CCR surface impoundment.

(5) All CCR surface impoundments that meet the requirements of § 265.1303(b) of this subpart shall be inspected annually by an independent registered professional engineer to assure that the design, operation, and maintenance of the surface impoundment is in accordance with recognized and generally accepted good engineering practices. The owner or operator must notify the state and the EPA Regional Administrator that a certification by the independent registered professional engineer that the design, operation, and maintenance of the surface impoundment is in accordance with recognized and generally accepted good engineering practices has been placed in the operating record.

(b) When a potentially hazardous condition develops, the person owning or operating the CCR surface impoundment shall immediately:

(1) Take action to eliminate the potentially hazardous condition;

(2) Notify the Regional Administrator and State and local first responders;

(3) Notify and prepare to evacuate, if necessary, all personnel from the owner or operator's property which may be affected by the potentially hazardous conditions; and

(4) Direct a qualified person to monitor all instruments and examine the structure at least once every eight hours, or more often as required by an authorized representative of the Regional Administrator.

(c) After each inspection and instrumentation monitoring referred to in paragraphs (a) and (b) of this section, each qualified person who conducted all or any part of the inspection or instrumentation monitoring shall promptly record the results of such inspection or instrumentation monitoring in a book which shall be available in the operating record for inspection by an authorized representative of the Regional Administrator and such qualified person shall also promptly report the results of the inspection or monitoring to one of the persons specified in paragraph (d) of this section.

(d) All inspection and instrumentation monitoring reports recorded in accordance with paragraph (c) of this section shall include a report of the action taken to abate hazardous conditions and shall be promptly signed or countersigned by the person designated by the owner or operator as responsible for health and safety at the owner or operator's facility.

(e) The qualified person or persons referred to in this section shall be trained to recognize specific signs of structural instability and other hazardous conditions by visual observation and, if applicable, to monitor instrumentation.

§ 265.1305 Requirements for surface impoundment closure.

Prior to the closure of any CCR surface impoundment which meets the requirements of § 264.1303(b) of this subpart, the person owning or operating such CCR surface impoundment shall submit to and obtain approval from the Regional Administrator, a plan for closure in accordance with the requirements of § 265.228 and part 265 subpart G. This plan shall provide for major slope stability, include a schedule for the plan's implementation, and contain provisions to preclude the probability of future impoundment of water.

§ 265.1306 Landfills.

(a) Owners or operators of new CCR landfills and lateral expansions of existing landfills are exempt from the double liner and leachate collection system requirements of § 265.301(c), and the requirements of § 265.302, provided the owner or operator is in compliance with the requirements of paragraph (b) of this section. Owners or operators of existing landfills are also exempt from the liner requirements of paragraph (b)(1) of this section, provided they comply with the requirements of paragraph (c) of this section and the requirements at 40 CFR part 265 subparts F, G, H, and N.

(b) Prior to placement of CCRs in new landfills and lateral expansions, new landfills and lateral expansions shall be constructed:

(1) With a composite liner, as defined in paragraph (b)(2) of this section, and a leachate collection and removal system that is designed and constructed to maintain less than a 30-cm depth of leachate over the liner.

(2) For purposes of this subpart, composite liner means a system consisting of two components; the upper component must consist of a minimum 30-mil flexible membrane liner (FML), and the lower component must consist of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick. The FML component must be installed in direct and uniform contact with the compacted soil component.

(3) For purposes of this subpart, hydraulic conductivity means the rate at which water can move through a permeable medium. (*i.e.,* the coefficient of permeability.)

(c) Effective [date two years after the effective date of the final rule], all existing landfills that receive CCRs shall be operated and maintained with:

(1) A run-on control system to prevent flow onto the active portion of the CCR landfill during the peak discharge from a 24-hour, 25-year storm;

(2) A run-off control system from the active portion of the CCR landfill to collect and control at least the water volume resulting from a 24-hour, 25-year storm. Run-off from the active portion of the CCR landfill must be handled in accordance with § 265.1307 of this subpart.

§ 265.1307 Surface water requirements.

(a) Permits for CCR surface impoundments and CCR landfills shall include conditions to ensure that:

(1) The operation of the unit will not cause any violation of any requirements of the Clean Water Act, including, but not limited to, the National Pollutant Discharge Elimination System (NPDES) requirements, pursuant to section 402 of the Clean Water Act.

(2) The operation of the unit will not cause any violation of any requirement of an area-wide or state-wide water quality management plan that has been approved under section 208 or 319 of the Clean Water Act, as amended.

(b) [Reserved]

§ 265.1308 Air requirements.

(a) CCR surface impoundments and CCR landfills must be managed in a manner that fugitive dusts do not exceed 35 $\mu g/m^3$, unless an alternative standard has been established by the Regional Administrator.

(b) CCR surface impoundments must be managed to control wind dispersal of dusts consistent with the standard in paragraph (a) of this section unless an alternative standard has been established by the Regional Administrator.

(c) CCR landfills must be managed to control wind dispersal of dusts consistent with the standard in paragraph (a) of this section unless an alternative standard has been established by the Regional Administrator. CCRs placed in landfills as wet conditioned CCRs shall not result in the formation of free liquids.

(d) Tanks, containers, buildings and pads used for the storage must be managed to control the dispersal of dust. Pads must have wind protection that will ensure comparable levels of control.

(e) CCRs transported in trucks or other vehicles must be covered or otherwise managed to control the wind dispersal of dust consistent with the standard in paragraph (a) of this section unless an alternative standard has been established by the Regional Administrator.

PART 268—LAND DISPOSAL RESTRICTIONS

18. The authority citation for part 268 continues to read as follows:

Authority: 42 U.S.C. 6905, 6912(a), 6921, and 6924.

19. Section 268.2 is amended by revising paragraph (f) to read as follows:

§ 268.2 Definitions applicable in this part.

* * * * *

(f) Wastewaters are wastes that contain less than 1% by weight total organic carbon (TOC) and less than 1% by weight total suspended solids (TSS), except for coal combustion residuals, [waste code S001], which are wastewaters if the moisture content exceeds 50%.

* * * * *

20. Section 268.14 is amended by adding paragraph (d) to read as follows:

§ 268.14 Surface impoundment exemptions.

* * * * *

(d) The waste specified in 40 CFR Part 261 as EPA Special Waste Number S001 may continue to be placed in an existing CCR surface impoundment of this subpart for 60 months after the promulgation date of listing the waste provided the existing CCR surface impoundment is in compliance with the requirements of subpart F of part 265 of this chapter within 12 months after the promulgation of the new listing. Closure in accordance with subpart G of part 264 must be completed within two years after placement of waste in the existing CCR surface impoundment ceases.

21. Section 268.21 is added to Subpart C to read as follows:

§ 268.21 Waste specific prohibitions—Coal combustion residuals.

(a) Effective [date six months after the effective date of the final rule], nonwastewaters specified in 40 CFR part 261 as EPA Special Waste Number S001 are prohibited from land disposal.

(b) Effective [date 60 months after the effective date of the final rule], wastewaters specified in 40 CFR part 261 as EPA Special Waste Number S001 are prohibited from land disposal.

(c) The requirements of paragraphs (a) and (b) of this section do not apply if:

(1) The wastes meet the applicable treatment standards specified in subpart D of this Part;

(2) Persons have been granted an exemption from a prohibition pursuant to a petition under § 268.6, with respect to those wastes and units covered by the petition;

(3) The wastes meet the applicable treatment standards established pursuant to a petition granted under § 268.44;

(4) Persons have been granted an extension to the effective date of a prohibition pursuant to § 268.5, with respect to these wastes covered by the extension.

22. In § 268.40, the table "Treatment Standards for Hazardous Wastes" is amended by adding in alphanumeric order the new entry for S001 to read as follows:

§ 268.40 Applicability of treatment standards.

* * * * *

TREATMENT STANDARDS FOR HAZARDOUS WASTES

[Note: NA means not applicable]

Waste code	Waste description and treatment/regulatory subcategory [1]	Regulated hazardous constituent		Wastewaters	Nonwastewaters
		Common name	CAS [2] No.	Concentration in mg/L [3], or technology code [4]	Concentration in mg/kg [5] unless noted as "mg/L TCLP", or technology code
*	*	*	*	*	*
S001	Coal combustion wastes generated by the electric power sector. For purposes of this listing, the electric power sector is defined as electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public; *i.e.,* NAICS code 221112 plants. For the purposes of this listing, coal combustion wastes are defined as fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated by the electric power sector. This listing does not apply to coal combustion residuals that are: (1) Uniquely associated wastes with wastes from the burning of coal; (2) beneficially used; (3) placed in minefilling operations; (4) generated by facilities that are outside the electric power sector; or (5) generated from clean-up activities that are conducted as part of a state or federally required clean-up that commenced prior to the effective date of this rule..	Antimony	7440–36–0	TSS of 100mg/l and meet § 268.48.	Meet § 268.48.
		Arsenic	7440–38–2		
		Barium	7440–39–3		
		Beryllium	7440–41–7		
		Cadmium	7440–43–9		
		Chromium	7440–47–3		
		Lead	7439–92–1		
		Mercury	7439–97–6		
		Nickel	7440–02–0		
		Selenium	7782–49–2		
		Silver	7440–22–4		
		Thallium	7440–28–0		
*	*	*	*	*	*

Footnotes to Treatment Standard Table 268.40

[1] The waste descriptions provided in this table do not replace waste descriptions in 40 CFR 261. Descriptions of Treatment/Regulatory Subcategories are provided, as needed, to distinguish between applicability of different standards.

[2] CAS means Chemical Abstract Services. When the waste code and/or regulated constituents are described as a combination of a chemical with its salts and/or esters, the CAS number is given for the parent compound only.

[3] Concentration standards for wastewaters are expressed in mg/L and are based on analysis of composite samples.

[4] All treatment standards expressed as a Technology Code or combination of Technology Codes are explained in detail in 40 CFR 268.42 Table 1—Technology Codes and Descriptions of Technology-Based Standards.

[5] Except for Metals (EP or TCLP) and Cyanides (Total and Amenable) the nonwastewater treatment standards expressed as a concentration were established, in part, based upon incineration in units operated in accordance with the technical requirements of 40 CFR Part 264 Subpart O or Part 265 Subpart O, or based upon combustion in fuel substitution units operating in accordance with applicable technical requirements. A facility may comply with these treatment standards according to provisions in 40 CFR 268.40(d). All concentration standards for nonwastewaters are based on analysis of grab samples.

* * * * *

23. In § 268.42, Table 1 is amended by adding an entry for "RSLDS" to read as follows:

§ 268.42 Treatment standards expressed as specified technologies.

* * * * *

TABLE 1—TECHNOLOGY CODES AND DESCRIPTION OF TECHNOLOGY-BASED STANDARDS

Technology code	Description of technology-based standards
* * * * *	
RSLDS	Removal of solids and meet § 268.48 treatment levels.
* * * * *	

* * * * *

PART 271—REQUIREMENTS FOR AUTHORIZATION OF STATE HAZARDOUS WASTE PROGRAMS

24. The authority citation for part 271 continues to read as follows:

Authority: 42 U.S.C. 6905, 6912(a), and 6926.

25. Section 271.1(j) is amended by adding the following entries to Table 1 and Table 2 in chronological order by date of publication to read as follows.

§ 271.1 Purpose and scope.

* * * * *

(j) * * *

TABLE 1—REGULATIONS IMPLEMENTING THE HAZARDOUS AND SOLID WASTE AMENDMENTS OF 1984

Promulgation date	Title of regulation	Federal Register reference	Effective date
* * * * * * *			
[date of signature of final rule]	Listing of Special Waste S001	[Federal Register page numbers for final rule].	[effective date of final rule].

TABLE 2—SELF-IMPLEMENTING PROVISIONS OF THE SOLID WASTE AMENDMENTS OF 1984

Effective date	Self-implementing provision	RCRA citation	Federal Register reference
* * * * * * *			
[effective date of final rule].	Prohibition on land disposal of S001 waste with free liquids and prohibition on the disposal of S001 waste below the natural water table. For purposes of this provision, free liquids means liquids which readily separate from the solid portion of a waste under ambient temperature and pressure.	3001(b)(3)(A) and 3004(g)(4)(C).	[date of publication date of final rule Federal Register page numbers] [FR page numbers].

PART 302—DESIGNATION, REPORTABLE QUANTITIES, AND NOTIFICATION

26. The authority citation for part 302 continues to read as follows:

Authority: 42 U.S.C. 9602, 9603, and 9604; 33 U.S.C. 1321 and 1361.

27. In § 302.4, Table 302.4 is amended by adding the following new entry in alphanumeric order to the table to read as follows:

§ 302.4 Designation of hazardous substances.

* * * * *

TABLE 302.4—LIST OF HAZARDOUS SUBSTANCES AND REPORTABLE QUANTITIES

[Note: All comments/notes are located at the end of this table]

Hazardous substance	CASRN	Statutory code†	RCRA waste No.	Final RQ pounds (Kg)
* * * * * * *				
S001[f] Coal combustion residuals generated by the electric power sector (Electric Utilities and Independent Power Producers)	....	4	S001	1 (0. 4536)

TABLE 302.4—LIST OF HAZARDOUS SUBSTANCES AND REPORTABLE QUANTITIES—Continued

[Note: All comments/notes are located at the end of this table]

Hazardous substance	CASRN	Statutory code†	RCRA waste No.	Final RQ pounds (Kg)
* * *	* *	*	*	*

† Indicates the statutory source defined by 1, 2, 3, and 4, as described in the note preceding Table 302.4.

* * * * *

[f] *See* 40 CFR 302.6(b)(1) for application of the mixture rule to this hazardous waste.

* * * * *

28. Section 302.6 is amended by amending paragraph (b)(1)(iii), including the Table, to read as follows:

§ 302.6 Notification requirements.

* * * * *

(b) * * *

(1) * * *

(iii) For waste streams K169, K170, K171, K172, K174, K175, and S001, knowledge of the quantity of all of the hazardous constituent(s) may be assumed, based on the following maximum observed constituent concentrations identified by EPA:

Waste	Constituent	Max ppm
K169	Benzene	220.0
K170	Benzene	1.2
	Benzo (a) pyrene	230.0
	Dibenz (a,h) anthracene	49.0
	Benzo (a) anthracene	390.0
	Benzo (b) fluoranthene	110.0
	Benzo (k) fluoranthene	110.0
	3–Methylcholanthrene	27.0
	7,12–Dimethylbenz (a) anthracene	1,200.0
K171	Benzene	500.0
	Arsenic	1,600.0
K172	Benzene	100.0
	Arsenic	730.0
K174	2,3,7,8TCDD	0.000039
	1,2,3,7,8–PeCDD	0.0000108
	1,2,3,4,7,8–HxCDD	0.0000241
	1,2,3,6,7,8–HxCDD	0.000083
	1,2,3,7,8,9–HxCDD	0.000062
	1,2,3,4,6,7,8–HpCDD	0.00123
	OCDD	0.0129
	2,3,7,8–TCDF	0.000145
	1,2,3,7,8–PeCDF	0.0000777
	2,3,4,7,8–PeCDF	0.000127
	1,2,3,4,7,8–HxCDF	0.001425
	1,2,3,6,7,8–HxCDF	0.000281
	1,2,3,7,8,9–HxCDF	0.00014
	2,3,4,6,7,8–HxCDF	0.000648
	1,2,3,4,6,7,8–HpCDF	0.0207
	1,2,3,4,7,8,9–HpCDF	0.0135
	OCDF	0.212
K175	Mercury	9,200
S001	Antimony	3,100
	Arsenic	773
	Barium	7,230
	Beryllium	31
	Cadmium	760
	Chromium	5,970
	Lead	1,453
	Mercury	384
	Nickel	6,301
	Selenium	673
	Silver	338
	Thallium	100

* * * * *

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