

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:)	
)	
PROPOSED AMENDMENTS TO)	
CLEAN CONSTRUCTION OR DEMOLITION)	R2012-9B
FILL OPERATIONS)	(Rulemaking-Land)
(35 ILL. ADM. CODE 1100)	

NOTICE OF FILING

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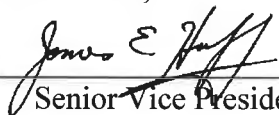
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Please take notice that I have today filed electronically with the Office of the Clerk of the Illinois Pollution Control Board the attached Pre-Filed Testimony of James E. Huff, P.E. and accompanying Attachments, a copy of which is served upon you.

HUFF & HUFF, INC.

By: 
 Senior Vice President

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PRE-FILED SUPPLEMENTAL TESTIMONY OF JAMES E. HUFF, P.E.

Introduction

My name is James E. Huff, and I was an active participant throughout the CCDD proceedings. I testified previously on whether monitoring wells are necessary and provided written comments in November 2012. My comments today are directed toward responding to a number of pre-filed questions and the proposed groundwater regulations contained in the Board's March 21, 2013 Proposed Rule Language. In addition to my previously submitted comments regarding the MAC list and the maximum soil pH, and I will provide additional comments on these two topics. The Board noted in its April 18, 2013 proceedings that Subdocket B will only address the groundwater monitoring issue, and participants are free to file a new rulemaking to address other issues; however, these issues are interrelated to the groundwater issue and can readily be addressed as part of Subdocket B, avoiding the unnecessary additional resources and costs for a separate docket.

RESPONSE TO THE BOARD'S PRE-FILED QUESTIONS

I offer the following to select questions from the Board:

3a Please comment on the prevalence of the other 620 Parameters in CCDD and Uncontaminated Soil.

The *Illinois Integrated Water Quality Report and Section 303(d) List-2012, Volume II: Groundwater*, prepared by the Illinois EPA addresses this question, and I have included this as

Attachment 1 to my testimony. This report focuses on volatile organics (VOCs), chlorides, nitrates, and herbicides. The latter two associated with the agricultural areas and the chlorides associated with highway de-icing, potassium chloride fertilizer, livestock waste, and water softening. Only the volatile organic compounds would be of concern with respect to the uncontaminated soil taken to a CCDD or Uncontaminated Soil Fill site.

It is important to remember that uncontaminated soil going to a CCDD or uncontaminated soil fill is an urban issue, and not an agricultural area issue. Excess soil from roadway construction activities are the primary source of these uncontaminated soils; and gasoline stations, dry cleaners, and similar types of commercial industries are located along roadways. VOCs migrate at a much faster rate than other contaminants. Metals to a large degree will be held in the soil due to the cationic exchange capacity of the soils. The Tier 1 Tables in 742 Appendix B are a good indicator of the potential for soil migration to groundwater concerns. For the volatile organic compounds, the soil migration to groundwater pathway is the most restrictive, while the majority of the other constituents have more restrictive ingestion remedial objectives due to lower mobility of the other contaminants.

While the Agency will argue that other constituents **could** be present, supporting data would indicate otherwise, including the previously provided groundwater data at CCDD facilities.

3b. What are the costs for a VOC and dissolved metal analysis versus running the entire 620 parameters?

Prices for VOC analysis on a groundwater sample are typically on the order of \$180 per sample. Assuming four wells, a duplicate, and field blank, that would be six analyses annually or \$1080 per year. The cost for metal analysis would depend on which metals are to be analyzed. The *620 List* includes a number of metals that are not commonly used in industrial or commercial facilities. For the suite of metals listed in the 620 regulations, costs would be on the order of \$306 per sample. With the same duplicate and trip blank, that would equate to six samples annually, or \$1,836 per year. If the testing were limited to the eight RCRA metals, the costs would be on the order of \$126 per sample, or \$756 per year. SVOCs are also included on the 620 list. The cost for SVOC analysis is on the order of \$300 per sample, or \$1,800 per year.

To run the complete 620 List, excluding the contaminants exempted, the cost per sample would be on the order of \$2,303 per sample, or with six samples per event, \$13,818 per year.

As will be discussed under my comments on the proposed regulation language, I do not believe four monitoring wells will be sufficient to meet the regulations as currently drafted, and a minimum of eight monitoring wells will be required, so the costs above can be doubled to reflect a more probable cost.

3c. Are the 620 metals standards based on dissolved concentrations?

This is really an excellent question that has never been clear in Illinois. The intent of the 620 regulations is to protect **groundwater**. Drinking water supplies are consistently low in suspended solids, and in fact the drinking water standards found at 40 CFR 141.13 specify a maximum turbidity of 1 Turbidity Unit. Monitoring wells in Illinois are often screened in unconsolidated units rich in silts and/or clays, and developing the well sufficiently to achieve a 1 Turbidity Unit level cannot be achieved. If total metals are run, the results simply reflect what is in the groundwater plus what is in particulate state. Specifying dissolved metals eliminates this variable while still being protective of the groundwater. Lead is a good example. Let's say the lead level in soil where a monitoring wells is installed is 100 mg/kg, less than the MAC limit of 107 mg/kg. To achieve a groundwater lead result of 0.0075 mg/L, an assuming no lead dissolved state, the sediment concentration would have to be less than 75 mg/L in the sample. With clay soils, it is common to have sediment concentrations an order of magnitude higher than this in groundwater samples. There are of course ways to minimize sediment in groundwater samples, and re-testing using a more refined procedure would be necessary, all at an additional cost that could be simply avoided by specifying the 620 metals are based on the dissolved metal concentrations.

5. Should the front end screening be amended if groundwater monitoring is adopted?

This is another excellent question. I testified previously that there are false positives with the PID meter, most notably humidity. The start of construction season this year occurred on a cold rainy day, and sure enough we had loads rejected due to *deflections* on the PID meter at the receiving facility. The rejected loads were from a residential neighborhood, and we subsequently told by

the receiving facility we had to prepare a Form 663 instead of the Form 662 that had been used, because of the rejected load, with the associated testing. We tested the rejected load for VOCs, and not surprisingly, none were detected. A week of construction was lost because of this issue, caused solely by the false positive of the PID meter. The receiving facilities have each adopted their own protocols, from requiring Form 663 on all projects to requiring testing for the full MAC list, which is their prerogative. If the receiving facilities are going to be responsible for sampling groundwater for VOCs, it would seem that each facility should be allowed to determine what PID response should trigger rejection, as they are clearly accepting additional responsibility with monitoring wells. If the Agency is uncomfortable with this approach, I had previously recommended a value of 5 ppm which would eliminate most of the false positives.

10. Please comment on the inclusion of remediation options at CCDD and fill sites.

I have testified as to the economic impact of the CCDD regulation in the past. My concern was that either very little soil would meet the definition of uncontaminated soil or that the CCDD and Uncontaminated Soil Fill (USF) sites would vacate this market if monitoring, as proposed, is adopted. Recognizing in these regulations that remedial options beyond pump and treat would reduce the uncertainty and remedial costs, should groundwater contamination be discovered, while still be protective of the environment. Relying on groundwater use restrictions, where acceptable to the local community, and groundwater management zones would protect the environment and go a long way to reducing the anxiety in the industry.

11. Pre-existing conditions:

This industry for many years was not heavily regulated as to what was received. To require monitoring wells on these existing facilities will not only pick up any new impacts, but also historic impacts. The concept of a baseline is indeed a “grandfather” approach to try and address the concerns of the current operators of these facilities. This was offered originally as an alternative for providing regulatory guidance on how groundwater impacts could be addressed beyond “pump and treat”. The original discussion assumed that if groundwater impacts are discovered, they would be found through additional monitoring as being statistically significant.

12. Please provide a range of remediation cost

Attachment 2 is an U. S. EPA report on pump and treat costs at Superfund sites, which would be similar to what would be required at these CCDD Facilities. Both capital and operating costs are provided. The median capital cost in 2001 dollars was \$2,000,000, or in 2013 costs this would be \$2,900,000 for installation. Operating costs are also provided in Attachment 2.

13. Please identify the specific provisions of the Agency's proposed rules that reference the non-degradation requirement.

Mr. Richard Cobb's testimony in the R08-18 proceedings at page 10 explains this concept, which has been included in the Agency's proposed CCDD regulations. The proposed CCDD regulations submitted to the Board made one concession in that Section 1100.720 allows operators to achieve Class I groundwater standards on the subject property in lieu of the being held to a non-degradation standard; however, if corrective actions are needed beyond the fill operation property boundaries, Subsection 1100.755(d) requires compliance with Part 620, and as Mr. Nightingale noted "includes the non-degradation provisions" (pg 36).

As currently drafted, Section 1100.750 Corrective Action Program at d) states

Take corrective action that achieves compliance with 35 Ill Adm. Code 620 beyond the fill operation's property boundary...

By reference to Part 620, the Agency can enforce its interpretation of Part 620, Subpart C: Non-degradation Provisions for Appropriate Groundwater. To eliminate this concern, I recommend changing Part 1100.755(d) to read:

Take corrective action that achieves the applicable numerical standards found in 35 Ill Adm. Code 620.410 or eliminate the exposure pathway through groundwater use restrictions.

COMMENTS ON PROPOSED RULE LANGUAGE

Section 1100.725(a)(2) Groundwater Monitoring System

This section specifies that samples which represent the quality of groundwater that is downgradient, “including both horizontal and vertical directions” be collected. Presumably the horizontal component would be satisfied by installing four monitoring wells around the perimeter of the fill operation. The vertical component; however, is more difficult to address. Without an extensive hydrogeologic study, the vertical component will be unknown. This will require a minimum of two wells screened at different elevations at each location, so the minimum number of monitoring wells and samples each sampling event will be eight, and this should be factored into the costs. Additional, monitoring wells installed within deeper aquifer units may not be indicative of impacts from the CCDD facilities. The deeper aquifer units are often under confined conditions that may represent conditions from regional sources, unrelated to the CCDD or USF operation.

Section 1100.725(b) Groundwater Monitoring System

Part b) of this section does not require screening wells into separate groundwater monitoring systems, provided that the sampling will “enable detection and measurement of constituents that have entered the groundwater from each unit.” It is unclear how one can accomplish this requirement without the separate screening of wells at different elevations, and would ask that the Agency provide some guidance in the record on this point.

Section 1100.735 Monitoring Parameters

The list in 35 Ill. Adm. Code 620.410 is excessive, and will result in unnecessary testing and follow-up work. Specific parameters with comments are as follows:

Total versus Dissolved Metals-Specifying dissolved metals will result in elimination of a significant number of false positives due to sediment.

Iron and Manganese-The presence of these elements is a function of the oxidation/reducing conditions within the aquifer, not the content in the uncontaminated soil. Major problems will result if these compounds remain on the list to be sampled and

comply with by the CCDD and UCF operators. **Recommend adding these two parameters to the Section 1100 Appendix A list of exemptions.**

Antimony, Beryllium, Boron, Cobalt, Selenium, Thallium, and Vanadium-The commercial use of these metals occur in only a few select industries. Due diligence prior to completing a Form 663 would indentify testing for these compounds prior to applying to a receiving facility, on the rare occasion that a Professional Engineer/Geologist encountered such an industry is encountered. It seems unreasonable to impose the economic burden of routinely testing every monitoring well at each quarry for these metals that are rarely encountered. Perhaps the Agency could provide groundwater data on these compounds from its statewide groundwater monitoring program that would shed additional insights on these compounds. **Recommend adding these metals to the Section 1100 Appendix A list of exemptions.**

Chloride, Sulfate, and Total Dissolved Solids-There is a statewide trend of increasing chlorides in our State's groundwater, as described by Kelly, Panno, and Hackley in the Illinois State Water Survey Report *The Sources, Distribution, and Trends of Chlorides in the Waters of Illinois* (March 2012). The significant sources of chlorides to groundwater do not include uncontaminated soil, but this increasing trend in groundwater chloride levels could trigger the Agency's non-degradation requirement due to the groundwater concentration increasing in a monitoring well due to off-site activity. Sulfates and Total Dissolved Solids contribution to groundwater do not include uncontaminated soil, and all three of these represent testing for testing sake, without any rational for the need to test for these parameters. These parameters are all listed as Secondary Drinking Water Standards due to taste issues, not health issues. **Recommend adding these three parameters to the Section 1100 Appendix A list of exemptions.**

Fluoride, Nitrate, and Perchlorate-Sources to groundwater of these three additional inorganic parameters are not associated with uncontaminated soil, and need not be tested. **Recommend adding these parameters to the Section 1100 Appendix A list of exemptions.**

Organic Chemical Constituents-Section 620.410(b) contains a long list of organic constituents. The volatile compounds tend to be mobile and represent a potential impact to groundwater, but to simply require testing all organics, without any regard to their mobility makes no technical or economic sense. As noted previously, the Agency's *Illinois Integrated Water Quality Report and Section 303(d) List-2012, Volume II: Groundwater*, focused on volatile organics, chlorides, nitrates, and herbicides, as these are the parameters that have impacted our State's groundwater. Soils from agricultural areas (which could contain herbicides) are not sent off site to CCDD and USF operations.

As a final comment, the Agency will likely be concerned that one or more of the parameters recommended **could** be present at these CCDD and USF sites. There is nothing that would preclude the Agency from collecting its own samples and testing for these parameters as they deem this to be an appropriate expenditure of the State's financial resources.

MAXIMUM PH ON UNCONTAMINATED SOIL

When the Board adopted the higher minimum pH of 6.25, it also imposed, unexpectedly to all participants, a maximum pH of 9.0. This has created a number of problems, as the aggregate limestone used beneath both roadways and buildings can have a pH as high as 12.45, as documented in my comments submitted on November 30, 2012. The soil pH limit does not apply to the CCDD material, although where CCDD material and uncontaminated soil are co-mingled, then the pH limit would apply. It is my understanding the Agency has recently tested at some of the permitted facilities in Illinois, and hopefully they will share the pH samples they found in the facilities that receive CCDD material with the uncontaminated soil. I have experienced rejected loads of aggregate with minimal uncontaminated soil due to elevated pH. As many of the quarries are limestone quarries, where pH values are higher than 9.0, this limit does not make technical sense. I would note that under the federal pretreatment regulations, there is no upper federal pH limit to what can be discharged to the sanitary sewer. If there is concern that an upper limit is necessary, then I would recommend 12.5, which would allow limestone to be placed in these limestone quarries. **Recommendation: Eliminate from the restriction on uncontaminated soil with pH values above 9.0.**

CODIFY THE MAXIMUM ALLOWABLE CONCENTRATIONS IN THE REGULATIONS

During the proceedings, only items like the minimum pH were vetted, relying on the Agency to then establish the MACs based on TACO and other criteria. The record included some discussion on the five percent of naturally occurring samples that will exceed the arsenic MAC, and whether the Agency believed this five percent would be classified as a waste in its view. No other constituent was discussed. The Agency has set MAC limits for iron and manganese at the median concentration in the State of Illinois. This is clearly a problem. Even when analyzing via the alternative SPLP test, samples routinely fail the MAC limits for these compounds because the median concentration is used as the threshold test.

Chromium exists in two oxidation states, trivalent and hexavalent. In nearly all soils, chromium will be present predominantly in the trivalent state. In my experience, I do not recall ever detecting hexavalent chromium in uncontaminated soils in Illinois, but perhaps the Agency has some more extensive database they could submit into the record. The Agency, without any discussion outside the Agency, elected to establish a **total** chromium MAC based on the **hexavalent** chromium value in Table C, the pH specific table in TACO. At pH 8.75 to 9.0, this value is 21 mg/kg **hexavalent** chromium. The current MAC set by the Agency is 21 mg/kg **total** chromium. In the Agency's 1984 *A Summary of Selected Background Conditions for Inorganics in Soil*, the **mean** total chromium concentration within metropolitan areas is 21.2 mg/kg and the **median** is 16.2 mg/kg. So we know that somewhere less than half of all soil in the metropolitan areas of Illinois will fail the total chromium MAC based on these results.

If one assumes that the iron, manganese, total chromium, and arsenic concentrations are independent of each other in uncontaminated soils in Illinois and assuming that 40 percent of the naturally occurring chromium will exceed 21 mg/kg, then if just these four metals are tested for, the probability of passing the MAC is as follows:

$$\begin{aligned} \text{Probability of passing} &= (P_{\text{iron}})(P_{\text{Mn}})(P_{\text{Cr}})(P_{\text{As}}) \\ &= (0.5)(0.5)(0.6)(0.95) \\ &= 0.14, \text{ or } \mathbf{14\%} \end{aligned}$$

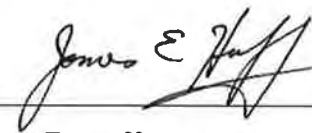
Clearly there is something very wrong when the MAC values have determined **86% of what is naturally occurring metals in the soil in Illinois is classified as *contaminated* soil!**

The Agency is aware of the above concerns, and has provided the following responses:

- 1) Why are you testing for these metals?
- 2) You can always run SPLP or TCLP.
- 3) Chromium could theoretically exist in uncontaminated soil in the hexavalent oxidation state.

Illinois needs to establish MAC limits that are protective of groundwater and also recognize background concentrations. The economic impact of the proposed CCDD regulations I provided in previous testimony and comments remain valid due to the above MAC concerns. Clearly the economic implication of the Agency's MAC values on these four metals is sufficient justification to request that the MACs be established within the framework of the Board's regulations, so that these issues are properly vetted. There are a number of CCDD and uncontaminated soil sites, as well as the Illinois Department of Transportation that require that all MAC compounds be tested for, and without some correction to the MAC tables, which the Illinois EPA has shown no inclination in doing, we are spending excessive taxpayers dollars on landfilling naturally occurring iron, manganese, chromium, and arsenic soils. **Recommendation: Expand the current docket to vet the MACs and bring these limits under the Part 1100 regulations.**

Thank you, this concludes my pre-filed testimony.



James E. Huff,

May 13, 2013

CERTIFICATE OF SERVICE

I, the undersigned, certify that on this 6th day of October, 2011, I have served electronically the attached Pre-Filed Testimony of James E. Huff, P.E., accompanying Attachments, and Notice of Filing upon the following person(s):

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James E. Huff, P.E.

Attachment 1

**ILLINOIS INTEGRATED WATER QUALITY REPORT
AND SECTION 303(d) LIST - 2012**

Clean Water Act Sections 303(d), 305(b) and 314

**Water Resource Assessment Information
and Listing of Impaired Waters**

Volume II: Groundwater

December 20, 2012

**Illinois Environmental Protection Agency
Bureau of Water**

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EXECUTIVE SUMMARY

This 2012 Integrated Report continues the reporting format first adopted in the 2006 reporting cycle. However, beginning with the 2010 cycle the Integrated Report was divided into two volumes: Volume I covering surface water quality and Volume II assessing groundwater quality. Prior to 2006, assessment information was reported separately in the Illinois Water Quality [Section 305(b)] Report and Illinois Section 303(d) List. The Integrated Report format is based on federal guidance for meeting the requirements of Sections 305(b), 303(d) and 314 of the Clean Water Act (CWA).

The basic purpose of this report (Volume II) is to provide information to the federal government and the citizens of Illinois on the condition of groundwater in the state. This information is provided in detail in Section C and in Appendix A.

Groundwater quality and quantity are linked. Analyses of groundwater data collected from 1990 to the present continue to show an overall statistically significant increasing trend of community water supply (CWS) wells¹ with volatile organic compound (VOC) detections per year. In addition, concentrations of chlorides in the CWS probabilistic network wells utilizing sand and gravel and shallow bedrock (i.e., Silurian Dolomite) aquifers in Northeastern Illinois show a 35 percent increase in concentration compared to the state wide ambient value. These chloride monitoring results represent an overall increasing trend of groundwater degradation. At the same time, future groundwater shortages are predicted in Northeastern Illinois (Meyer, Roadcap, et. al., 2009 CMAP, 2010)

A pilot project to assess the Mahomet Aquifer as part of a national effort to design a National Ground-Water Monitoring Network (NGWMN) has been initiated by a team of state and federal agencies in Illinois and Indiana. Thus, this report includes a special focus on the quality of groundwater from CWS probabilistic network wells in the Mahomet-Teays bedrock valley. For further background on this project see the Advisory Committee on Water Information (ACWI) Subcommittee on Ground Water (SOGW) web page at: <http://acwi.gov/sogw/index.html>

¹ "Community water supply" means a public water supply which serves or is intended to serve at least 15 service connections used by residents or regularly serves at least 25 residents.

The results show that of the 354 CWS probabilistic network wells:

- **28 (8 percent)** were determined to be Not Supporting (“poor”) due to the elevated levels of nitrate and VOCs that include trichloroethylene and tetrachloroethylene. All of these wells draw their water from shallow sand and gravel aquifers, except for one, which is using a deep well from the Cambrian/Ordovician bedrock aquifer in the northern part of the state);
- **90 (25 percent)** were determined to be Not Supporting (“fair”) due to statistically significant increases chloride (Cl-) above background, detections of VOCs, nitrate (total nitrogen) greater than 3 mg/l, but have not exceeded the health-based Groundwater Quality Standards (GWQS); and
- **236 (67 percent)** were determined to be Fully Supporting (“good”), which show no detections of any of the above analytes.

Additionally, trend analyses for VOCs also show that there is a statistically significant increase in the number of CWS wells with VOC detections, despite the fact that the number of CWS analyzed for VOCs over the same time period declined, and the detection limit remained constant.

Illinois groundwater resources are being degraded. Degradation occurs based on the potential or actual diminishment of the beneficial use of the resource. When contaminant levels are detected (caused or allowed) or predicted (threat) to be above concentrations that cannot be removed via ordinary treatment techniques, applied by the owner of a private drinking water system well, potential or actual diminishment occurs. At a minimum, private well treatment techniques consist of chlorination of the raw source water prior to drinking.

PART A: INTRODUCTION

A-1. Reporting Requirements

The 2012 Integrated Report is based on guidance from the United States Environmental Protection Agency (USEPA) which is intended to satisfy the requirements of Sections 305(b), 303(d) and 314 of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) and subsequent amendments (hereafter, collectively called the “Clean Water Act” or “CWA”) in a single combined report. For this reporting cycle the Integrated Report is being divided into two volumes: Volume I covering surface water quality and Volume II assessing groundwater quality.

Accordingly, Section 102 of the CWA requires:

SEC. 102 [33 U.S.C. 1252] Comprehensive Programs for Water Pollution Control:

- (a) The Administrator shall, after careful investigation, and in cooperation with other Federal agencies, State water pollution control agencies, interstate agencies, and the municipalities and industries involved, prepare or develop comprehensive programs for preventing, reducing, or eliminating the pollution of the navigable waters **and ground waters** and improving the sanitary condition of surface and **underground waters**. In the development of such comprehensive programs due regard shall be given to the improvements which are necessary to conserve such waters for the protection and propagation of fish and aquatic life and wildlife, recreational purposes, and the **withdrawal of such waters for public water supply**, agricultural, industrial, and other purposes. For the purpose of this section, the Administrator is authorized to make joint investigations with any such agencies of the condition of any waters in any State or States, and of the discharges of any sewage, industrial wastes, or substance which may adversely affect such waters. (Emphasis added)

Further, Section 104(a)(5) of the CWA [33 U.S.C. 1254]) requires:

- 5) in cooperation with the States, and their political subdivisions, and other Federal agencies establish, equip, and maintain a water quality surveillance system for the purpose of monitoring the quality of the navigable waters **and ground waters** and the contiguous zone and the oceans and the Administrator shall, to the extent practicable, conduct such surveillance by utilizing the resources of the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the United States Geological Survey, and the Coast Guard, **and shall report on such quality in the report required under subsection (a) of section 516; and [104(a)(5) amended by PL 102-285] (Emphasis added)**

Section 516 of the CWA requires U.S. EPA to provide a report to Congress on the quality of water, including groundwater. States are required to report biennially on the quality of water with an emphasis on navigable waters pursuant to Section 305(b) of the CWA, and compared to the objectives established in Section 304(a)(1) of the CWA. Section 304(a)(1)(A) of the CWA

requires that water quality criteria developed must also consider pollutants that originate from groundwater:

“The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall develop and publish, within one year after the date of enactment of this title (and from time to time thereafter revise) criteria for water quality accurately reflecting the latest scientific knowledge (A) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life, shore lines, beaches, esthetics, and recreation which may be expected from the presence of pollutants in any body of water, **including ground water...**”

Thus, for these reasons, and the hydrologic connection between groundwater and surface water, that the Illinois EPA has established an integrated monitoring strategy, and includes a volume in our Section 305(b) Report on ambient groundwater monitoring results.

Illinois reports the resource quality of its waters in terms of the degree to which the beneficial uses² of those waters are attained and the reasons (causes and sources) beneficial uses may not be attained. In addition, states are required to provide an assessment of the water quality of all publicly owned lakes, including the status and trends of such water quality as specified in Section 314(a)(1) of the CWA.

Section 303(d) of the CWA and corresponding regulations in Title 40 of the Code of Federal Regulations, require states to:

- Identify water quality-limited waters where effluent limitations and other pollution control requirements are not sufficient to implement any water quality standard;
- Identify pollutants causing or expected to cause water quality standards violations in those waters;
- Establish a priority ranking for the development of Total Maximum Daily Load³ (TMDL) calculations including waters targeted for TMDL development within the next two years; and,
- Establish TMDLs for all pollutants preventing or expected to prevent the attainment of water quality standards.

This list of water quality limited waters is often called the 303(d) List.

To the extent possible, this 2012 Illinois Integrated Report is based on USEPA's *Guidance for 2006 Assessment, Listing and Reporting Requirements Pursuant to Sections 303(d), 305(b) and 314 of the Clean Water Act* issued July 29, 2005 and additional guidance contained in USEPA memorandums from the Office of Wetlands, Oceans and Watersheds regarding Clean Water Act Sections 303(d), 305(b), and 314 Integrated Reporting and Listing Decisions.

² Beneficial uses, also called designated uses, are discussed in more detail in Section B-2 Groundwater Protection Programs, Illinois Groundwater Quality Standards.

³ Total Maximum Daily Load calculations determine the amount of a pollutant a water body can assimilate without exceeding the state's water quality standards or impairing the water body's designated uses.

A-2. Changes from the 2010 Report Methodology and Format

As stated above, the 2010 Integrated Report was divided into two volumes: Volume I covering surface water quality and Volume II assessing groundwater quality. This was done to accommodate the increased size of the Integrated Report, which has been greatly expanded to include more water quality information. This two volume format also improves the organizational structure of the report and makes it easier for the reader to find the specific information that may be of concern.

In all other aspects, the Illinois EPA is using the same methodology and format in 2012 as was completed in 2010 with no significant changes.

PART B: BACKGROUND INFORMATION

B-1. Total Waters

There are approximately 4,864 groundwater dependent public water supplies in the state, of which 1,180 utilize community water supplies (either source water or purchase). In addition, the Illinois Department of Public Health (IDPH) estimates approximately 400,000 residences of the state are served by private wells. This equates to approximately 30 percent of the population in the state that utilize groundwater as their primary source of drinking water. To assess the groundwater resources of the state, the Illinois EPA utilizes three primary aquifer classes that were developed by O'Hearn and Schock (1984). These three principal aquifers are sand and gravel, shallow bedrock and deep bedrock aquifers. O'Hearn and Schock defined a principal aquifer as having a potential yield of 100,000 gallons per day per square mile and having an area of at least 50 miles. Approximately 58 percent (32,000 square miles) of the state is underlain by principal aquifers. Of these, about 33 percent (18,500 square miles) are major shallow groundwater sources. The following are numbers of CWS wells that withdraw from these aquifers: Out of 3,420 active CWS wells, 46 percent (1,563) utilize sand and gravel aquifers; 21 percent (732) utilize a shallow bedrock aquifer; 24 percent (807) utilize a deep bedrock aquifer, 5 percent (171) utilize a combination of two or more aquifers (mixed) and 4 percent (147) are undetermined.

Table B-1. Illinois Atlas.

Topic	Value	Scale	Source
State Population in year 2010	12,830,632		US Census Bureau
State Surface Area (sq. mi.)	57,918		US Census Bureau
Active CWS Facilities	1,746	N/A	SDWIS
Surface Facilities	87	N/A	SDWIS
Groundwater Facilities	999	N/A	SDWIS
Mixed Facilities	8	N/A	SDWIS
Surface Purchase Facilities	469	N/A	SDWIS
Groundwater Purchase Facilities	183	N/A	SDWIS
Active CWS Wells	3,420	N/A	SDWIS
Confined Wells	2,240	N/A	SDWIS
Unconfined Wells	1,172	N/A	SDWIS

SDWIS = Safe Drinking Water Information System

B-2. Groundwater Protection Programs

Illinois Groundwater Quality Standards

Since the inception of the Illinois Environmental Protection Act (Act) (415 ILCS 5) in 1970, it has been the policy of the State of Illinois to restore, protect, and enhance the groundwater of the State as a natural and public resource. Establishment of comprehensive groundwater quality standards is a critical component of Illinois' groundwater protection program. To this end, the Illinois EPA established the Groundwater Quality Standards (35.Ill.Adm.Code 620). For a detailed explanation and listing of Illinois' Groundwater Quality Standards (GWQS), see the Illinois Pollution Control Board's (Board) webpage at: <http://www.ipcb.state.il.us>. Further, Section 12(a) of the Act [415 ILCS 5/12(a)] also applies to groundwater.

Groundwater Management Zone

Within any class of groundwater, a groundwater management zone may be established as a three dimensional region containing groundwater being managed to mitigate impairment caused by the release of contaminants from a site: that is subject to a corrective action process approved by the Illinois EPA; or for which the owner or operator undertakes an adequate corrective action in a timely and appropriate manner.

Groundwater Protection

For a full description of Illinois' groundwater protection programs see the Illinois Groundwater Protection Act Biennial Report at: <http://www.epa.state.il.us/water/groundwater/groundwater-protection/index.html> or contact the Groundwater Section at 217/785-4787 for more information.

B-3. Cost/Benefit Assessment

Section 305(b) requires the state to report on the economic and social costs and benefits necessary to achieve Clean Water Act objectives. Information on costs associated with water quality improvements is complex, and not readily available for developing a complete cost/benefit assessment. The individual program costs of pollution control activities in Illinois, the general surface water quality improvements made, and the average groundwater protection program costs follow.

Cost of Pollution Control and Groundwater/Source Water Protection Activities

The Illinois EPA Bureau of Water distributed a total of \$239.3 million in loans during 2010 for construction of municipal wastewater treatment facilities. Other Water Pollution Control program and Groundwater/Source Water Protection costs for Bureau of Water activities conducted in 2010 are summarized in Table B-2.

Table B-2. Water Pollution Control Program Costs for the Illinois Environmental Protection Agency's Bureau of Water, 2010

Activity	Total
Monitoring	\$5,414,600
Planning	\$1,537,200
Point Source Control Programs	\$14,346,900
Nonpoint Source Control Programs	\$9,705,300
Groundwater/Source-Water Protection	\$2,096,300
Total	\$33,100,300

Groundwater Improvements

Protecting and managing groundwater is critical. Groundwater is an important natural resource that not only provides Illinois' citizens water for drinking and household uses, but also supports industrial, agricultural, and commercial activities throughout the state.

Unfortunately, industrial, agricultural and commercial activities can often produce VOCs. They are usually produced in large volumes and are associated with products such as plastics, adhesives, paints, gasoline, fumigants, refrigerants, and dry-cleaning fluids. They can reach groundwater through many sources and routes, including leaking storage tanks, landfills, infiltration of urban runoff and wastewater, septic systems, and injection through wells. Volatile organic compounds are an important group of environmental contaminants to monitor and manage in groundwater because of their widespread and long-term use, as well as their ability to persist and migrate in groundwater. Further analysis of VOC detections in CWS wells are provided in Section C-6 of this Integrated Report.

The Illinois EPA and IDPH continue to promote the "Safe Well Water Initiative" to increase awareness of private well owners in Illinois of the need to have regular testing for VOCs that potentially may have historically contaminated groundwater sources. The primary purpose of this effort is to ensure that citizens across our state who obtain drinking water from an estimated 400,000 private wells do not have a potential health risk from contamination.

As part of this initiative, the Illinois EPA has posted several helpful documents on our Web site, <http://www.epa.state.il.us/community-relations/fact-sheets/safe-water-wells/index.html>, including instructions on private well testing, laboratories accredited to analyze water samples for VOCs, links to fact sheets regarding potential health effects from exposure to specific VOCs, and information on Illinois' Right To Know (RTK) Laws that keep the public informed about their public and private drinking water sources

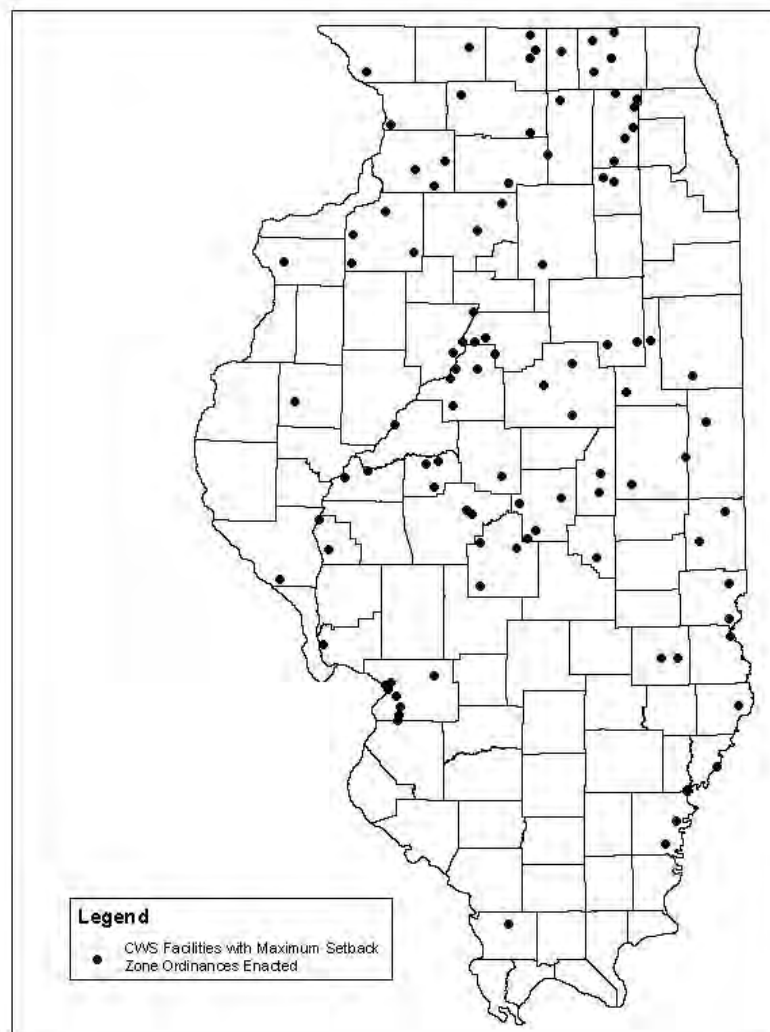
Maximum setback zones are used to expand protection to a CWS well and lower potential for groundwater contamination. Maximum setback zone protection is becoming increasingly important because of RTK legislation. Due to the increasing trend of VOC contamination, the voluntary wellhead protection approach pays off, and costly, unneeded expenses may be avoided with additional protection. The Illinois EPA and Illinois Rural Water Association have provided maximum setback zone educational information during CWS site visits and at professional conventions.

The locations of the CWSs that have adopted maximum setback zones are shown in Figure B-1. A total of 111 CWS with a total of 360 active wells have maximum setback zone protection. During this two-year reporting period, Caterpillar Trails Public Water District, Cowden, Geneseo, Illiopolis, Lake in the Hills, Mazon, and Ridge Farm have pursued adopting maximum setback zones for 23 CWS wells. Additionally, Albion, Assumption, Curran-Gardner Public Water District, Earlville, Hoopston, Toluca, Tonica, and Wenona are pursuing maximum setback zone adoption for 18 CWS wells. Furthermore, the Fayette Water Company is pursuing maximum setback zones through the Board for six CWS wells.

For a detailed discussion of groundwater protection improvements, please refer to the recently published Interagency Coordinating Committee on Groundwater Biennial Comprehensive Status and Self-Assessment Report on Illinois Groundwater Protection Program at:

<http://www.epa.state.il.us/water/groundwater/groundwater-protection/index.html>.

Figure B-1. Maximum Setback Zones Adopted



PART C: GROUNDWATER MONITORING AND ASSESSMENT

C-1. Resource-Quality Monitoring Program

Hydrologic Background

To assess the groundwater resources of the state, the Illinois EPA utilizes three primary aquifer classes (O'Hearn and Schock, 1984). These three "principal aquifers" are sand and gravel, shallow bedrock and deep bedrock aquifers, as illustrated in figures C-1 thru C-3. A principal aquifer is defined as having a potential yield of 100,000 gallons per day per square mile and having an area of at least 50 miles.

Figure C-1. Principal Sand and Gravel Aquifers in Illinois



Figure C-2. Principal Shallow Bedrock Aquifers in Illinois

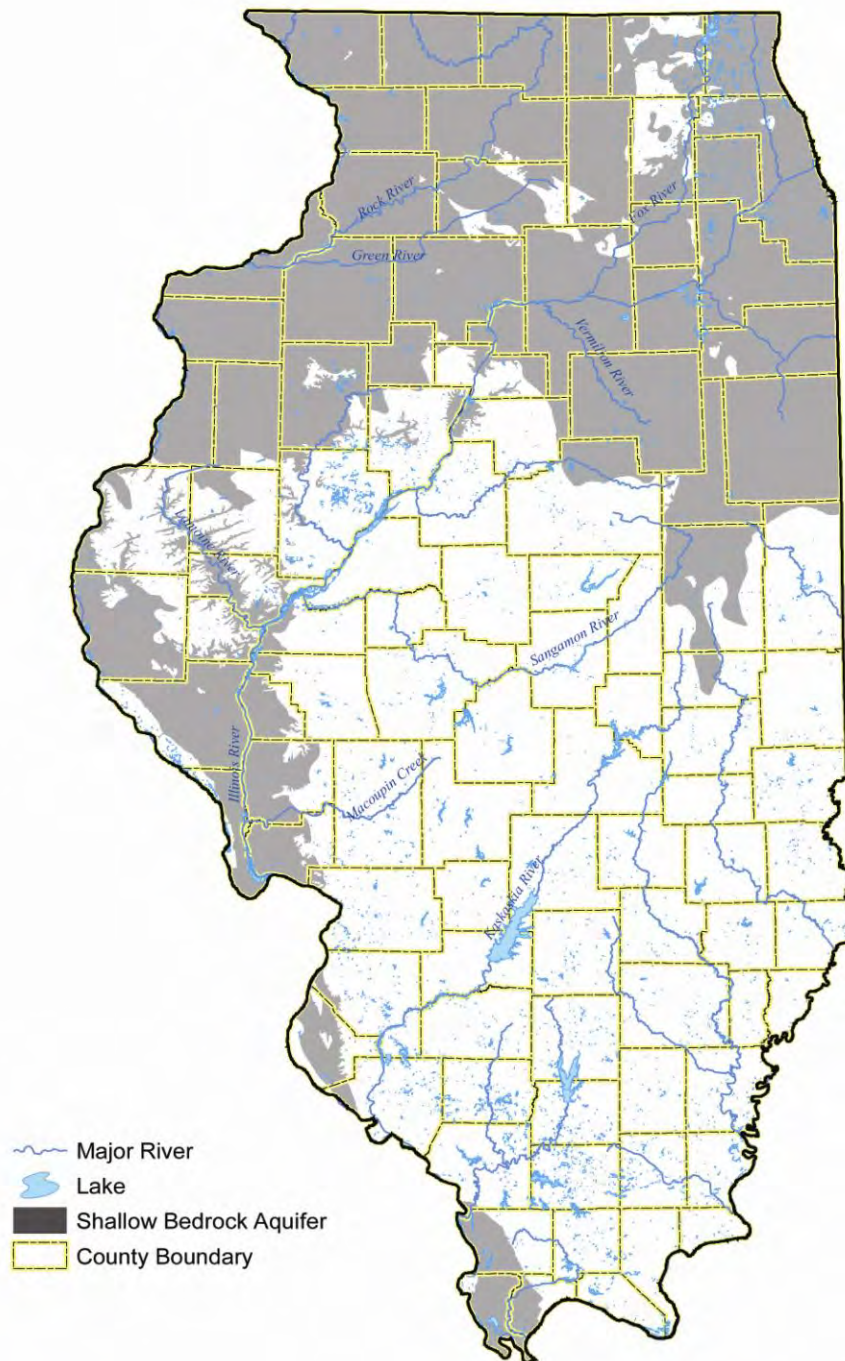
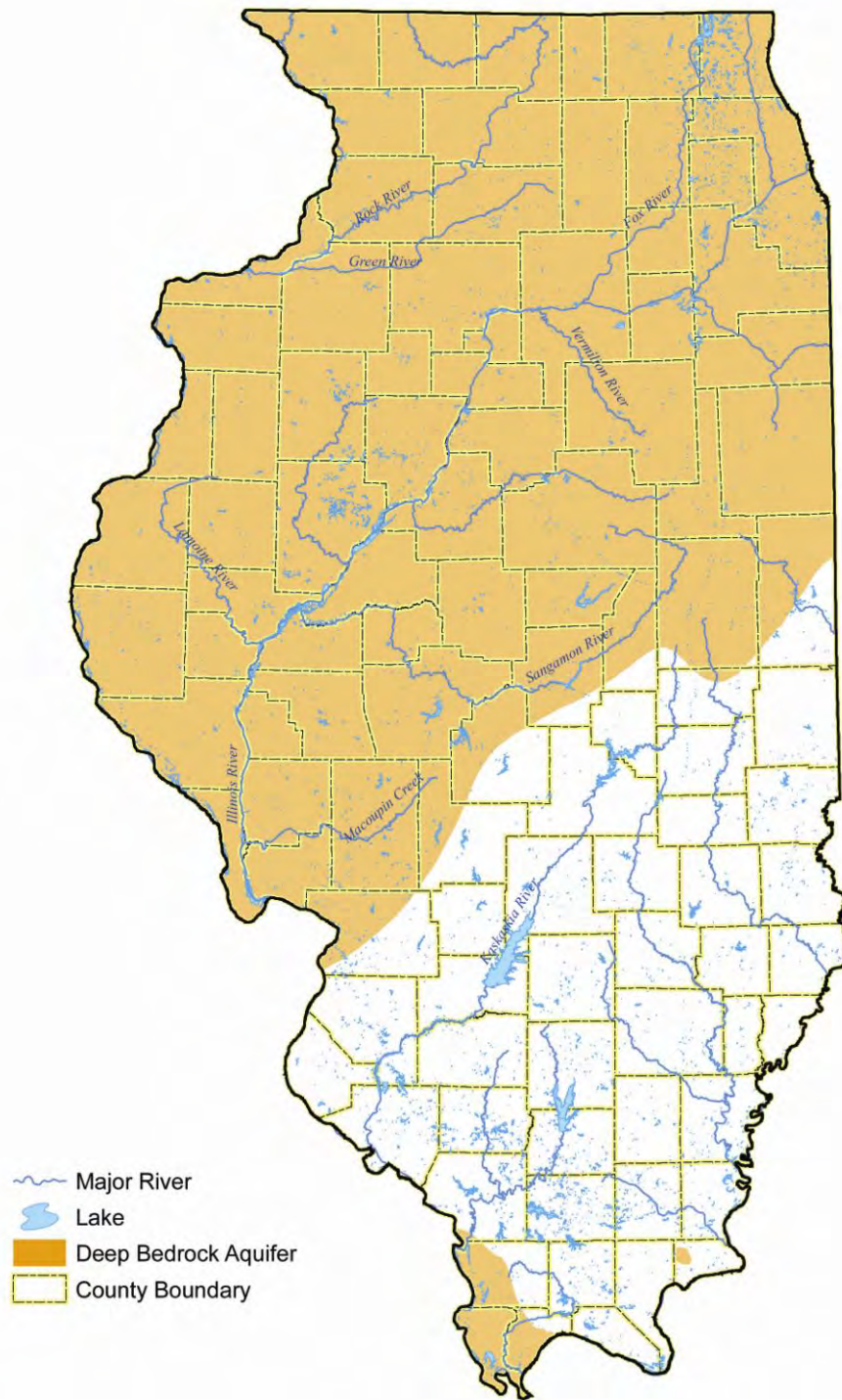


Figure C-3. Principal Deep Bedrock Aquifers in Illinois



Water resource availability can be expressed in a number of ways. In the groundwater field, the term “potential yield” or “safe yield” is often used. Potential aquifer yield is the maximum amount of groundwater that can be continuously withdrawn from a reasonable number of wells and well fields without creating critically low water levels or exceeding recharge (Wehrmann, et. al., 2003). Statewide estimates of groundwater availability, based on aquifer potential yield estimates, were developed in the late 1960s (Illinois Technical Advisory Committee on Water Resources, ITACWR, 1967). The ITACWR report presented maps of the estimated potential yields, expressed as recharge rates in gallons per day per square mile (gpd/mi²), of the principal sand and gravel and shallow bedrock aquifers of Illinois. For reference, a recharge rate of 100,000 gpd/mi² is equal to 2.1 inches/year (Wehrmann, et. al., 2003).

The 1967 ITACWR report stated the following:

- The potential yield of the [sic] principal sand and gravel and bedrock aquifers in Illinois are estimated to be 4.8 and 2.5 billion gallons per day (bgd), respectively;
- The total groundwater potential in Illinois based on full development of either sand and gravel or bedrock aquifers, whichever has the higher recharge rate, is estimated to be 7.0 bgd;
- Principal sand and gravel aquifers underlie only about 25 percent of the total land area in Illinois;
- About 3.1 bgd, or about 65 percent of the total potential yield of the principal sand and gravel aquifers in the state, is concentrated in less than 6 percent of the total land area in Illinois and is located in alluvial deposits that lie directly adjacent to major rivers such as the Mississippi, Illinois, Ohio, and Wabash;
- About 0.5 bgd, or about 10 percent of the total potential sand and gravel yield is from the principal sand and gravel aquifers in the major bedrock valleys of the buried Mahomet Valley in east-central Illinois and in the river valleys of the Kaskaskia, Little Wabash, and Embarras Rivers in southern Illinois;
- Of the total estimated yield of bedrock aquifers in the State, 1.7 bgd, or 68 percent, is available from the shallow bedrock aquifers, mainly dolomites in the Northern third of the State;
- The potential yield of the shallow dolomite varies. In areas where the more permeable shallow dolomites lie directly beneath the glacial drift, the potential yield ranges from 100,000 to 200,000 gpd/mi²;
- In areas where less permeable dolomites lie directly beneath the drift or are overlain by thin beds of less permeable rocks of Pennsylvanian age, the potential yield ranges from 50,000 to 100,000 gpd/mi²; and
- Where the overlying Pennsylvanian rocks are thick, the potential yield is less than 50,000 gpd/mi².

Future groundwater shortages are predicted in Northeastern Illinois (Meyer, Roadcap, et. al., 2009). In addition, although shortages are not predicted, the Mahomet Aquifer in Champaign/ Urbana shows significant drawn down trends (Roadcap, and Wehrmann, 2009 and MAC, 2009). Approximately 58 percent (32,000 square miles) of the state is underlain by principal aquifers; of these, about 33 percent (18,500 square miles) are shallow groundwater sources. The following are numbers of community water supply wells that withdraw from these aquifers:

Out of 3,420 active CWS wells:

- 46 percent (1,563) utilize a sand and gravel aquifer;
- 21 percent (732) utilize a shallow bedrock aquifer;
- 24 percent (807) utilize a deep bedrock aquifer;
- 5 percent (171) utilize a combination of two or more aquifers (mixed)
- 4 percent (147) are undetermined.

There are approximately 4,864 groundwater dependent public water supplies in the state, of which 1,180 utilize CWS (either source water or purchase). In addition, the Illinois Department of Public Health estimates approximately 400,000 residences of the state are served by private wells⁴.

Water that moves into the saturated zone and flows downward, away from the water table is recharge. Generally, only a portion of recharge will reach an aquifer. The overall recharge rate is affected by several factors, including intensity and amount of precipitation, surface evaporation, vegetative cover, plant water demand, land use, soil moisture content, depth and shape of the water table, distance and direction to a stream or river, and hydraulic conductivity of soil and geologic materials (Walton, 1965).

Figure C-4. Potential for Aquifer Recharge in Illinois

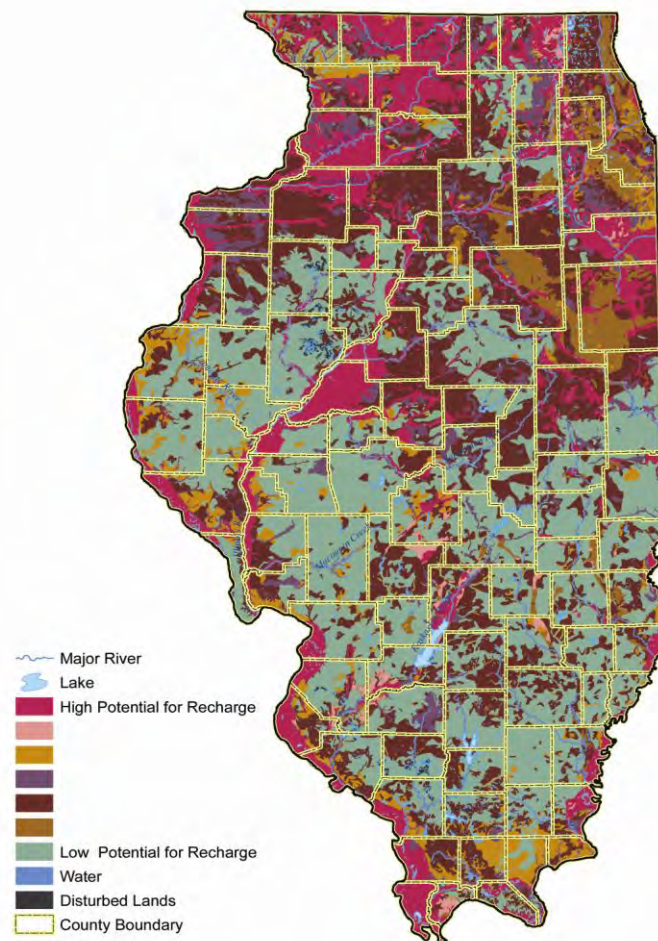


Figure C-4 illustrates the potential for aquifer recharge, defined as the probability of precipitation reaching the uppermost aquifer. The map is based on a simplified function of depth to the aquifer, occurrence of major aquifers, and the potential infiltration rate of the soil. This simplification assumes that recharge rates are primarily a function of leakage from an overlying aquitard (fine

⁴ "Private Water System" means any supply which provides water for drinking, culinary, and sanitary purposes and serves an owner-occupied single family dwelling. (Section 9(a)(5) of the Illinois Groundwater Protection Act [415 ILCS 55/9(a)(5)])

grained non-aquifer materials). Moreover, recharge may also be occurring from outside of a watershed boundary. Additionally, pumping stresses from potable water supply wells located adjacent to watershed boundaries may change the natural groundwater flow directions. Therefore, aquifer boundaries may not be consistent with surface watershed boundaries. Additional and more detailed information is available via Illinois EPA's Environmental Facts Online (ENFO): <http://www.epa.state.il.us/enfo/>.

Groundwater contribution to stream flow in the form of base flow was analyzed for 78 drainage basins in Illinois (O'Hearn and Gibb, 1980). This study determined that median base flow per square mile of drainage area generally increases from the Southwest to the Northeast at all three flow durations. Figure C-5 shows the three-year low flow streams. This provides a good indicator of groundwater base flow in surface water.

Increased withdrawal of groundwater is having a direct impact on surface water quantity. Groundwater modeling studies conducted in Kane County show that as of 2003 stream flow capture by groundwater pumping had reduced natural groundwater discharge to streams in and near Kane County by about 17 percent (Meyer, Roadcap, et. al., 2009).

Figure C-5. Three-Year Low Flow Streams in Illinois



Illinois Groundwater Monitoring Network

Section 13.1 of the Act (415 ILCS 5/13.1) requires the Illinois EPA to implement a groundwater monitoring network to assess current levels of contamination in groundwater and to detect future degradation of groundwater resources. Further, Section 7 of the IGPA (415 ILCS 55/7) requires the establishment of a statewide ambient groundwater monitoring network comprised of CWS wells, non-community water supply wells, private wells, and dedicated monitoring wells. The Interagency Coordinating Committee on Groundwater (ICCG) serves as a groundwater monitoring coordinating council. The following provides a summary of the Illinois EPA's network of CWS wells.

Prototype Ambient Groundwater Monitoring

The collection of high quality chemical data is essential in assessing groundwater protection efforts. In 1984, the Illinois State Water Task Force published a groundwater protection strategy. This strategy led to the addition of Section 13.1 to the Act (415 ILCS 5/13.1) which required the Illinois EPA to develop and implement a Groundwater Protection Plan (Plan) and to initiate a statewide groundwater-monitoring network. In response to these requirements, the Illinois EPA and the United States Geological Survey (USGS) Illinois District Office, located in Urbana, IL, began a cooperative effort to implement a pilot groundwater monitoring network (i.e., ambient monitoring network) in 1984 (Voelker, 1986). The CWS well ambient network design started with pilot efforts in 1984, moved to implementation of the ISWS network design (O'Hearn, M. and S. Schock, 1984) for several years, and was followed by sampling all of Illinois' CWS wells (3,000+) (Voelker, 1988 and 1989).

The prototype monitoring efforts included development of quality assurance and field sampling methods. Illinois EPA's quality assurance and field sampling methods, originally developed in 1984 in cooperation with the USGS, were compiled into a field manual in 1985 (Cobb and Sinnott, 1987, and Barcelona, 1985). This manual has since been revised many times to include quality improvements. Monitoring at all stations sampled by Illinois EPA is completed by using Hydrolab® samplers to insure that in-situ groundwater conditions are reached prior to sampling. Water quality parameters include: field temperature, field specific conductance, field pH, field pumping rate, inorganic chemical (IOC) analysis, synthetic organic compound (SOC), and VOC analysis. All laboratory analytical procedures are documented in the Illinois EPA Laboratories Manual.

In the year 2000, the Illinois EPA tasked the USGS to conduct a yearlong independent evaluation of our groundwater quality sampling methodology. The USGS concluded that Illinois EPA sampling program (sampling methodology guidelines, water quality meter calibration, and sampling performance) is considered to provide samples representative of aquifer water quality. Only minor revisions to the sampling program were suggested (Mills and Terrio 2003). In addition, Illinois EPA also participates in the annual USGS National Field Quality-Assurance Program.

Coordinated Ambient Monitoring

From the experience gained from these prototype networks, implemented pursuant to Section 13.1 of the Act, Illinois EPA designed a probabilistic monitoring network of CWS wells (Gibbons 1995). The design of this network was completed in coordination with the USGS, the Illinois State Geological Survey (ISGS), and the ISWS, with USGS performing the detailed design. The goal of the network is to represent contamination levels in the population of all active CWS wells. The network wells were selected by a random stratified probability-based approach using a 95 percent confidence level (CWS Probabilistic Monitoring Network). This results in an associated plus or minus 5 percent precision and accuracy level. Further, the random selection of the CWS wells was stratified by depth, aquifer type and the presence of aquifer material within 50 feet of land surface to improve precision and accuracy. Illinois EPA used geological well log records and construction log detail to perform this process.

The random stratified selection process included nearly 3,000 CWS wells resulting in 354 fixed monitoring locations, see Figure C-6. Additionally, in order to prevent spatial or temporal bias 17 random groups of 21 wells, with alternates, were selected from all the 354 fixed station wells. To further assure maximum temporal randomization within practical constraints, the samples from each sample period are collected within a three-week timeframe.

This probabilistic network is designed to provide an overview of the groundwater conditions in the CWS wells; provide an overview of the groundwater conditions in the principle aquifers (e.g., sand and gravel, Silurian, Cambrian-Ordovician, etc.); establish baselines of water quality within the principle aquifers; identify trends in groundwater quality in the principle aquifers; and evaluate the long-term effectiveness of the IGPA, CWA and Safe Drinking Water Act (SDWA) program activities in protecting groundwater in Illinois. Illinois EPA has also developed an integrated surface and groundwater monitoring strategy. This "Water Monitoring Strategy, 2007-2012" document identifies the data collection programs, and their associated goals and objectives, that will be carried out by Illinois EPA, see: <http://www.epa.state.il.us/water/water-quality/monitoring-strategy/2007-2012/index.html>. This monitoring strategy will implemented through 2012 in order to answer the question, "What is the quality of Illinois' waters?" Figure C-7 shows the Probabilistic Groundwater Monitoring Network wells integrated with the surface water monitoring stations.

During the 1997 monitoring cycle, Illinois EPA initiated a rotating monitoring network of CWS wells. Illinois EPA rotates every two years from the probabilistic (fixed station) network to special intensive or regional studies. For this reporting period, the Groundwater Section has evaluated monitoring results from the 2010 probabilistic monitoring network of CWS wells.

Figure C-6. Active Community Water Supply Wells and Community Water Supply Probabilistic Network Wells

All CWS Wells in Illinois

CWS Probabilistic Network Wells in Illinois

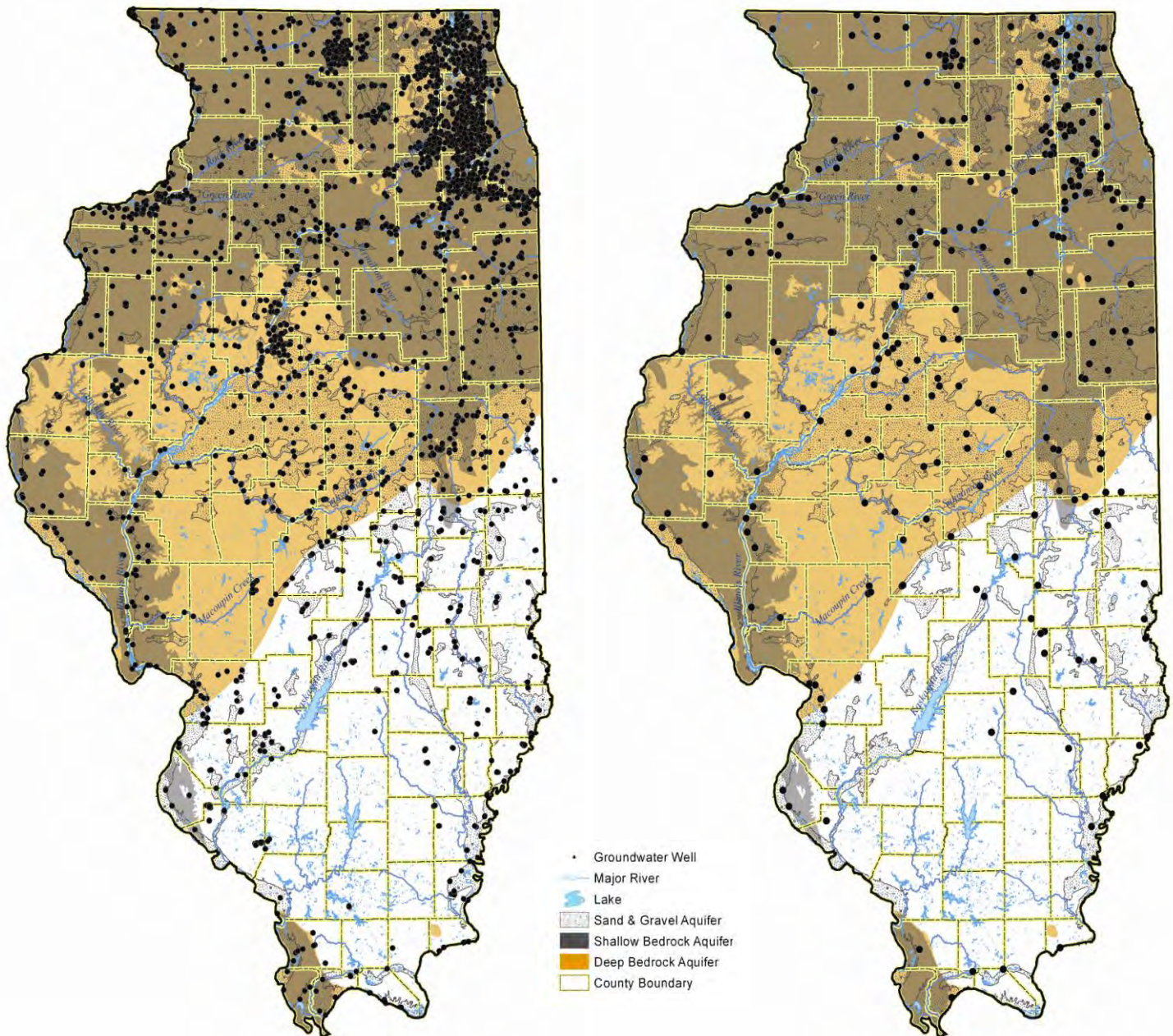
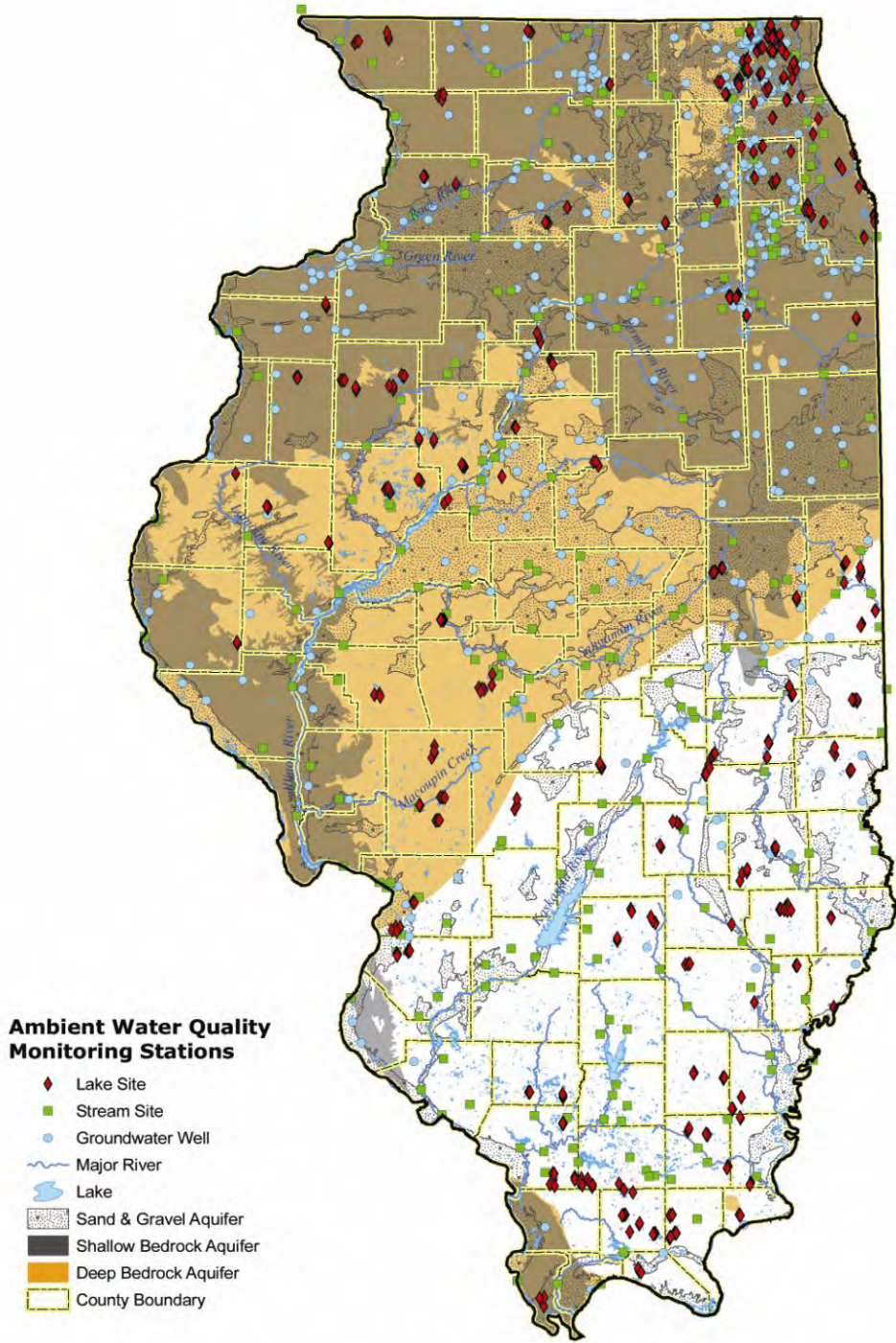


Figure C-7. Illinois EPA's integrated surface and groundwater monitoring network sites



A cooperative was established with the USGS to evaluate the occurrence of pesticides and their transformation products in CWS wells (Mills and McMillan, 2004). A random stratified statistical method was used to select 117 wells from the 354 well fixed station network to ensure representation of the major aquifer types in Illinois. For details on the pesticide sub-network of the CWS probabilistic network, see Illinois Integrated Water Quality Report and Section 303(d) List-2008 at: <http://www.epa.state.il.us/water/tmdl/303-appendix/2008/2008-final-draft-303d.pdf>, and <http://www.epa.state.il.us/water/groundwater/publications/herbicides-in-source-water-report.pdf>.

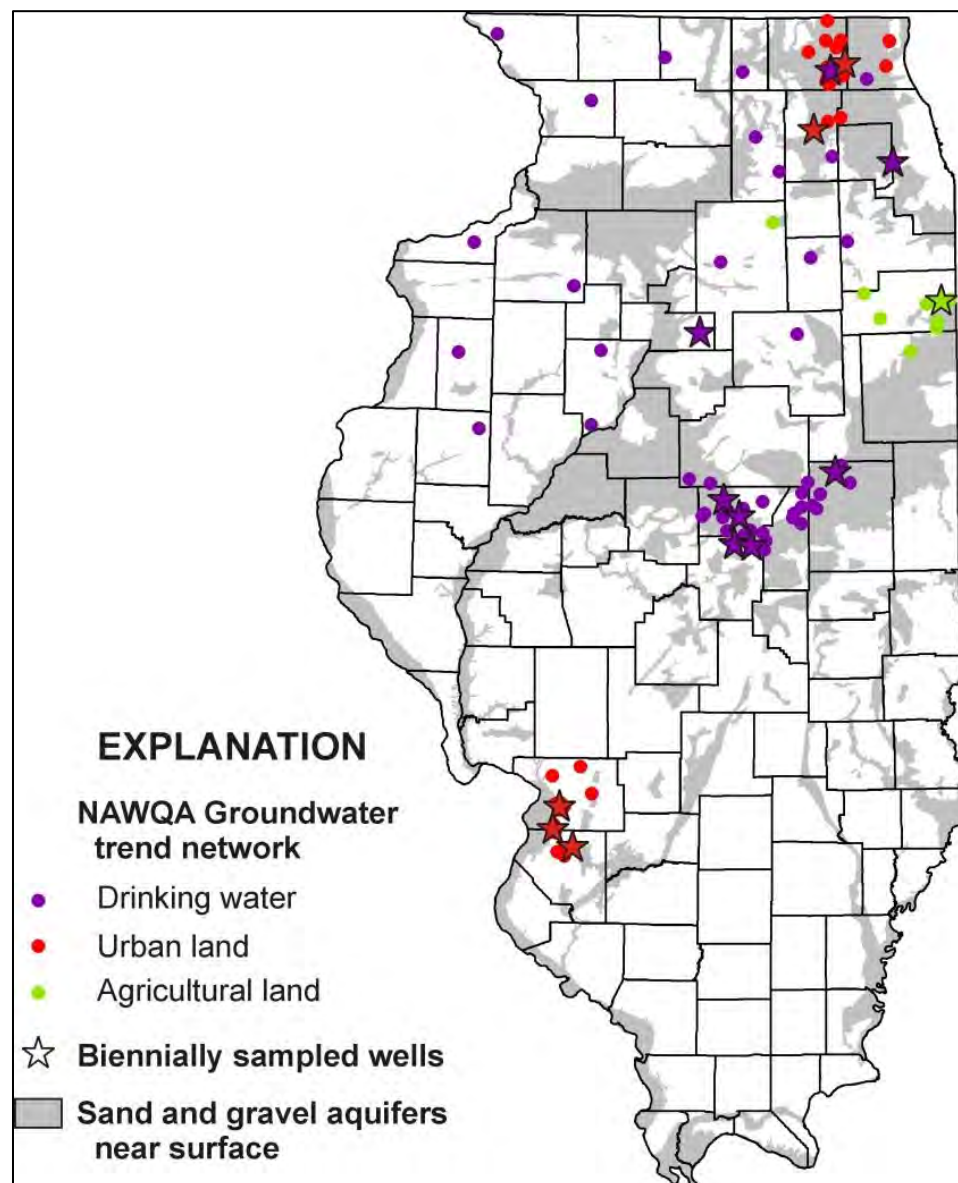
As previously stated, the IGPA required the establishment of a statewide ambient groundwater monitoring network coordinated by the ICCG, and comprised of CWS wells; non-CWS⁵ wells; private wells; and dedicated monitoring wells. Illinois also used a statistically-based approach for designing: a pilot rural private well monitoring network (Schock and Mehnert, 1992, and Goetsch et.al., 1992) and the Illinois Department of Agriculture (IDA) dedicated pesticide monitoring well network (Mehnert et al. 2005). The ICCG continues to coordinate with the USGS on groundwater monitoring studies occurring within Illinois, as described in: <http://www.epa.state.il.us/water/tmdl/303-appendix/2008/2008-final-draft-303d.pdf>.

Dedicated Monitoring Well Network for Illinois Generic Management Plan for Pesticides in Groundwater – The IDA is the state lead agency for the regulation of pesticide use in Illinois. The IDA is responsible for managing pesticide use to prevent adverse effects to human health and the environment. Illinois, like many states, is voluntarily implementing the U.S. EPA-recommended provisions of pesticide management plans to protect groundwater. In June 2000, under the leadership of the IDA, the Pesticide Subcommittee of the ICCG approved the *Illinois Generic Management Plan for Pesticides in Groundwater* (IDA, 2000). The management plan, which was revised in 2006, describes the framework to be used by the State of Illinois for addressing the risks of groundwater contamination by pesticides. Background information on the history of the management plan, including the development and design of a dedicated groundwater monitoring well network can be found at: <http://www.epa.state.il.us/water/groundwater/groundwater-protection/index.html>

USGS Illinois River Basin National Water Quality Studies – As part of the National Water Quality Assessment (NAWQA) program, the USGS is assessing both the Lower and Upper Illinois River Basins (LIRB and UIRB, respectively), see Figure C-8. A summary report of the LIRB activities through 1998 is available, see USGS Circular 1209; a similar summary of the UIRB activities through 2001 is also available, see USGS Circular 1230. Water quality and water-level data continues to be collected.

⁵ "Non-Community Water System" means a public water system which is not a community water system, and has at least 15 service connections used by nonresidents, or regularly serves 25 or more nonresident individuals daily for at least 60 days per year. (Section 9(a)(4) of the Illinois Groundwater Protection Act [415 ILCS 55/9(a)(4)]).

Figure C-8. U.S. Geological Survey NAWQA Water-Quality Network Wells



In 2010, the 30-well network in an urban land-use study area near Chicago was sampled for a large suite of pesticides, trace elements, and VOCs. In 2012, a 30-well network in the agricultural land-use study area near Kankakee will be sampled for a similar suite of constituents. The wells are mostly monitoring wells in the shallow aquifer system. In years when the full network of wells (approximately 30 wells) are not sampled, then a subset of five wells are re-sampled for assessing changes and trends (biennial samples).

Every year since 2005, water levels have been collected at all 111 wells that are part of the NAWQA trends network (table below). The Cambrian-Ordovician network was initiated in 2007 and water levels have been collected every year since it was initiated. The sampling plans for the NAWQA networks in Illinois are summarized in Table C-1, below.

Table C-1. NAWQA Networks Sampling Plans

Area of Illinois	Principal aquifer	Network type	Number Of Active Wells	Initial Network Sample	Decadal Network Sample	Biennial Sampling (5-well subset of full network)
Lower Illinois River Basin	glacial aquifer system	urban land use	26	2005	2015	2013, 2011, 2009, 2007
Lower Illinois River Basin	glacial aquifer system	drinking water resource	30	1996	2007	2013, 2011, 2009, 2005, 2002
Upper Illinois River Basin	Cambrian-Ordovician	drinking water resource	31	2007	2017	2013, 2011, 2009
Upper Illinois River Basin	glacial aquifer system	urban land use	26	2000	2010	2013, 2011, 2009, 2007, 2005, 2003
Upper Illinois River Basin	glacial aquifer system	agricultural land use	29	1999	2012	2013, 2011, 2009, 2007, 2005, 2003

The data are available in the NAWQA data warehouse Web site that provides for data delivery and mapping <http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:0>. Additionally, the data is being summarized by principal aquifer, such as the glacial aquifer system, and water-quality data from over 150 wells in the UIRB and LIRB are included in this regional synthesis. Reports and interactive maps of the regional data, including Illinois data, can be found at: <http://water.usgs.gov/nawqa/studies/praq/>.

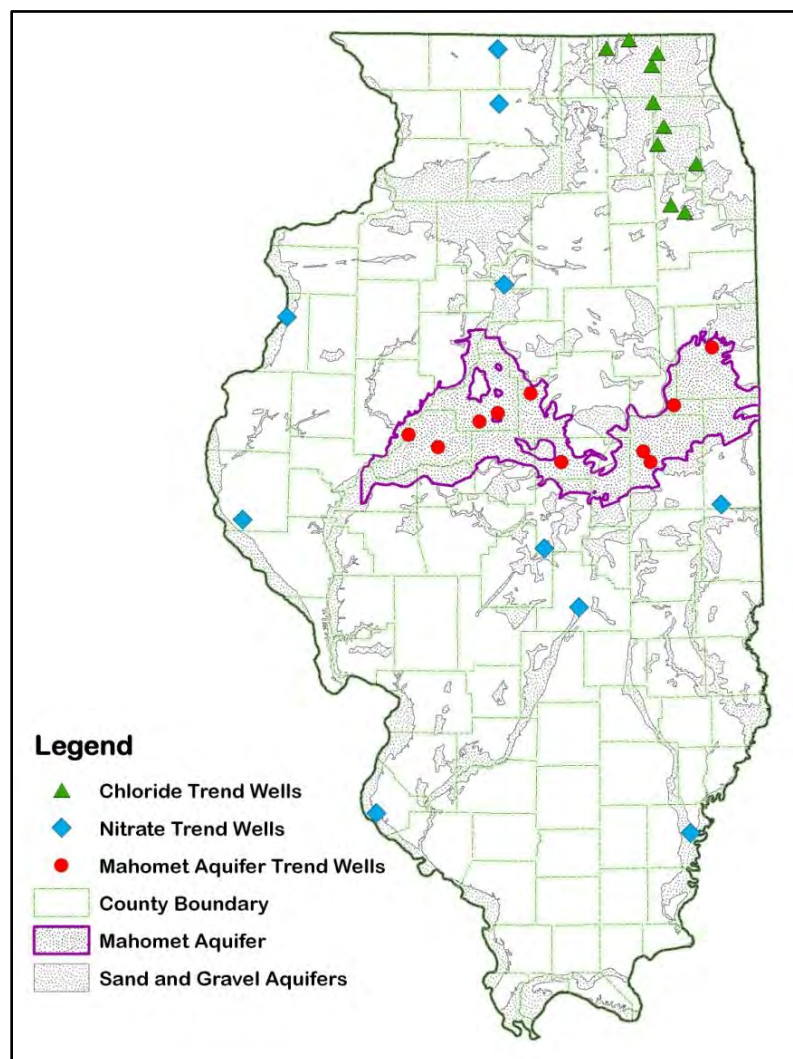
Illinois EPA Trend Monitoring Network

For the calendar year 2011, the Illinois EPA developed an inorganic chemical (IOC) Trend Monitoring Network consisting of three trend subsets with ten wells within each group (see Figure C-9). The 30 CWS wells were selected from the Probabilistic Sampling Network which provided wells with a history of IOC results. The subsets include Nitrate Trend wells, Chloride Trend wells, and Mahomet Aquifer Trend wells. Each well was sampled once every two months at approximately the same time of the month to maintain an even temporal interval between sampling events. When available, the static and pumping water levels were obtained. The groundwater monitoring data will be analyzed to determine if there were any fluctuations in the water chemistry during the next IGPA reporting period. Moreover, the detailed analysis will be included in the 2014 Integrated Report.

The *Nitrate Trend* wells are distributed throughout the state and are largely situated within sand and gravel aquifers that are more susceptible to nonpoint source contamination. These wells were selected based upon their history of nitrate detections which ranged from an average concentration of 4-11 ug/L (micrograms per liter). The majority of the wells selected for the Nitrate Trend network are located within or directly adjacent to agricultural fields and is less than 100 feet in depth.

The *Chloride Trend* wells are all concentrated in Northeastern Illinois, including, Cook, DuPage, Kane, McHenry, and Will Counties. This part of the state has been experiencing increasing levels of chloride concentrations in the past 50 years possibly related to runoff from increased use of road salt. The shallow aquifers of the region are vulnerable to surface-derived contaminants, and the increase in developed land may be increasing the rate at which groundwater quality is being degraded. Approximately 16 percent of the samples collected from municipal wells in northeastern Illinois in the 1990s had chloride concentrations greater than 100 mg/L; median values were less than 10 mg/L prior to 1960, before extensive road salting. Wells indicating both a history of relative stable chloride levels and apparent increasing levels were selected. The sand and gravel and the shallow (Silurian) bedrock aquifers are represented.

Figure C-9. Illinois EPA 2011 Trend Monitoring Network



The *Mahomet Aquifer Trend* wells are a subset of wells selected as part of a pilot study for the National Groundwater Monitoring Network (NGWMN) of the Mahomet-Teays Aquifer. The NGWMN was proposed by the Subcommittee on Ground Water of the Federal Advisory Committee on Water Information with the goal to collect and to analyze data for present and long-term water quality management and implementation needs. The Mahomet Aquifer stretches across central Illinois and into western Indiana. These trend wells were initially chosen in conjunction with the ISWS as part of the NGWMN pilot study, and were added to the Illinois EPA 2011 Trend Network as continued support in cooperation with the Mahomet-Teays Aquifer study (Statement of Interest, NGWMN, 2009).

C-2. Assessment Methodology

Overall Use Support

Though there are many uses of groundwater in Illinois, the groundwater use assessments are based primarily upon CWS chemical monitoring analyses. The assessment of chemical monitoring data essentially relies on the Board's Class I: GWQS.

The fixed station Probabilistic Monitoring Network of CWS wells is utilized to predict the likelihood of attaining full use support in the major aquifers in Illinois. As previously described, the overall use support is based on compliance with Illinois' Class I GWQS. Class I standards include the nondegradation standards. The attainment of use support is described as Full and Nonsupport, as described below:

Full Support

Good - indicates that no detections occurred in organic chemical monitoring data and inorganic constituents assessed were at or below background levels for the groundwater source being utilized.

Nonsupport

Fair - indicates that organic chemicals were detected and therefore exceed the nondegradation standard, but measured levels are less than the numerical Class I GWQS, and inorganic constituents assessed were above background level (nondegradation standard) but less than the numerical Class I GWQS.

Poor - indicates that organic chemical monitoring data detections were greater than the Class I GWQS and inorganic chemicals assessed were greater than both the background concentration and Class I GWQS.

Organic results in the probabilistic network of CWS wells, which are commonly known to be anthropogenic in nature, were analyzed by well and year. It was determined that a detection of an organic contaminant would be recorded and not averaged. In this manor, the Illinois EPA is able to track the contamination and determine if a trend in that CWS well exists.

Individual Use Support

Groundwater in Illinois supports many uses. For over 50 years, the USGS has been collecting data on estimated water withdrawals by state, source of water, and category. According to the USGS⁶, the major uses of groundwater in Illinois are domestic, public water supply, agricultural, livestock, industrial, and thermoelectric.

According to the USGS, Illinois uses approximately 15.2 billion gallons of fresh water per day. Only a small percentage – 1,210 million gallons per day (MGD), is from groundwater sources, as illustrated in Figure C-10. Irrigation uses most of the groundwater with over 479 MGD (40 percent), followed by Public Water Supplies use - 406 MGD (34 percent). Industrial (self-supplied) withdraws slightly more than 128 MGD (11 percent), followed by Domestic, which includes private well usage, 101 MGD (8 percent), and Livestock/Aquaculture at 44 MGD (3 percent). Mining (both fresh and saline) accounts for 41 MGD (3 percent) and Thermoelectric sources withdraw the least amount with approximately 7 MGD (1 percent) of groundwater usage in the State.

In addition, the ISWS conducts an annual survey of Illinois CWSs as to how much water they use in a year. These data are presented in Figure C-11 in MGD. For purposes of this discussion, only CWS use will be considered for the following assessment. All other uses are assumed to be full support with the exception of Domestic, which is assessed by the Illinois Department of Public Health.

Figure C-10. Groundwater Withdrawals in Illinois (USGS 2005)

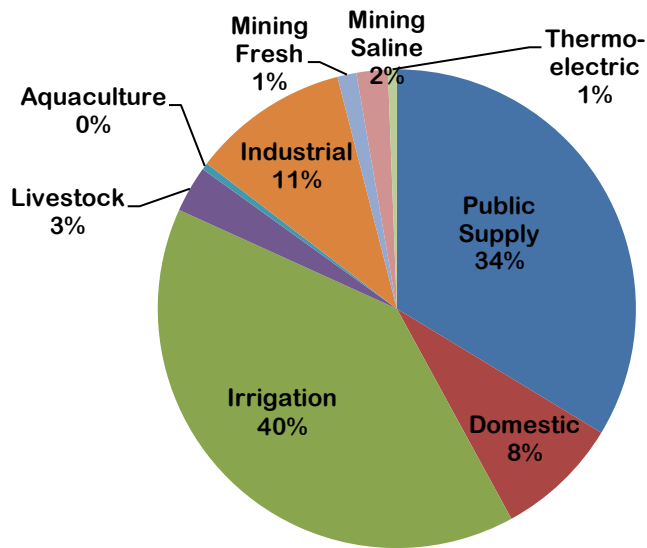
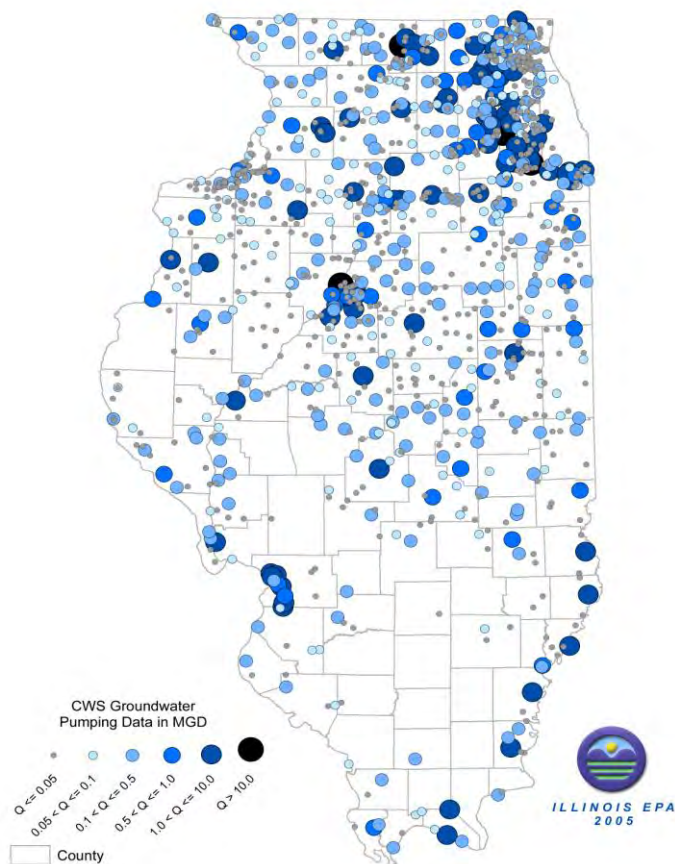


Figure C-11. Statewide CWS Pumping Rates (ISWS, 2004)



⁶ Based on USGS Circular 1344, 2005, which can be found at <http://pubs.usgs.gov/circ/1344/>

The ISWS has updated an analysis of groundwater use to aquifer potential yield in Illinois and prepared a report summarizing the findings (Wehrmann, 2003). This report compared Year 2000 groundwater withdrawals against estimated aquifer potential yields. The comparison is presented as a ratio of groundwater use (withdrawals) to groundwater yield (i.e., potential aquifer yield) on a township basis. A high use-to-yield ratio (e.g., >0.9) suggests an area where groundwater availability problems exist or could be impending⁷ in the near future (Wehrmann, 2003). For additional information, see the ISWS report at:

<http://www.sws.uiuc.edu/pubdoc/CR/ISWSCR2004-11.pdf>

Wehrmann (2003) pointed out that major withdrawals from sand and gravel aquifers can be seen in the Metro-East area of St. Louis and in Quincy along the Mississippi River; in the Peoria-Pekin area along the Illinois River, in the Fox River corridor in Northeastern Illinois, and in the Champaign area of east-central Illinois. Major withdrawals from the shallow bedrock aquifers can be clearly seen almost solely in Northeastern Illinois in southern Cook, Kankakee and Will Counties for communities such as Crest Hill, Lockport, Manteno, New Lenox, Park Forest, and Romeoville (Wehrmann, 2003). Major withdrawals from the deep bedrock are found spread across northern Illinois, particularly in the Rockford area of north-central Illinois, the Fox River corridor, and farther south in the area of Joliet and the I-55 industrial corridor near Channahon (Wehrmann, 2003).

In addition, comprehensive hydrogeologic analysis and demand studies in Northeastern Illinois predict future water shortages (Meyer, Roadcap, et. al., 2009 and CMAP, 2010). For further detail see, <http://chicagoareaplanning.org/watersupply> and http://www.isws.illinois.edu/iswsdocs/wsp/ppt/NEIL_RWSPG_Mar2009.pdf

Groundwater contributes to stream flow in the form of base flow in many of these river corridors. Thus, stream flows may also be impacted in areas where the ratio of use to yield is greater than 0.9. This is especially true in Northeastern Illinois due to the following factors: Supreme Court limitations on Lake Michigan water withdrawals; continued population growth; and a deep aquifer condition beyond sustainable recharge. It is predicted that these factors will force an increased reliance on the use of the sand and gravel and shallow bedrock aquifer resources. These shallow aquifers are in direct hydraulic connection to surface waters. This can result in decreased base flow in area streams that may have an impact on surface water quality and stream habitat.

In addition, some groundwater in Illinois is designated as Class III "special resource." Special Resource Groundwater is described as the groundwater contributing to highly sensitive areas such as dedicated nature preserves that supports ecologically sensitive areas such as the Parker Fen in McHenry County and the Southwest Sinkhole Karst Plain located in Monroe, St. Clair and Randolph Counties. For a complete list of currently adopted and proposed Class III Special Resource Groundwater designated areas of the state, see:

<http://www.epa.state.il.us/water/groundwater/groundwater-protection/index.html>

⁷ (Note: The delineation of high groundwater use to-yield areas by this method should be considered simply as a means for calling attention to areas to prioritize on a statewide basis for water resources planning and management (Wehrmann, 2003).)

C-3. Potential Causes and Potential Sources of Impairment

Potential Causes of Impairment

As previously stated, when possible, assessments of overall groundwater use support is based upon application of Illinois' GWQS (including non-degradation standards) to water quality sample measurements from the probabilistic network of CWS wells. Generally, a detection of an organic contaminant above the laboratory practical quantification limit or the detection of an inorganic constituent above the naturally occurring background level in a CWS well is considered a cause of less than full use support.

Potential Sources of Impairment

Illinois EPA utilized a database of potential sources that have been inventoried as part of well site surveys, hazard reviews; groundwater protection needs assessments, source water assessments, and other special field investigations to evaluate potential sources of contamination relative to CWS Wellhead Protection Areas (WHPAs). Further, the Illinois EPA relied on a Geographic Information System (GIS) to calculate land use activities proximate to the probabilistic network of CWS wells⁸. Table C-2 describes the most prevalent (common) potential sources of groundwater contamination in Illinois relative to CWS WHPAs.

⁸ County by county land cover grid data for Illinois derived from Thematic Mapper (TM) Satellite data from the Landsat 4 sensor. Dates of the imagery used range from 1995 to 2002.

Table C-2. Most Prevalent Potential Sources of Ground Water Contamination⁹

Contaminant Sources	Occurrence of Potential Source¹⁰	Contaminants¹¹
AGRICULTURAL ACTIVITIES		
Agricultural chemical facilities	587	A, B, E
Animal feedlots	66	E, J, K, L
Drainage wells	3	A, B, C, D
Fertilizer applications	323	A, B, E
Irrigation practices	63	A, B, E
Pesticide applications	174	A, B, E
STORAGE AND TREATMENT ACTIVITIES		
Land application	14	A, B, D, E, G, H, J
Material stockpiles	683	G, H
Storage tanks (above ground)	2,249	C, D
Storage tanks (underground)	2,878	C, D
Surface impoundments	236	E, G, H, J, K, L
Waste piles	231	E, G, H
Waste tailings	9	G, H, I, J
DISPOSAL ACTIVITIES		
Deep injection wells	9	A, B, C, D, E, F, G, H, I, M
Landfills	40	C, D, G, H, J
Septic systems	6,290	E, G, H, J, K, L
Shallow injection wells	9	A, B, C, D, E, F, G, H, J, K, L
OTHER		
Hazardous waste generators	-	A, B, C, D, G, H
Hazardous waste sites	97	A, B, C, D, G, H
Industrial facilities	1,565	A, B, C, D, G, H
Material transfer operations	232	A, B, C, D, E, F, G, H
Mining and mine drainage	19	G, H, M
Pipelines and sewer lines	111	C, D, E, G, H, J, K, L
Salt storage and road salting	76	G
Salt water intrusion	-	G
Spills	9	A, B, C, D, E, G, J
Transportation of materials	164	A, B, C, D, E
Manufacturing/repair shops	1,554	C, D, G, H
Urban runoff	1,184	A, B, D, E, G, H, J, K, L
Other sources (potential routes of contamination such as drainage wells, improperly abandoned potable water wells, or sand & gravel quarries)	249	A, B, D, E, J, K, L
FACILITY TREATMENT AND RECREATION		
Former storage facility	113	A, B, C, D, E, G, H
Commercial waste or chemical handling facility	1,078	C, D, E, G, J
Public utilities facility	203	E, F, G, H, J, K, L
Waste treatment facility	202	E, G, H, J, K, L
Recreational facility	581	J, L
Agriculture materials storage and sales	-	A, B, E, G, M

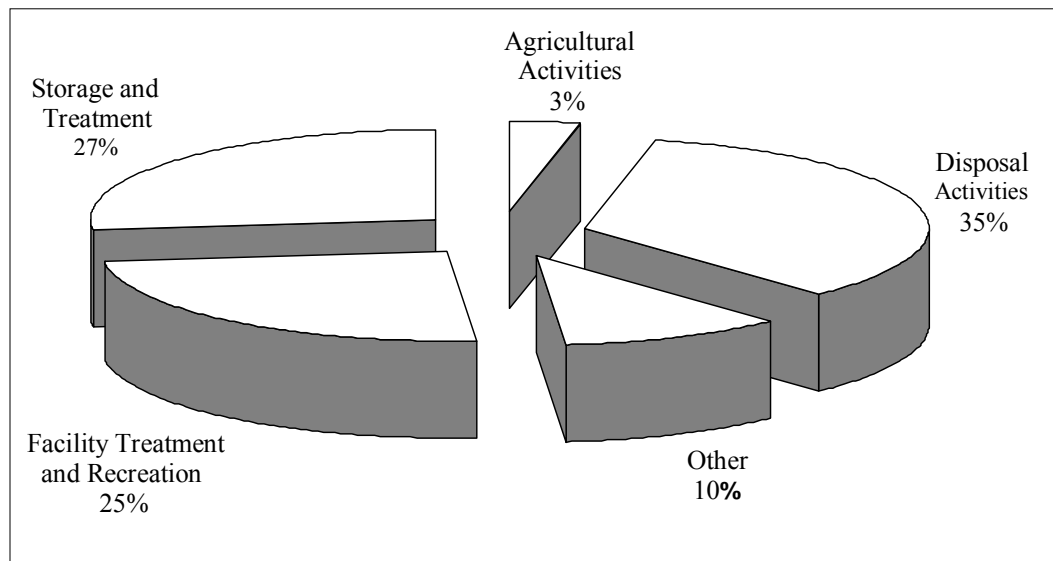
⁹ The basis for the analysis provided in this table is a combination of existing monitoring data and potential source of groundwater contamination data from the completed CWS well site survey reports which Illinois EPA has conducted over the past 20 years.

¹⁰ Occurrences are based solely on the Illinois EPA Groundwater Section's existing databases. This is only an estimate and should not be used as anything more than an approximation of potential sources of contamination to CWS wells in Illinois.

¹¹ Contaminants: A. Inorganic pesticides; B. Organic pesticides; C. Halogenated solvents; D. Petroleum compounds; E. Nitrate; F. Fluoride; G. Salinity/brine; H. Metals; I. Radio-nuclides; J. Bacteria; K. Protozoa; L. Viruses; and M. Other.

The Illinois EPA identified 16,354 potential sources of groundwater contamination of which 1,163 are considered threatening. Figure C-12 shows the most threatening potential contamination sources associated with CWS wells with VOC detects. The most prevalent potential source category was land disposal activities (2,953 sites) and the most threatening potential source category was chemical/petroleum processing/storage (255 sites) facilities.

Figure C-12. Most Threatening Potential Contamination Sources in Community Water Supply Wells with VOC detections



In addition, ISWS research on CWS wells in Northeastern Illinois has determined that road salting is the most threatening potential source causing and contributing to chloride contamination above background levels in this part of the state. Approximately 16 percent of the samples collected from CWS wells in Northeastern Illinois during the 1990s had chloride concentrations greater than 100 mg/L. However, prior to 1960 – before extensive road salting practices, the median values of groundwater samples collected from Northeastern Illinois were less than 10 mg/L (Kelly and Wilson, 2004). The 75th quartile value of the sand and gravel CWS probabilistic network wells in Northeastern Illinois show a 35 percent increase in chloride concentration compared to the state wide ambient value of CWS wells in the network.

The current occurrence of herbicide compounds found in the pesticide sub-network of the CWS probabilistic network of wells indicates that various factors, along with current agricultural land use contribute to herbicide occurrence. The USGS study of herbicide transformation and parent products determined:

“... a strong inverse relation (-0.81) between current use of land for corn and soybean production and the current occurrence of herbicide compounds in underlying aquifers indicates that various factors, along with current agricultural land use contribute to herbicide occurrence. These factors include, among others, land-use history, ground-

water age, ground-water flow patterns, geology, soil microbiology, and chemistry and persistence of the herbicide compounds (Mills and McMillan, 2004).”

C-4. Monitoring Results

Illinois Department of Agriculture Dedicated Pesticide Monitoring Well Network Results

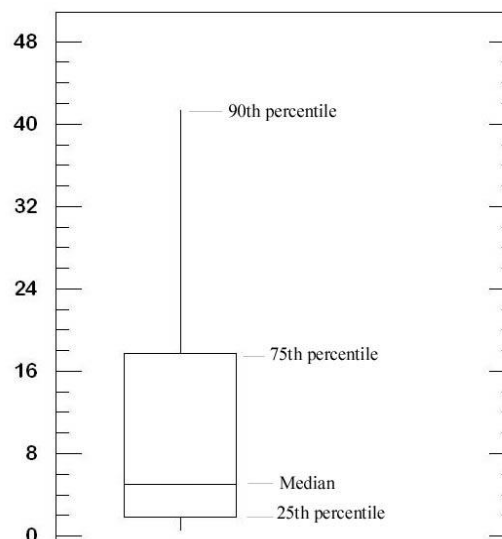
Results of the most recent sampling period (132 samples collected from October 2008 through September 2010) indicate that parent pesticides were detected in ten of the samples (7.9 percent). Atrazine was detected in five samples, metolachlor was detected in three samples, and acetochlor and simazine were each detected in one sample. Three of those samples had concentrations above levels of concern. One or more of the atrazine degradation products was present above the minimum reporting level in 19.0 percent of the samples. One or more of the metabolites of the chloroacetanilide herbicides was detected in 53.8 percent of the samples. None of those samples had concentrations above levels of concern. For a detailed discussion of the IDA's dedicated pesticide monitoring well network results see: <http://www.epa.state.il.us/water/tmdl/303-appendix/2008/2008-final-draft-303d.pdf>.

CWS Probabilistic Monitoring Network Results

Statistics have a critical role in determining environmental impacts to groundwater quality, especially with respect to IOCs. The problem is technically interesting: given a new measurement for a well in the network, drilled in a particular aquifer, and analyzed for a particular substance, what is the probability that the measurement represents an effect of an unnatural source (Gibbons, 1995). Thus, this becomes a problem of statistical prediction. Given a collection of historical or background measurements for a substance, what limit or interval will contain the new measurement with a desired level of confidence? The wells in the CWS probabilistic network are not necessarily located in areas geographically removed from potential sources of contamination, as described above (Gibbons, 1995).

Illinois EPA is using box plots to represent a snapshot of IOC measurement results for network wells drilled in particular aquifers. As illustrated in Figure C-13, a box plot provides a statistical prediction of the concentration of a substance bounded by percentiles. In other words, the box plot shows what concentration occurs between 90, 75, and 25 percent of the time for a CWS drilled in a particular aquifer. However, because the historical data set for the network may include measurement results that are due to unnatural sources, additional regional and/or site specific evaluation may be needed to determine if measurements are occurring due to natural versus unnatural sources. Figures C-14(a-d) show the IOC results for the CWS probabilistic network

Figure C-13. Sample Box Plot for the Following Figures



wells drilled in sand and gravel, shallow bedrock, deep bedrock, and mixed aquifers.

Figure C-14a. Inorganic Water Quality Data in Illinois Principal Aquifers

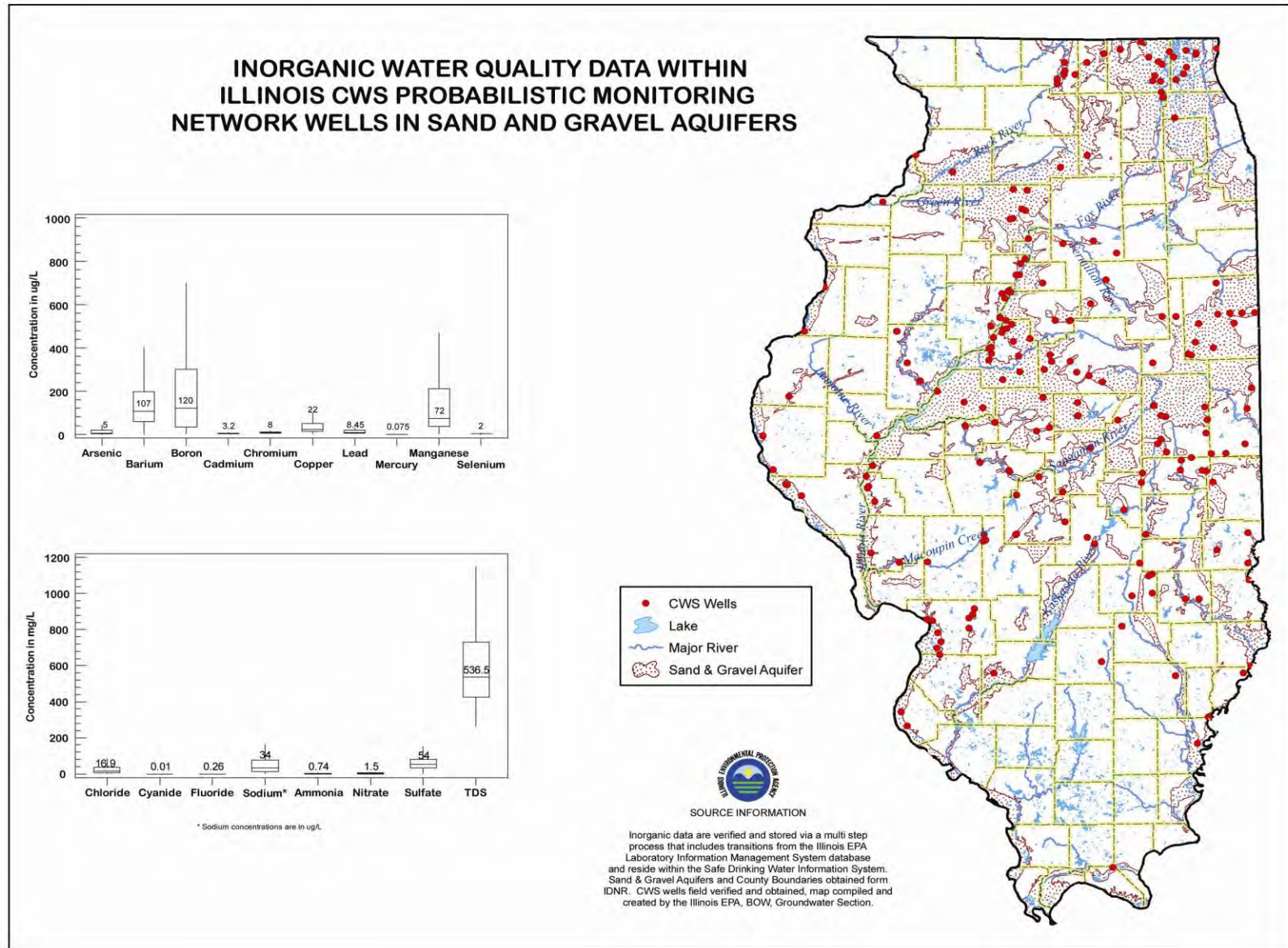


Figure C-14b. Inorganic Water Quality Data in Illinois Principal Aquifers

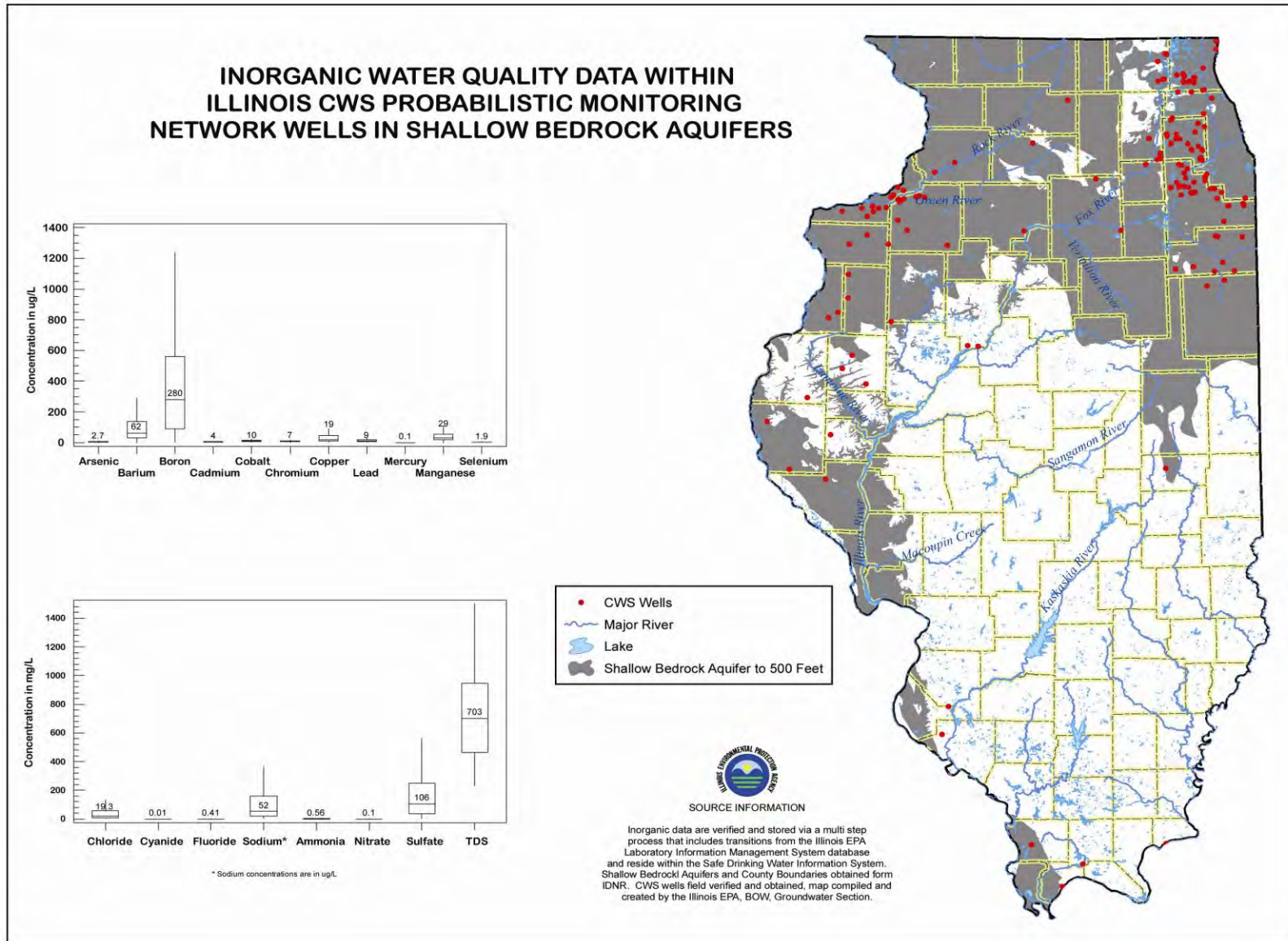


Figure C-14c. Inorganic Water Quality Data in Illinois Principal Aquifers

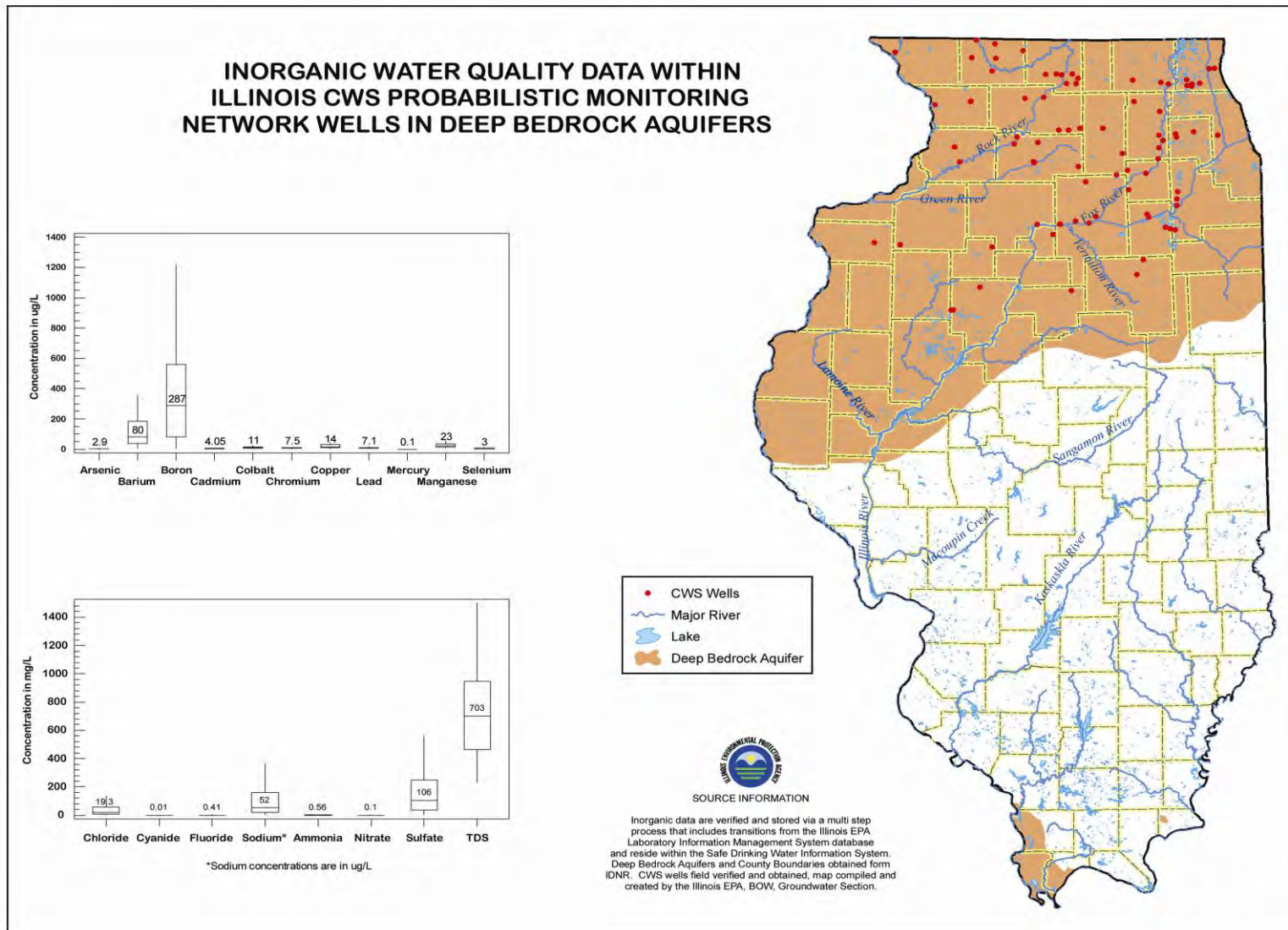
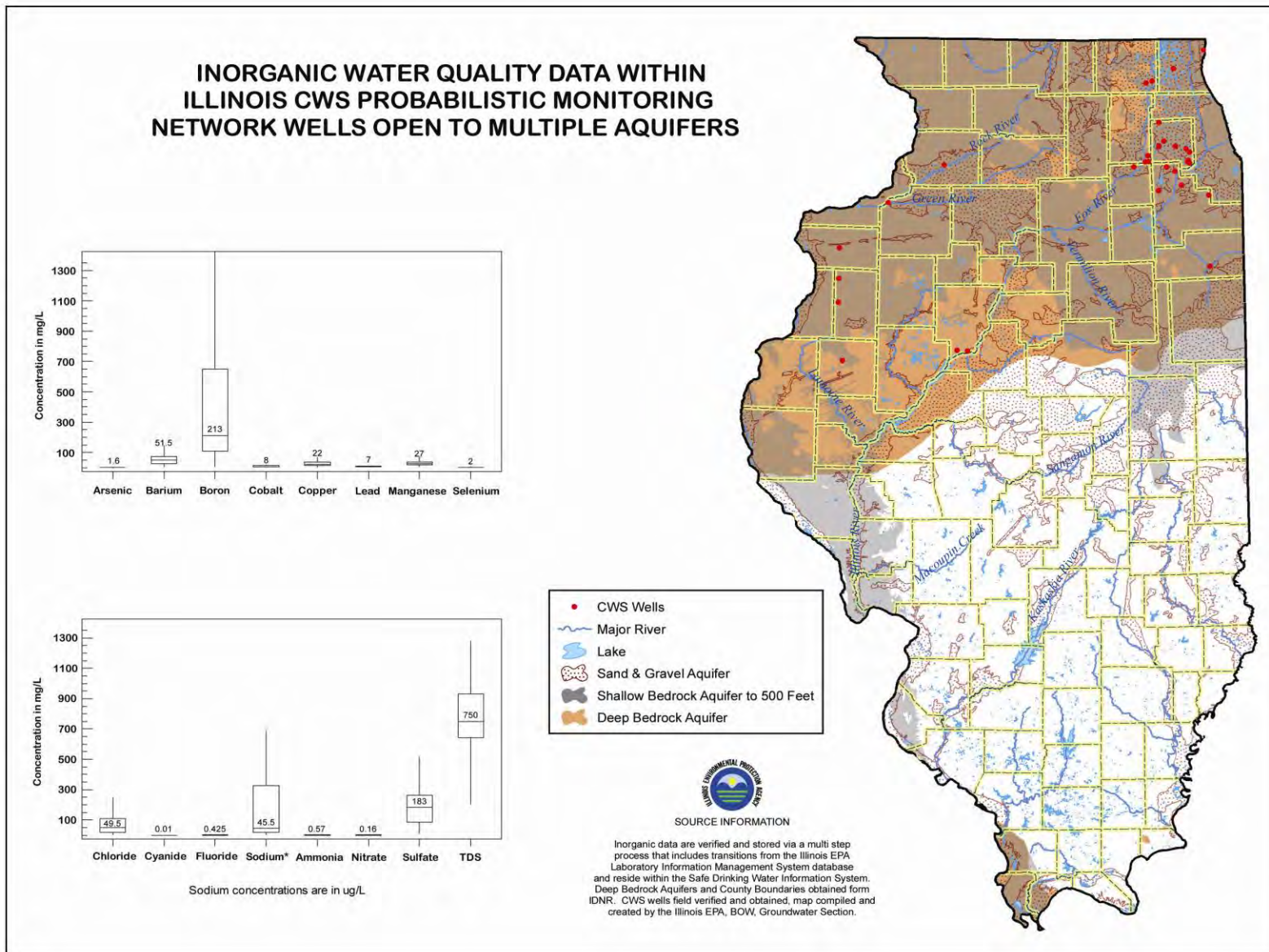


Figure C-14d. Inorganic Water Quality Data in Illinois Principal Aquifers



Northeastern Illinois Chlorides

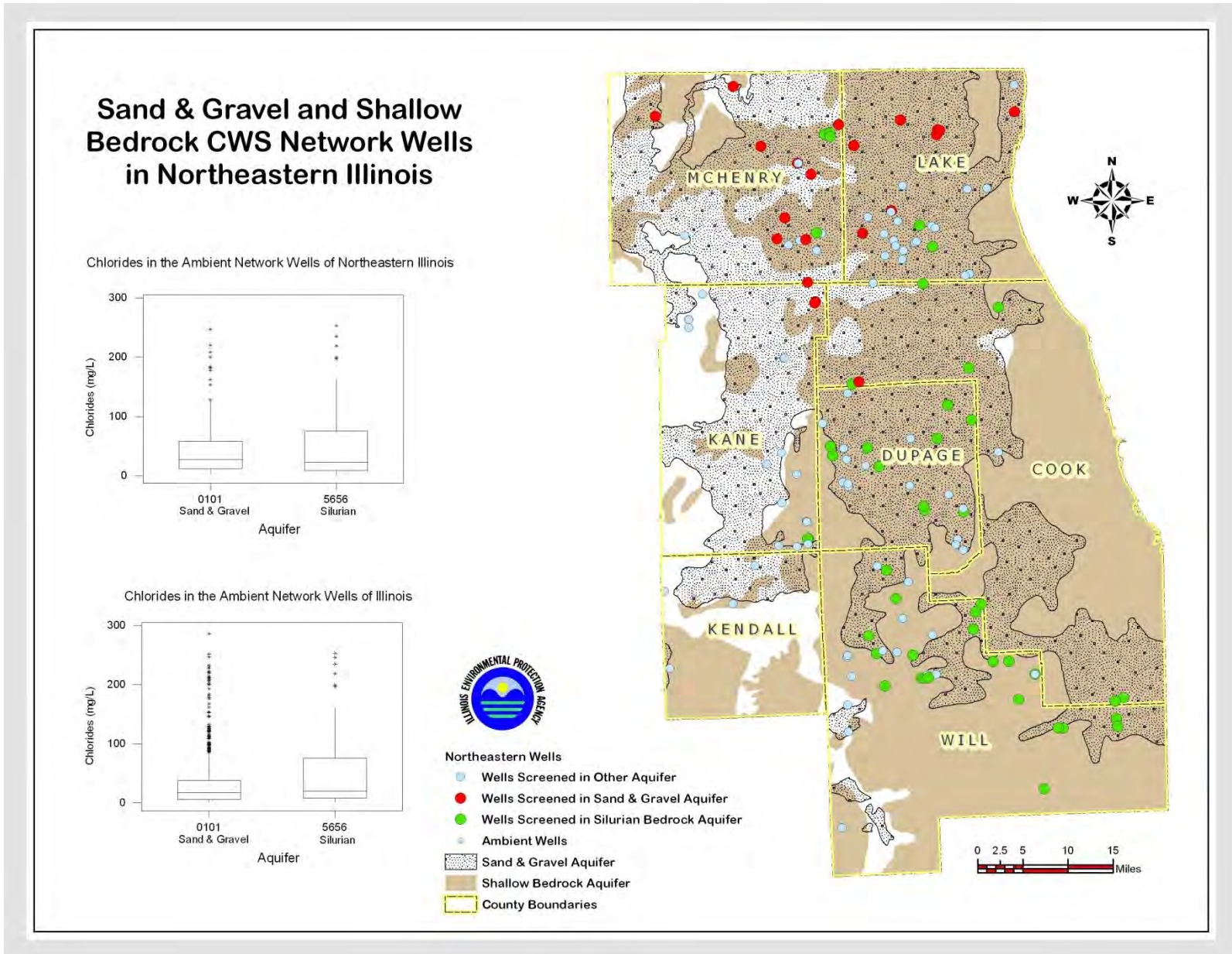
In addition to the state wide evaluation of inorganic compounds in the CWS probabilistic network presented in the maps above, Illinois EPA specifically analyzed the concentrations of chlorides in the network wells utilizing sand and gravel and shallow bedrock (i.e., Silurian Dolomite) aquifers in Northeastern Illinois (Figure C-15). Table C-3 provides a comparison of the statistical values between the Northeastern Illinois wells and the state wide CWS Network wells:

Table C-3. Northeastern Illinois and CWS Network Well Chloride statistics

Aquifer Type	Number of samples (N)	Mean	Median	Min	Max	Q3
Sand and Gravel State wide	1258	31.73	17.58	0.50	978.00	37.90
Sand and Gravel N.E. III	135	51.41	27.00	1.30	928.00	58.20
Aquifer Type	Number of samples (N)	Mean	Median	Min	Max	Q3
Silurian State wide	334	57.19	20.15	1.00	843.00	75.58
Silurian N.E. IL	282	46.75	22.00	1.00	451.00	75.58

The 75th quartile value of the sand and gravel CWS probabilistic network wells in Northeastern Illinois show a 35 percent increase in chloride concentration compared to the state wide ambient value in the CWS probabilistic network. Furthermore, as suspected there are not significant differences between the network wells in the Silurian Dolomite and Northeastern Illinois since the majority of the Silurian aquifer occurs in this portion of the state.

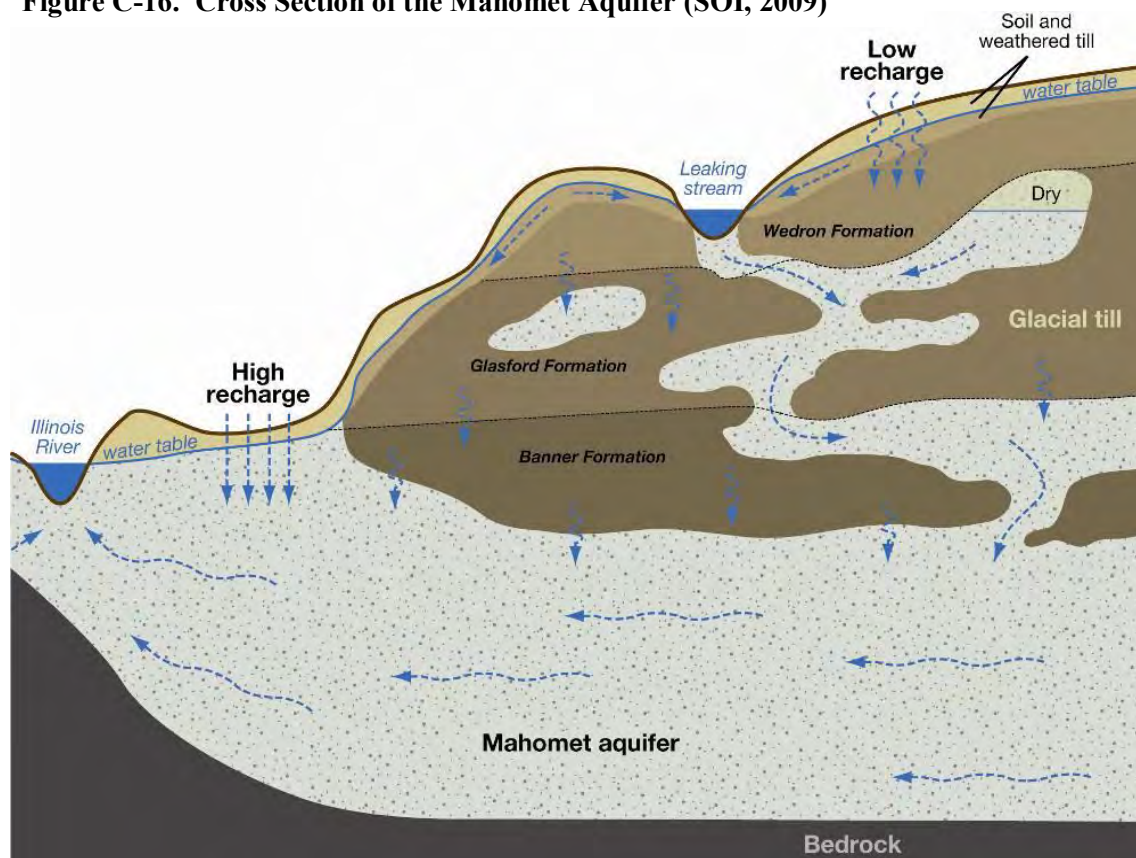
Figure C-15. Northeastern Illinois CWS Network Wells



The Mahomet Aquifer

Illinois EPA has done a focused evaluation the CWS probabilistic network wells screened in the Mahomet Aquifer. The aquifer occupies a portion of the Teays Bedrock Valley extending across east-central Illinois from the Indiana border near Hoopston to the Illinois River. The Mahomet Aquifer is comprised of various unconsolidated geologic materials as illustrated in the following conceptual model of the hydrogeology (Figure C-16)

Figure C-16. Cross Section of the Mahomet Aquifer (SOI, 2009)



Arsenic is a naturally occurring inorganic compound that has been the subject of numerous research projects and investigations in the Mahomet Aquifer. The concentration of arsenic in the CWS probabilistic network wells screened in different hydrogeologic units in the Mahomet-Teays Bedrock Valley are shown in the box plots in Figure C-17.

Further, several other inorganic compounds present in the CWS probabilistic network wells screened in the respective geologic formations in the Mahomet-Teays Aquifer are provided in Figures C-18 through C-22.

Figure C-17. Arsenic Levels in the Mahomet Aquifer

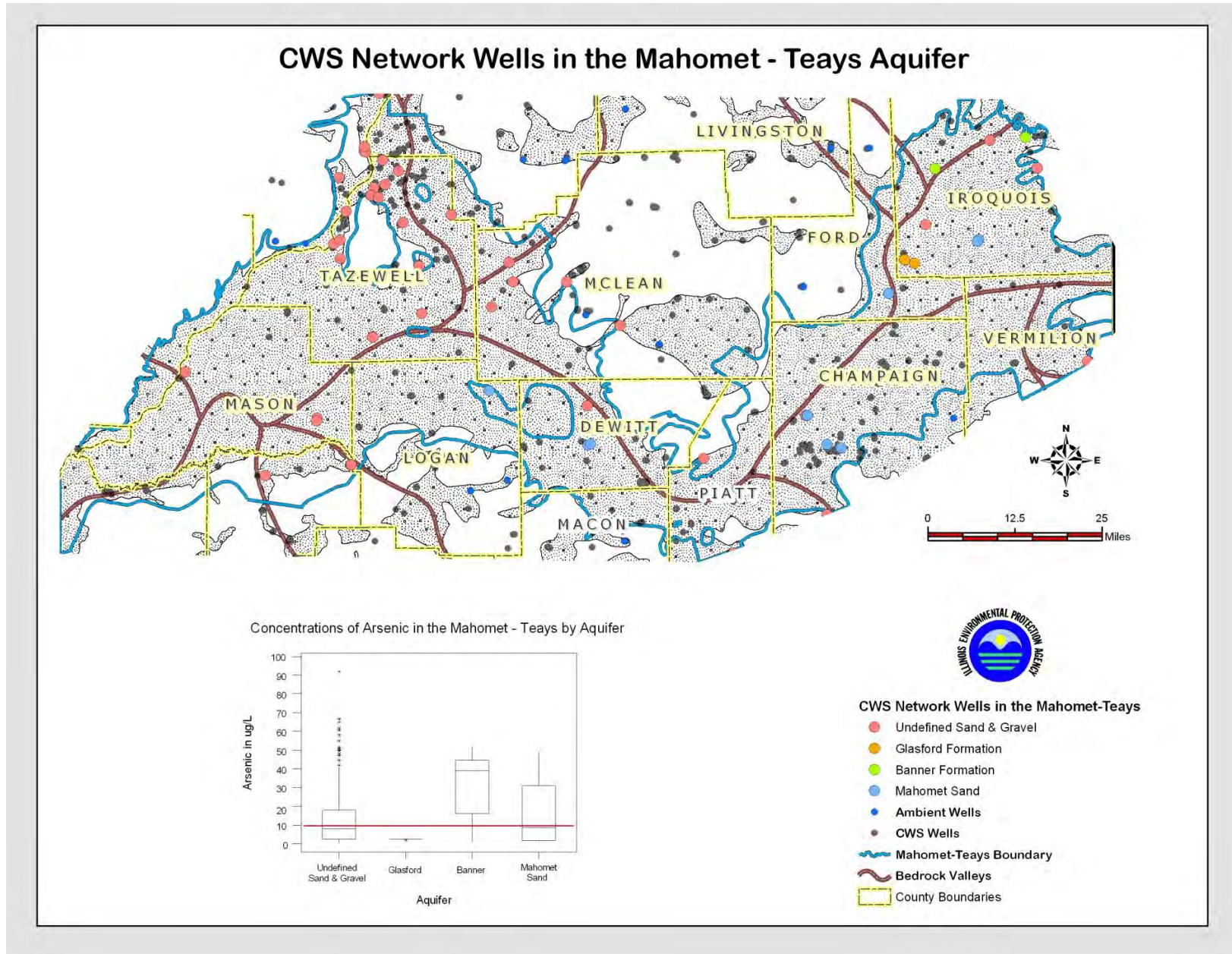


Figure C-18. Iron and TDS Levels in the formations of the Mahomet Aquifer

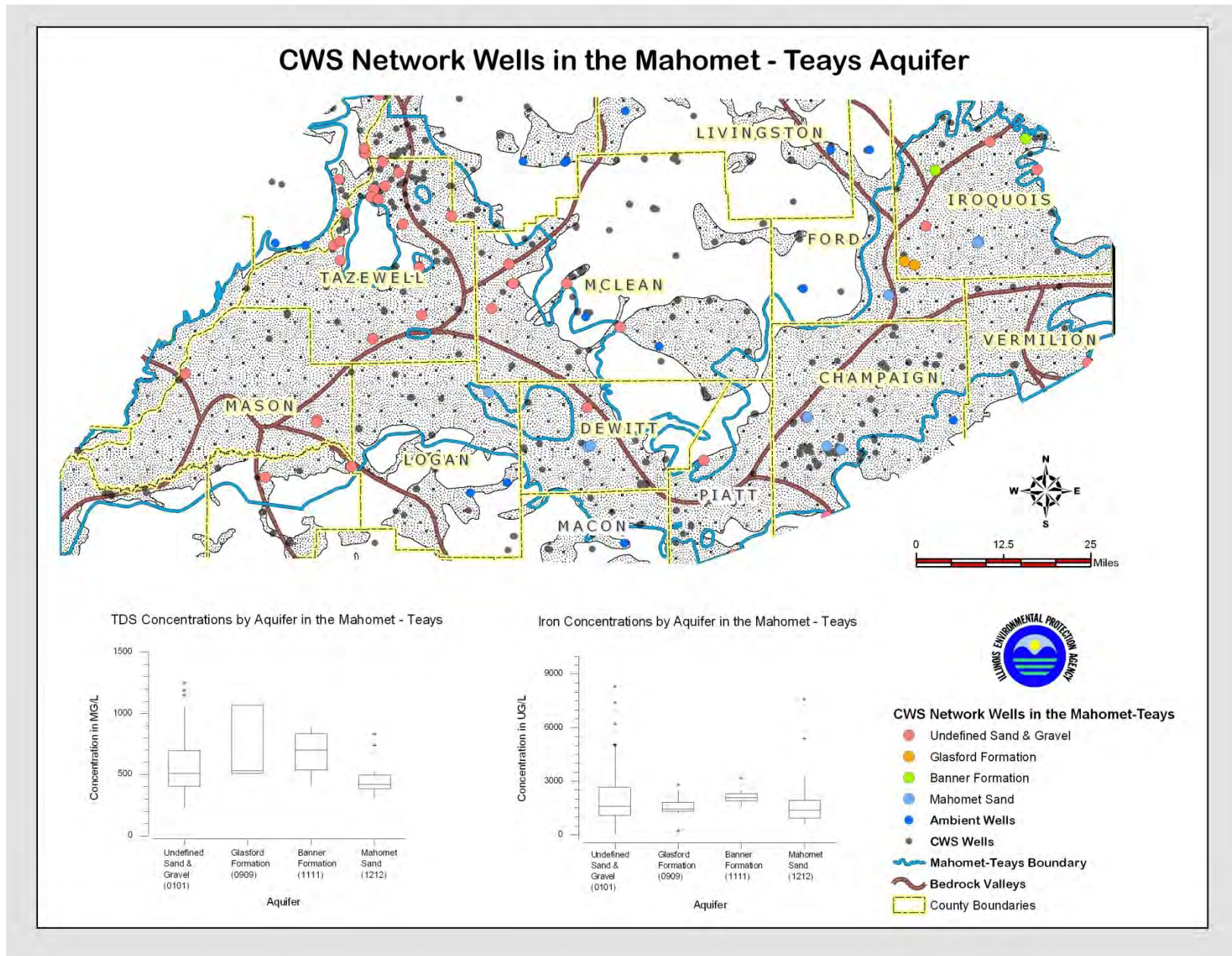


Figure C-19. IOC Levels in the Undefined Sand and Gravel of the Mahomet Aquifer

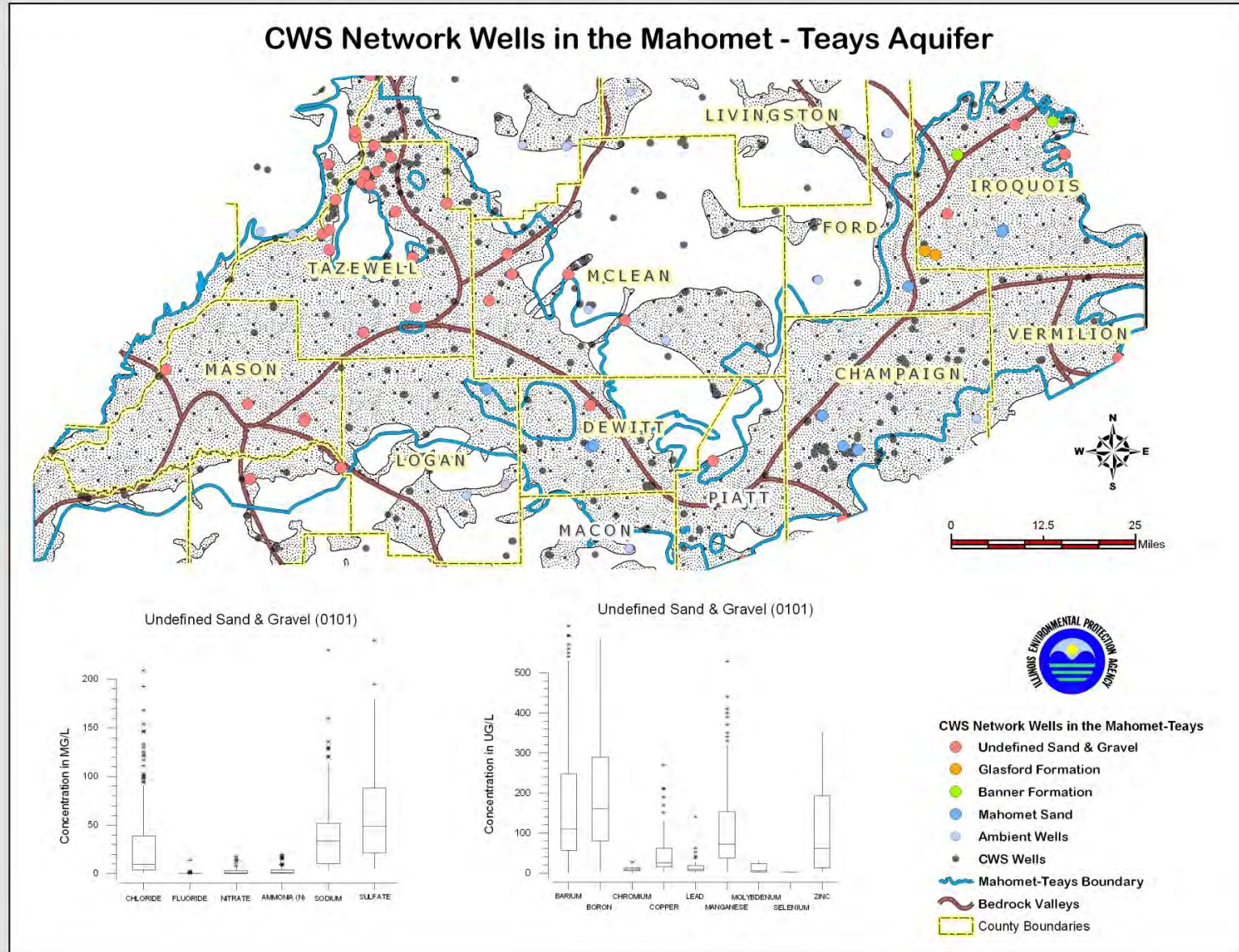


Figure C-20. IOC Levels in the Glasford Formation of the Mahomet Aquifer

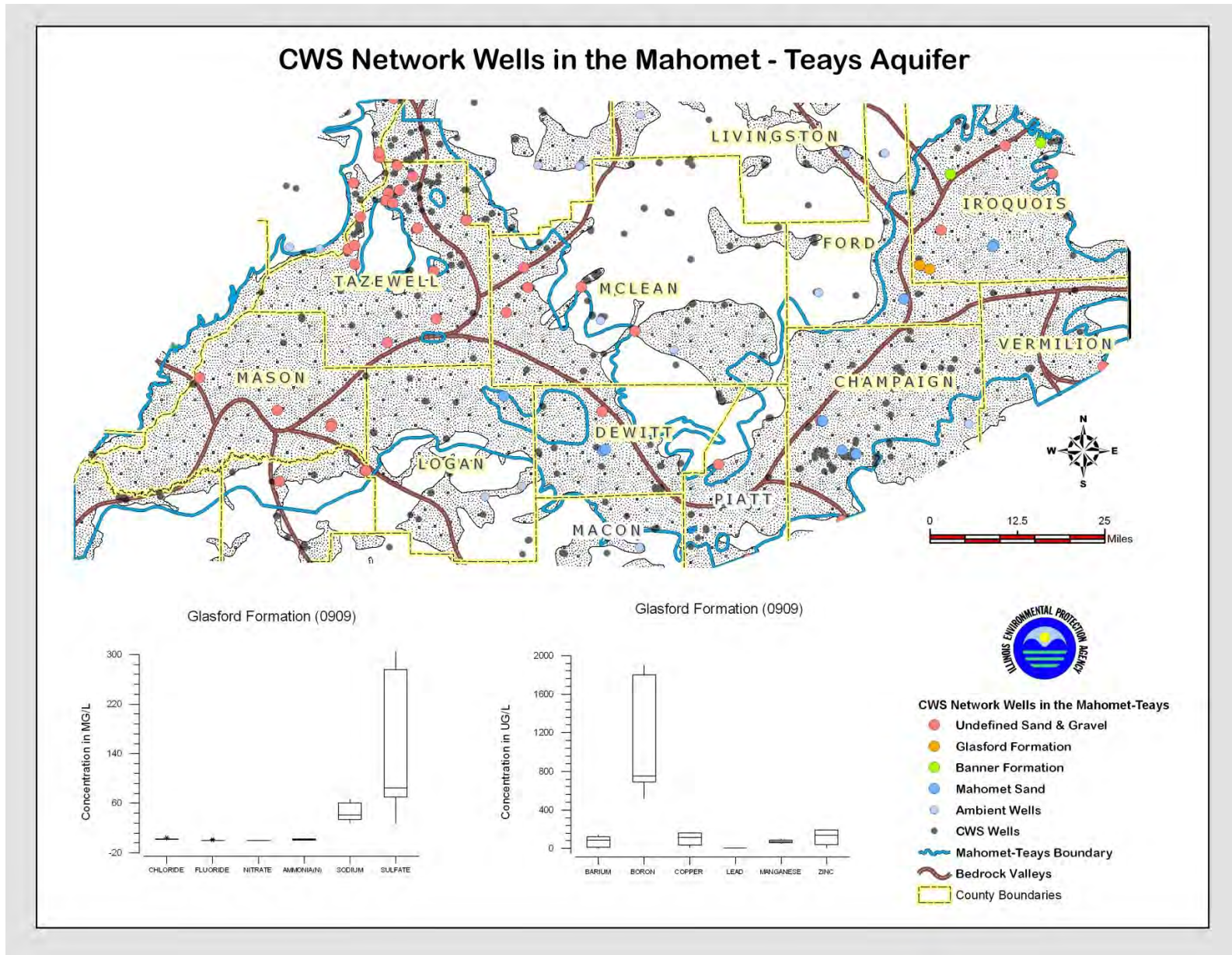


Figure C-21. IOC Levels in the Banner Formation of the Mahomet Aquifer

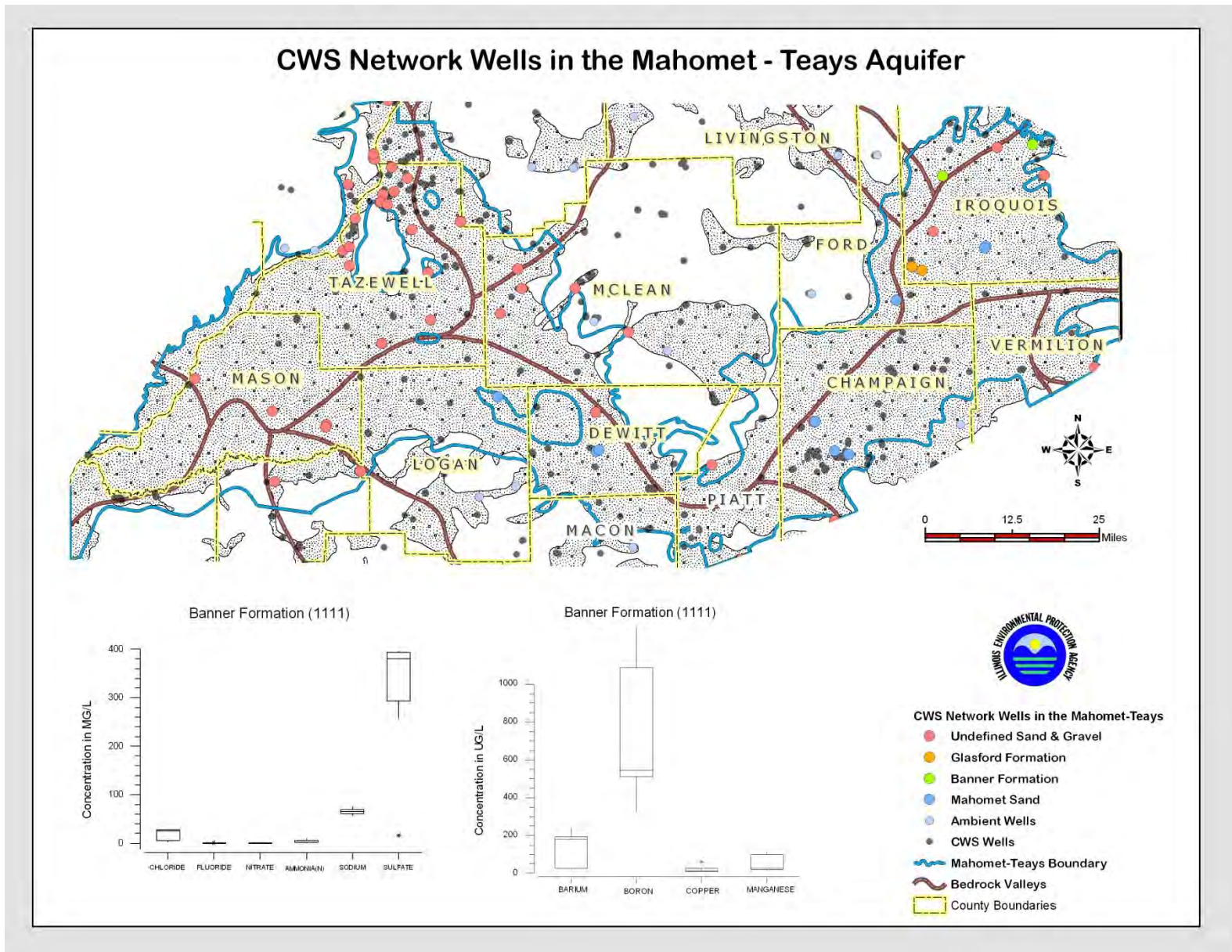
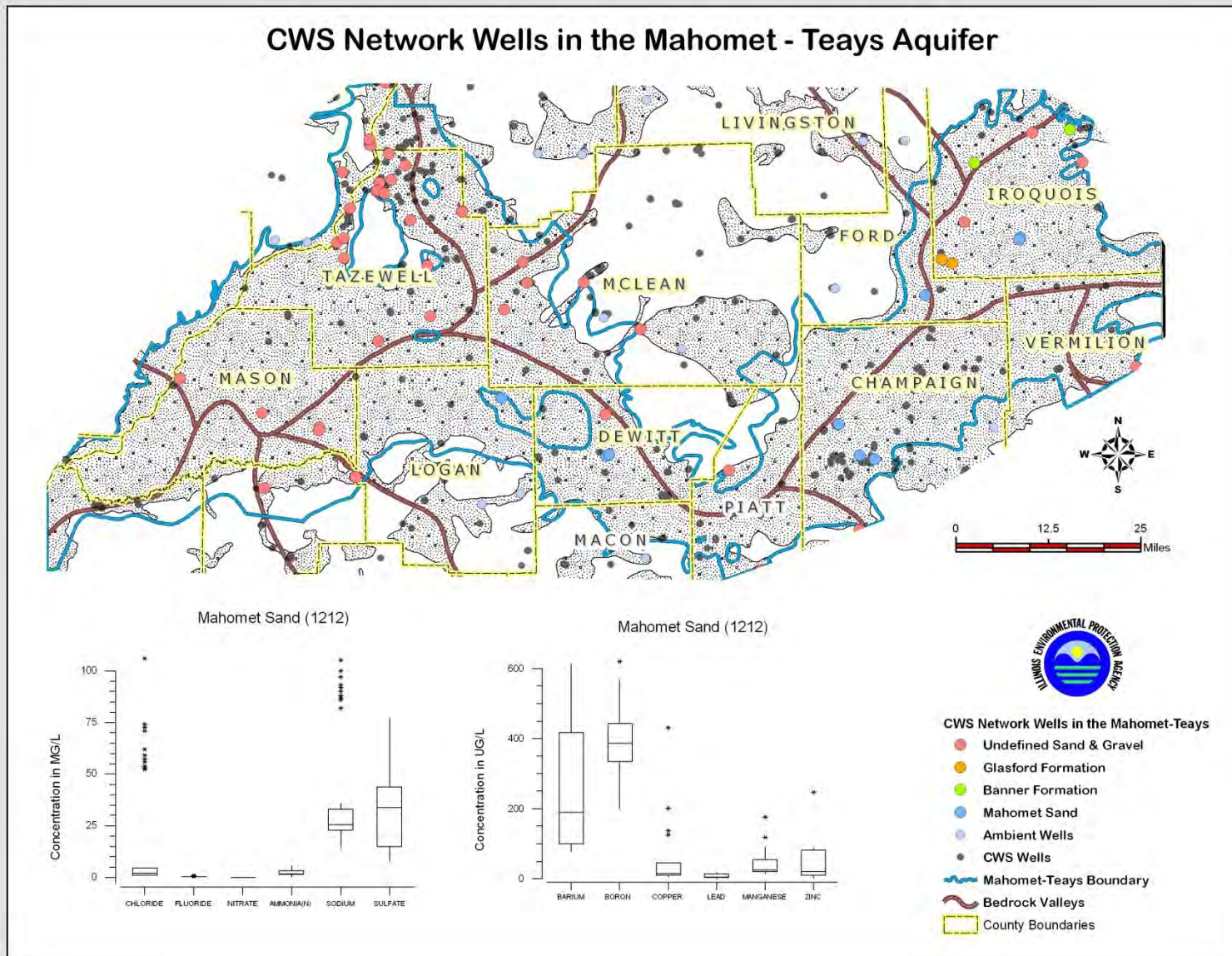


Figure C-22. IOC Levels in the Mahomet Sand of the Mahomet Aquifer

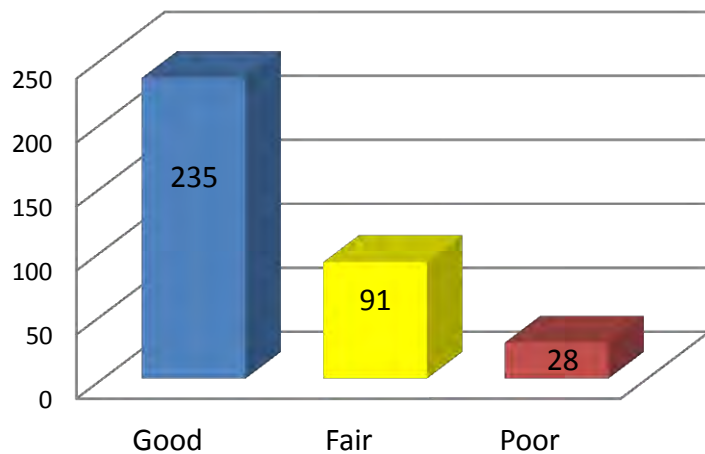


The Illinois EPA included the groundwater monitoring data on nitrate from the CWS Ambient Network wells screened in the Glasford Formation (Figure C-20c) and the data on nitrate and sulfate from the CWS Ambient Network wells screened in the Banner Formation (Figure C-20d), however, the number of these sample sets may not be statistically representative.

C-5. Use Support Evaluation

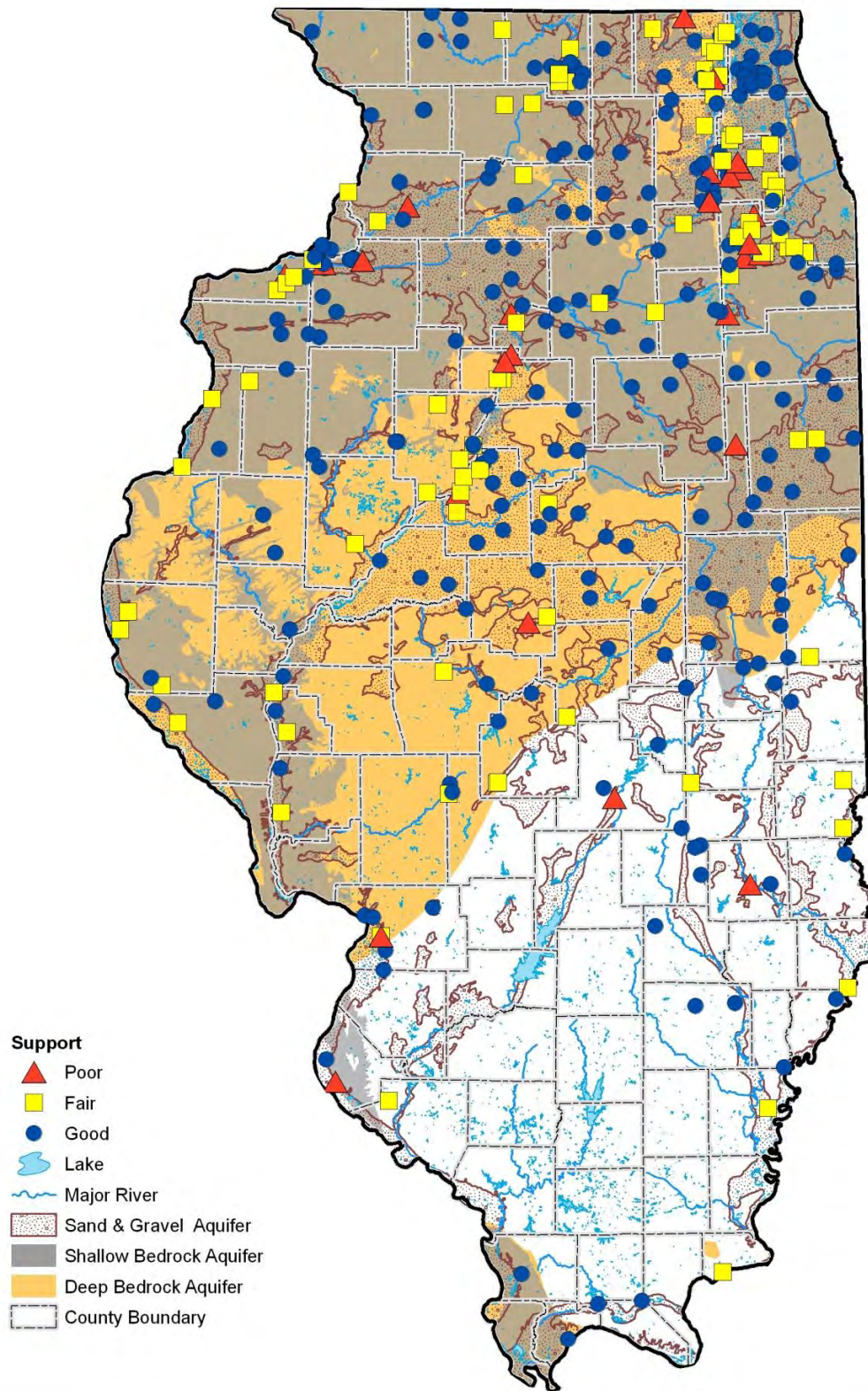
Figure C-23 and C-24 summarize use support in the State of Illinois as determined by measurements in the probabilistic network of CWS wells. The results show that of the 354 CWS probabilistic network wells:

Figure C-23. Use Support in CWS Network Wells



- **28 (8 percent)** were determined to be Not Supporting (“poor”) due to the elevated levels of nitrate and VOCs that include trichloroethylene and tetrachloroethylene. All of these wells draw their water from shallow sand and gravel aquifers, except for one, which is using a deep well from the Cambrian/Ordovician bedrock aquifer in the Northern part of the state);
- **91 (25 percent)** were determined to be Not Supporting (“fair”) due to statistically significant increases of chloride (Cl-) above background levels, detections of VOCs, nitrate (total nitrogen) greater than 3 mg/l, but have not exceeded the health-based GWQS; and
- **235 (67 percent)** were determined to be Fully Supporting (“good”), which show no detections of any of the above analytes.

Figure C-24. Use Support for the CWS Ambient Network Wells within Illinois' Principal Aquifers

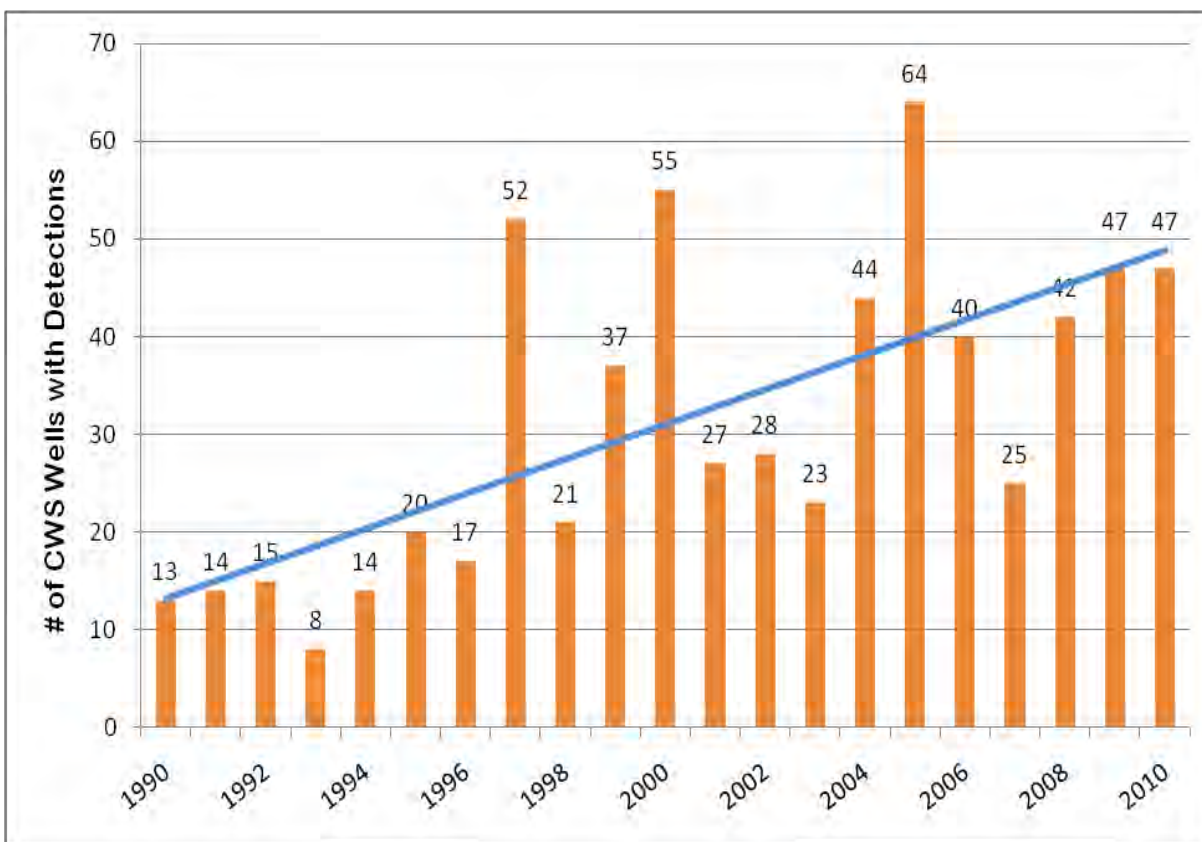


C-6. Potential Causes of Impairment

Volatile Organic Compounds in CWS Wells

As previously stated, when possible, assessments of groundwater overall use support is based upon Illinois' GWQS within the probabilistic network of CWS wells. Generally, a detection of an organic contaminant above the laboratory practical quantification limit or the detection of an inorganic constituent above the naturally occurring background level in a CWS well is considered a cause of less than full use support. To assess the potential impairment that VOCs are having on Illinois' groundwater resources, the Illinois EPA compiled groundwater monitoring data from CWS wells (1990 to the present) to complete a VOC trend analysis. The Illinois EPA included the monitoring data collected through 2010 for all of the CWS wells (not just the fixed station network wells) for this Integrated Report. While year-to-year assessment of groundwater monitoring data from CWS wells has shown fluctuations of VOCs, analyses of this data indicate a statistically increasing trend of VOC contamination in CWS wells. Unfortunately, this overall trend (i.e. blue line) has continued to increase over time as illustrated in Figure C-25.

Figure C-25. Long-term VOC Trend from all CWS Wells



As illustrated above, analyses of groundwater monitoring data collected from 1990 to the present indicates a statistically significant increasing trend of CWS wells with VOC detections per year, despite the fact that the number of CWS analyzed for VOCs over the same time period declined, and the detection limit remained constant. Evaluation of the causal data indicates that total xylenes and 1,1,1- trichloroethane are the most frequently detected VOCs in CWS wells.

A long-term investigation by the U.S. Geological Survey continues to provide the most comprehensive national analysis, to date, of the occurrence of VOCs in groundwater. One of the major findings is that these compounds were detected in most aquifers throughout the nation, and were not limited to a few specific aquifers or regions. For additional information on this investigation, see: http://toxics.usgs.gov/highlights/monitoring_vocs.html.

Chlorides in CWS Wells

To assess the potential impairment that chlorides are having on Illinois' groundwater resources, the Illinois EPA compiled groundwater monitoring data from the CWS probabilistic network wells. The 75th quartile value of the sand and gravel CWS probabilistic network wells in Northeastern Illinois show a 35 percent increase in concentration of chlorides compared to the state wide ambient value in the CWS probabilistic network screened in sand and gravel. Further, ISWS research determined that: approximately 16 percent of the samples collected from CWS wells in Northeastern Illinois in the 1990s had Cl⁻ concentrations greater than 100 mg/L; median values were less than 10 mg/L prior to 1960, before extensive road salting (Kelly and Wilson, 2004).

Groundwater Degradation

Illinois groundwater resources are being degraded. Degradation occurs based on the potential or actual diminishment of the beneficial use of the resource. When contaminant levels are detected (caused or allowed) or predicted (threat) to be above concentrations that cannot be removed via ordinary treatment techniques, applied by the owner of a private drinking water system well, potential or actual diminishment occurs. At a minimum, private well treatment techniques consist of chlorination of the raw source water prior to drinking. This groundwater degradation is exacerbated due to the predicted shortages of drinking water sources in the Northeastern Illinois.

It should be noted that groundwater that is consumed via a CWS has to be treated before it is delivered to the users. This treatment often includes methods for removing various contaminants, including the ones previously mentioned in this section. For more information on waters that are being consumed from CWS, the public can contact their local CWS or the applicable *Consumer Confidence Report* at <http://epadata.epa.state.il.us/water/bowccr/ccrselect.aspx>

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Attachment 2



Cost Analyses for Selected Groundwater Cleanup Projects: Pump and Treat Systems and Permeable Reactive Barriers

SUMMARY

Groundwater contamination is present at many Superfund and RCRA corrective action sites. Groundwater cleanup technologies, such as pump-and-treat (P&T) systems and permeable reactive barriers (PRBs), are being used at a number of those sites. Information about the costs of groundwater cleanup technologies and factors that affect those costs may be valuable to site managers, technology developers and users, and others involved in groundwater remediation efforts to identify and evaluate those technologies for new and ongoing projects. This report presents the results of an analysis, performed by the U.S. Environmental Protection Agency (EPA), of costs for groundwater cleanup incurred at 48 sites (the 32 P&T sites and 16 PRB sites listed in Exhibit 1). The report is based on data in case studies prepared by EPA and other members of the Federal Remediation Technologies Roundtable (FRTR) and by the Remediation Technologies Development Forum (RTDF), and supplements EPA's analysis of 28 groundwater remediation projects (*Groundwater Cleanup: Overview of Operating Experience at 28 Sites, September 1999, EPA 542-R-99-006*).

The analysis of the 48 sites found that there is a significant amount of variability in the costs of groundwater cleanups and that many of the factors that affect costs are site-specific. However, the following overall conclusions can be drawn:

- The types of contaminant groups in the groundwater affect the capital costs of a P&T system. In general, capital costs and annual operating costs were lower for sites at which chlorinated solvents are present, alone or with other volatile organic compounds (VOCs), than for sites at which other combinations of contaminants (such as VOCs with metals) are present. For sites at which complex combinations are present, it generally was necessary to use more complex aboveground treatment systems.
- The types of above-ground treatment affect the annual operating costs of a P&T system. For P&T sites at which chlorinated solvents are present, alone or with other VOCs, and at which air stripping or granular activated carbon (GAC) treatment only are used, annual operating costs were lower than for sites at which the same contaminants are present but a wider variety of treatment technologies are used. The additional treatment technologies sometimes require additional labor and use of both chemicals and energy.
- For the sites in this analysis, the capital costs for PRBs generally were lower than those for P&T systems. Decisions about whether a PRB or P&T system would be less expensive for a given site generally are based on total life-cycle costs for each type of system (including total capital and operating costs); such site-specific factors as hydrogeology, contaminant type, extent of contamination, and remedial goals often are considered in making such decisions. In addition, PRBs may not be technically feasible at all sites.

The FRTR includes senior executives of eight agencies that have an interest in exchanging information about remediation technologies. Primary members include the U.S. Departments of Defense, Energy, and the Interior, and EPA. Other participants include the Nuclear Regulatory Commission, the National Aeronautics and Space Administration, the Tennessee Valley Authority, and the U.S. Coast Guard. Information about the Roundtable is available through the FRTR's web site at <www.frtr.gov>. Information about the P&T sites was obtained from FRTR case studies.

The RTDF includes members representing industry, government, and academia who have an interest in identifying steps government and industry can take together to develop and improve the environmental technologies needed to address their mutual cleanup problems in the safest, most cost-effective manner possible. Information about the RTDF is available through the RTDF's web site at <www.rtdf.org>. Information about PRB sites was obtained primarily from an RTDF report; limited information was obtained from FRTR and other sources.

- Economies of scale were observed when the P&T system treats relatively large volumes of groundwater. For systems treating more than 20 million gallons of groundwater per year, capital and annual operating costs per volume of groundwater treated per year appear to be lower than those costs for systems treating less than 20 million gallons per year.

CRITERIA FOR SELECTING SITES FOR ANALYSIS

Exhibit 2 provides a description of P&T and PRB technologies. In selecting sites for this analysis, the available FRTR and RTDF case studies were screened using the following criteria:

- The P&T or PRB system was operated on a full-scale basis (rather than as a pilot-scale or field demonstration).
- For P&T sites, information was available about the capital cost, the annual average operating cost, and the amount of groundwater treated per year of system operation; for PRB sites, information was available about the capital cost.
- For P&T sites, aquifer cleanup goals (not containment-only goals) had been established.

For the analysis, 48 sites were identified (32 P&T sites and 16 PRB sites, including one site at which a PRB replaced a P&T system), as shown in Exhibit 1.

EXHIBIT 1. ALPHABETICAL LIST OF SELECTED SITES	
Site Name	
P&T Sites (32)	
Amoco Petroleum Pipeline, Michigan	Mystery Bridge at Highway 20 Superfund Site, DOW/DSI,
Baird and McGuire Superfund Site, Massachusetts	Odessa Chromium I Superfund Site, OU 2, Texas
Bofors Nobel Superfund Site, OU 1, Michigan	Odessa Chromium IIS Superfund Site, OU 2, Texas
City Industries Superfund Site, Florida	Old Mill Superfund Site, Ohio
Des Moines TCE Superfund Site, OU 1, Iowa	SCRDI Dixiana Superfund Site, South Carolina
Former Firestone Facility Superfund Site, California	Site A (confidential Superfund site), New York
Former Intersil, Inc. Site, California*	Sol Lynn/Industrial Transformers Superfund Site, Texas
French Limited Superfund Site, Texas	Solid State Circuits Superfund Site, Missouri
Gold Coast Superfund Site, Florida	Solvent Recovery Services of New England, Inc. Superfund Site,
JMT Facility RCRA Site (formerly Black & Decker), New York	Sylvester/Gilson Road Superfund Site, New Hampshire
Keefe Environmental Services Superfund Site, New Hampshire	Twin Cities Army Ammunition Plant Superfund Site (TCAAP),
King of Prussia Technical Corporation Superfund Site, New	United Chrome Superfund Site, Oregon
LaSalle Electrical Superfund Site, Illinois	U.S. Aviex Superfund Site, Michigan
Libby Groundwater Superfund Site, Montana	U.S. Department of Energy (DOE) Kansas City Plant, Missouri
McClellan Air Force Base Superfund Site, OU B/C California	U.S. DOE, Savannah River site, A/M Area, South Carolina
Mid-South Wood Products Superfund Site, Arkansas	Western Processing Superfund Site, Washington
PRB Sites (16)	
Aircraft Maintenance Facility, Oregon	Industrial Site, Northern Ireland
Caldwell Trucking, New Jersey	Industrial Site, South Carolina
Federal Highway Administration Facility, Colorado	Kansas City Plant, Missouri
Former Drycleaning Site, Germany	Lowry Air Force Base, Colorado
Former Intersil, Inc. Site, California*	Marzone Inc./Chevron Chemical Company, Georgia
Former Manufacturing Site, New Jersey	Nickel Rim Mine Site, Ontario, Canada
Industrial Site, Kansas	U.S. Coast Guard Support Center, North Carolina
Industrial Site, New York	Y-12 Site, Oak Ridge National Laboratory, Tennessee

*Both a PRB and a P&T system were operated at the former Intersil site.

EXHIBIT 2. SELECT GROUNDWATER TREATMENT TECHNOLOGIES**Pump and Treat (P&T)**

P&T involves extracting contaminated groundwater through recovery wells or trenches and treating the groundwater by *ex situ* (aboveground) processes, such as air stripping, carbon adsorption, biological reactors, or chemical precipitation. Variables in the design of a typical P&T system include:

- The number and pumping rate of groundwater extraction points (determined by such factors as the extent of contamination and the productivity of the contaminated aquifer)
- The *ex situ* treatment processes employed (determined by such factors as system throughput and the contaminants that require remediation)
- The discharge location for the effluent from the treatment plant (determined by such factors as location of the site and regulatory requirements)

Additional information about the fundamentals of P&T technology can be found in *Design Guidelines for Conventional Pump-and-Treat Systems*.

Permeable Reactive Barriers (PRBs)

A PRB is an *in situ* (below-ground) treatment zone of reactive material that degrades or immobilizes contaminants as groundwater flows through it. PRBs are installed as permanent, semi-permanent, or replaceable units across the flow path of a contaminated plume. Natural gradients transport contaminants through strategically placed media. The media degrade, sorb, precipitate, or otherwise remove groundwater contaminants. The choice of the reactive media for a PRB is based on the specific organic or inorganic contaminant to be remediated. Most PRBs installed to date use zero-valent iron (Fe⁰) as the reactive medium for converting contaminants to nontoxic or immobile species. Other applications under development use limestone, organic carbon, or bone char phosphate. The hydrogeologic setting at the site also is crucial; PRBs are best applied to shallow, unconfined aquifer systems in unconsolidated deposits, as long as the reactive material is more conductive than the aquifer.

Most PRBs are installed in one of two basic configurations: funnel-and-gate or continuous trench, although other techniques such as hydrofracturing also are used. The funnel-and-gate system employs impermeable walls to direct the contaminated plume through a gate, or treatment zone, that contains the reactive media. In a continuous trench configuration, a trench is installed across the entire path of the plume and is filled with reactive media. Most PRBs installed to date have had depths of 50 feet (ft) or less. PRBs having depths of 30 ft or less can be installed with a continuous trencher, while those installed at depths between 30 and 70 ft require a more innovative installation method, such as biopolymers. Installation of PRBs at depths greater than 70 ft is more challenging.

IMPORTANT DATA CONSIDERATIONS

Several important considerations related to the data and results presented in this report are listed below:

- The sites selected are not a statistically representative sample of groundwater remediation projects; rather, they present a range of the types of systems that are used to clean up groundwater at Superfund and RCRA corrective action sites.
- Cost data were provided by EPA remedial project managers (RPMs), site owners, or vendors; include both actual and estimated costs of groundwater cleanup; and were not verified independently by EPA.
- Groundwater cleanup has been completed at only two of the 32 P&T sites and is ongoing at the other P&T sites. For the 30 P&T sites where remediation is ongoing, the costs presented in this report do not necessarily represent the total cost of cleaning up groundwater at the site.
- Because groundwater cleanup is ongoing at most of the sites and the total time necessary to complete cleanup is not known, this report presents the average annual operating costs rather than the total operating costs incurred during site remediation. Likewise, no net present value (NPV) was calculated for the remedial costs because additional costs will be incurred at sites at which remediation is ongoing, and the length of time each system will operate in the future is not known. Rather, costs are presented as unit costs (cost per year or cost per 1,000 gallons). The unit costs are described in more detail later in this report.
- The costs for PRB and P&T systems presented in this report may include costs for source control remedies (such as slurry walls) employed at the sites, when the source control was an integrated part of the groundwater cleanup. Exhibits 10 and 11 present the components included in the costs for each of the sites included in this analysis.

METHODOLOGY FOR EVALUATING THE COSTS OF P&T AND PRB TECHNOLOGIES

Total capital and total annual operating costs were provided in the individual case studies by EPA RPMs, site owners, and vendors. For this analysis, the following methodology was used to calculate unit costs and adjusted costs for the 48 sites.

Unit Costs

There are several ways in which unit costs can be calculated for groundwater remediation systems. The following three types of unit costs were used in this analysis:

- **Average operating cost per year of operation:** This value was calculated by dividing the total operating cost to date by the number of years represented by that cost. Several factors affect the average operating cost per year, including throughput of the system, the treatment processes required to treat the extracted groundwater, and the operating efficiency of the system. Because a breakdown of annual operating costs by year was not available for most of the sites, the change in operating costs over the life of a site's remediation system could not be evaluated.
- **Capital cost per 1,000 gallons of groundwater treated per year:** This value represents the relative costs of installing remedial systems of various capacities, and is influenced by such factors as:
 - the complexity of the aquifer (which affect the size and complexity of the system needed to extract the contaminated groundwater)
 - the types of contaminants targeted for treatment at the site (which affect the components of the treatment plant needed to remove the contaminants)
 - the water and air discharge limits for the particular site (which affect the treatment plant components needed)
 - restoration goals (which affect the time frame for cleanup)
- **Average annual operating cost per 1,000 gallons of groundwater treated per year:** This value represents the relative costs of operating systems of various capacities and complexities. Similar to the capital cost per 1,000 gallons of groundwater treated per year, this unit cost is highly dependent on such site-specific factors as the complexity of the aquifer, the types of contaminants targeted for treatment, the water and air discharge limits, and the restoration goals.

Adjusted Costs

Remediation costs for the selected sites were adjusted for the location of the site (location adjustment) and for the years in which costs were incurred (inflation adjustment). Those adjustments are described below and in Appendix A to this report. Appendix A presents the equations used to adjust the total capital and total annual operating costs; gives equations used to calculate the average annual operating costs; and shows example calculations for one of the sites.

- **Location adjustment:** Costs were adjusted for location by multiplying the costs provided for each site by an Area Cost Factor (ACF) Index published by the U.S. Army Corps of Engineers in PAX Newsletter No. 3.2.1, dated March 31, 1999 and available at <http://www.hq.usace.army.mil/cemp/e/es/pax/paxtoc.htm>.
- **Inflation adjustment:** The inflation factor used for this analysis was based on the Construction Cost Index published by Engineering News Record. The most current year that had an annual average inflation adjustment factor available at the time of preparing this report was for 1999. Costs were adjusted to year 1999 dollars by multiplying the costs provided for each site by an inflation adjustment factor for the year in which the costs were incurred. For capital cost time adjustment, the inflation adjustment factor for the actual year that the costs were incurred was used. For annual operating cost time adjustment, the inflation adjustment factor for the median year of all years over which the costs were incurred was used. The Construction Cost Index is available at <http://www.enr.com/cost/costcci.asp>.

RESULTS AND CONCLUSIONS

This analysis considered six main factors that affect the cost of P&T and PRB technology applications (discussed in reference 1): (1) characteristics or properties of contaminants present, (2) system design and operation, (3) source control, (4) hydrogeologic setting, (5) extent of contamination, and (6) remedial goals. The analysis found that the costs varied significantly between sites and that many of the factors that affect costs are site-specific. In addition, the amount of information available about each of the factors varied by site. For the analysis, general conclusions were identified about the effect of a factor when information related to that factor was available for five or more sites.

Exhibits 3 through 9 present the results of the cost analysis for the 48 sites, with detailed data for each site summarized in Exhibits 10 and 11 for P&T and PRB sites, respectively. Exhibit 3 provides an overall summary of the remedial cost and unit cost data for the 48 sites included in the analysis, while Exhibits 4 through 9 present 25th percentile, 50th percentile (median), 75th percentile, and average costs, based on the types of contaminants present, the technologies used, and the volume of groundwater treated each year. General conclusions about the effect of contaminant property factors and system design and operation factors are presented below.

Cost Category	P&T Sites (32 Sites)				PRB Sites (16 Sites)			
	25 th Percent.	Median	75 th Percent.	Average	25 th Percent.	Median	75 th Percent.	Average
Years of system operation (with data available)	4	5	8	6	NC	NC	NC	NC
Average volume of groundwater treated per year (1,000 gallons per year)	7,000	30,000	100,000	120,000	NC	NC	NC	NC
Total capital cost (\$)¹	1,700,000	2,000,000	5,900,000	4,900,000	440,000	680,000	1,000,000	730,000
Average operating cost per year (\$ per year)¹	180,000	260,000	730,000	770,000	NC²	NC²	NC²	NC²
Capital cost per volume of groundwater treated per year (\$/1,000 gallons per year)¹	23	78	350	280	NC	NC	NC	NC
Average annual operating cost per volume of groundwater treated per year (\$/1,000 gallons per year)¹	5	16	41	32	NC	NC	NC	NC

Source: FRTR and RTDF; refer to Exhibit 1 for a list of sites.

¹ All reported costs were adjusted for site locations and years in which costs were incurred, as described in the text.

² Two of the case studies at PRB sites (Intersil and USCG) included annual operating costs for the PRB systems. Those costs are presented in Exhibit 11.

NC = Not calculated; insufficient data available.

Contaminant property factors:

Contaminant properties affect the cost of groundwater remediation systems. These properties define (1) the relative ease with which contaminants can be removed from the extracted groundwater (by *ex situ* treatment technologies), (2) the steps that are required to treat the groundwater, and (3) the complexity of the mixture of contaminants. Sites analyzed on the basis of contaminant property factors included sites contaminated with chlorinated solvents, alone or with other VOCs, and sites at which other combinations of contaminants were present. On the basis of site-specific data, the following conclusions can be made about contaminant property factors:

- The type of contaminant groups in the groundwater affects both the capital and the annual operating cost of a P&T system, as shown in Exhibit 4. For sites with chlorinated solvents alone or with other VOCs (such as ethers or ketones), capital costs were lower than those for sites with other combinations of contaminants (such as chlorinated solvents, BTEX, metals, PCBs, or PAHs). The median capital cost for P&T systems removing chlorinated solvents, alone or with other VOCs, is \$1,900,000, as compared with a median capital cost of \$7,400,000 for P&T systems removing other combinations of contaminants. The type of contaminant groups in the groundwater has similar effects on the annual operating cost of a P&T system. Sites at which chlorinated solvents, alone or with other VOCs, were present had lower annual operating costs than sites at which other combinations of contaminants were present. The median annual operating cost for P&T systems removing chlorinated solvents alone, or with other VOCs, is \$12 per 1,000 gallons treated, as compared with a median annual operating cost of \$39 per 1,000 gallons treated for P&T systems removing other combinations of contaminants.

EXHIBIT 4. COST COMPARISON OF P&T SYSTEMS THAT TREAT VARIOUS CONTAMINANT GROUPS

Contaminant Group	Cost Range			Average Cost	Number of Sites
	25 th Percentile	Median	75 th Percentile		
Total Capital Cost²					
Chlorinated solvents, alone or with other VOCs	\$1,200,000	\$1,900,000	\$4,400,000	\$3,600,000	18
Other combinations of contaminants (solvents, BTEX, metals, PCBs or PAHs) ¹	\$4,300,000	\$7,400,000	\$15,000,000	\$8,900,000	9
Average Annual Operating Cost per 1,000 Gallons Treated^{2,3}					
Chlorinated solvents, alone or with other VOCs	\$3	\$12	\$40	\$26	18
Other combinations of contaminants (solvents, BTEX, metals, PCBs or PAHs) ¹	\$10	\$39	\$61	\$53	9

¹ The costs of P&T systems that treat only metals or only BTEX are not included in this exhibit because data were available for only three such systems. General conclusions were developed about the effect of a factor when information about that factor was available for five or more sites.

² All reported costs were adjusted for site locations and years in which costs were incurred, as described in the text.

³ The average volume of groundwater treated per year for the 18 sites at which chlorinated solvents, alone or with other VOCs, were present and the nine sites at which a combination of contaminants were present are 160,000,000 and 65,000,000 gallons, respectively.

- The type of above-ground treatment affects the annual operating cost of a P&T system. For sites contaminated with chlorinated solvents, alone or with other VOCs, Exhibit 5 compares the annual operating costs of treatment systems using air stripping or GAC only with annual operating costs of treatment systems using a wider variety of treatment technologies. For P&T sites for which remedial cleanup goals had been established for chlorinated solvents, alone or with other VOCs, and using air stripping or GAC treatment only, annual operating costs were lower than those for sites for which remedial cleanup goals had been established for the same contaminants but at which other combinations of treatment technologies, such as biological treatment or filtration, were used. The median average annual operating cost for P&T systems removing chlorinated solvents with air stripping or GAC only is \$3 per 1,000 gallons treated. The median average annual operating cost for P&T systems removing the same contaminants with other combinations of treatment technologies is \$40 per 1,000 gallons treated. At sites for which remedial cleanup goals had been established for chlorinated solvents, alone or with other VOCs, treatment technologies besides air stripping or GAC may be necessary because other substances present in the groundwater may inhibit the effectiveness of the air stripping or GAC units. For example, at Sol Lynn, the initial treatment system included an air stripper and GAC unit only. However, an iron filter was added to the treatment train to minimize fouling of the packing of the air stripper. Such additional treatment technologies may require additional labor and use of chemicals or electricity.

EXHIBIT 5. ANNUAL OPERATING COST COMPARISON OF VARIOUS P&T TECHNOLOGIES AT SITES CONTAMINATED WITH CHLORINATED SOLVENTS, ALONE OR WITH OTHER VOCs

Treatment Technology	Average Annual Operating Cost per 1,000 Gallons Treated ^{1,2}			Number of Sites
	25 th Percentile (\$)	Median (\$)	75 th Percentile (\$)	
AS and/or GAC treatment only	2	3	12	11
Other combination of treatment technologies (see Exhibit 10)	28	40	41	7
All sites with chlorinated solvents, alone or with other VOCs	3	12	40	18

¹ All reported costs were adjusted for site locations and years when costs were incurred, as described in the text.

² The average volume of groundwater treated per year for the 11 sites at which air stripping (AS) or granular activated carbon (GAC) was used, the 7 sites at which other combinations of treatment technologies were used, and the 18 sites at which chlorinated solvents alone or with other VOCs, were present are 260,000,000; 19,000,000; and 160,000,000 gallons, respectively.

System design and operation factors:

The cost of a groundwater remediation system is affected by a number of factors including the type of treatment technologies used to remediate the site, the adequacy of a system design to remediate the site, system downtime, system optimization efforts, the amount and type of monitoring performed, and the use of multiple primary treatment technologies (for example, P&T and an *in situ* technology). On the basis of site-specific data, the following conclusions can be made about system design and operation factors:

- For the sites included in the analysis, the total capital costs for PRBs generally were lower than those for P&T systems. As demonstrated in Exhibit 6, the 75th percentile of total capital costs for the 16 PRB projects (\$1,000,000) was less than the 25th percentile of total capital costs for the 32 P&T projects (\$1,700,000). The data included in the analysis show that the total capital cost of a very large PRB may approach the total capital cost of a small P&T system. In addition, the median total capital cost for the 32 P&T projects is \$2,000,000; the median total capital cost for the 16 PRB projects is \$680,000. Decisions about whether a PRB or P&T system would be less expensive for a given site generally are based on total life-cycle costs for each type of system; such site-specific factors as hydrogeology, contaminant type, extent of contamination, and remedial goals should be considered in making those decisions. Further, PRBs may not be feasible at every site; therefore, a comparison of P&T and PRB systems may not be appropriate for a given site.

EXHIBIT 6. CAPITAL COST COMPARISON OF P&T AND PRB SYSTEMS

Technology	Capital Cost Range ¹			Average Capital Cost ¹ (\$)	Number of Sites
	25 th Percentile (\$)	Median (\$)	75 th Percentile (\$)		
P&T	1,700,000	2,000,000	5,900,000	4,900,000	32
PRBs	440,000	680,000	1,000,000	730,000	16

¹ All reported costs were adjusted for site locations and years when costs were incurred, as described in the text

- Two of the case studies at PRB sites included annual operating costs for the PRB systems. The adjusted annual operating costs for the PRBs at those sites are \$75,000 at the U.S. Coast Guard site and \$120,000 at the Intersil site. The annual operating costs included in the analysis are those for relatively new PRB systems, and operating costs included monitoring costs only; maintenance was not required during the period of operation for which data were available. As a PRB system ages, maintenance of the system may be required, including replacement of the exhausted reactive medium and other repairs of the PRB system. Decisions about whether a PRB or a P&T system would be less expensive would include an analysis of total life-cycle costs for each type

of system. Again, such site-specific factors as hydrogeology, contaminant type, extent of contamination, and remedial goals should be considered in making those decisions.

- Economies of scale were observed when relatively large volumes of groundwater were treated annually by a P&T system. For sites at which more than 20 million gallons of groundwater per year are treated, the capital and annual operating costs per volume of groundwater treated per year appear to be lower than at sites where 20 million gallons or less are treated per year. As Exhibit 7 shows, the median capital costs per volume of groundwater treated per year for P&T sites at which 20 million gallons or less are treated per year and for those at which more than 20 million gallons are treated per year are \$440 per 1,000 gallons per year and \$24 per 1,000 gallons per year, respectively. The data show a similar trend in annual operating costs per volume of groundwater treated per year. The median average annual operating costs per volume of groundwater treated per year for P&T sites at which 20 million gallons or less are treated per year and for those at which more than 20 million gallons are treated per year are \$42 per 1,000 gallons per year and \$5 per 1,000 gallons per year, respectively.

Exhibits 8 and 9 show the distribution of the unit capital costs and the average annual operating costs for the P&T sites included in the analysis, respectively, as a function of volume of groundwater treated per year. For sites at which more than 20 million gallons per year are treated, operating and capital costs are lower than costs for sites at which 20 million gallons or less per year are treated. Unit costs vary more for sites at which 20 million gallons or less per year are treated than for sites at which 20 million or more gallons per year are treated. Because of the variability in the costs, these data are not intended for use in making estimates of costs for other sites.

EXHIBIT 7. COMPARISON OF UNIT TREATMENT COST FOR P&T SITES WITH VOLUME TREATED PER YEAR

Size of Treatment System Size (1,000 gallons/year)	Cost Range			Average Cost	Number of Sites
	25 th Percentile	Median	75 th Percentile		
Capital Cost Per Volume of Groundwater Treated Per Year (\$/1,000 gallons/year)¹					
≤ 20,000	\$200	\$440	\$730	\$580	14
> 20,000	\$14	\$24	\$62	\$49	18
Average Annual Operating Cost Per Volume of Groundwater Treated Per Year (\$/1,000 gallons)^{1,2}					
≤ 20,000	\$33	\$42	\$64	\$62	14
> 20,000	\$3	\$5	\$7	\$10	18

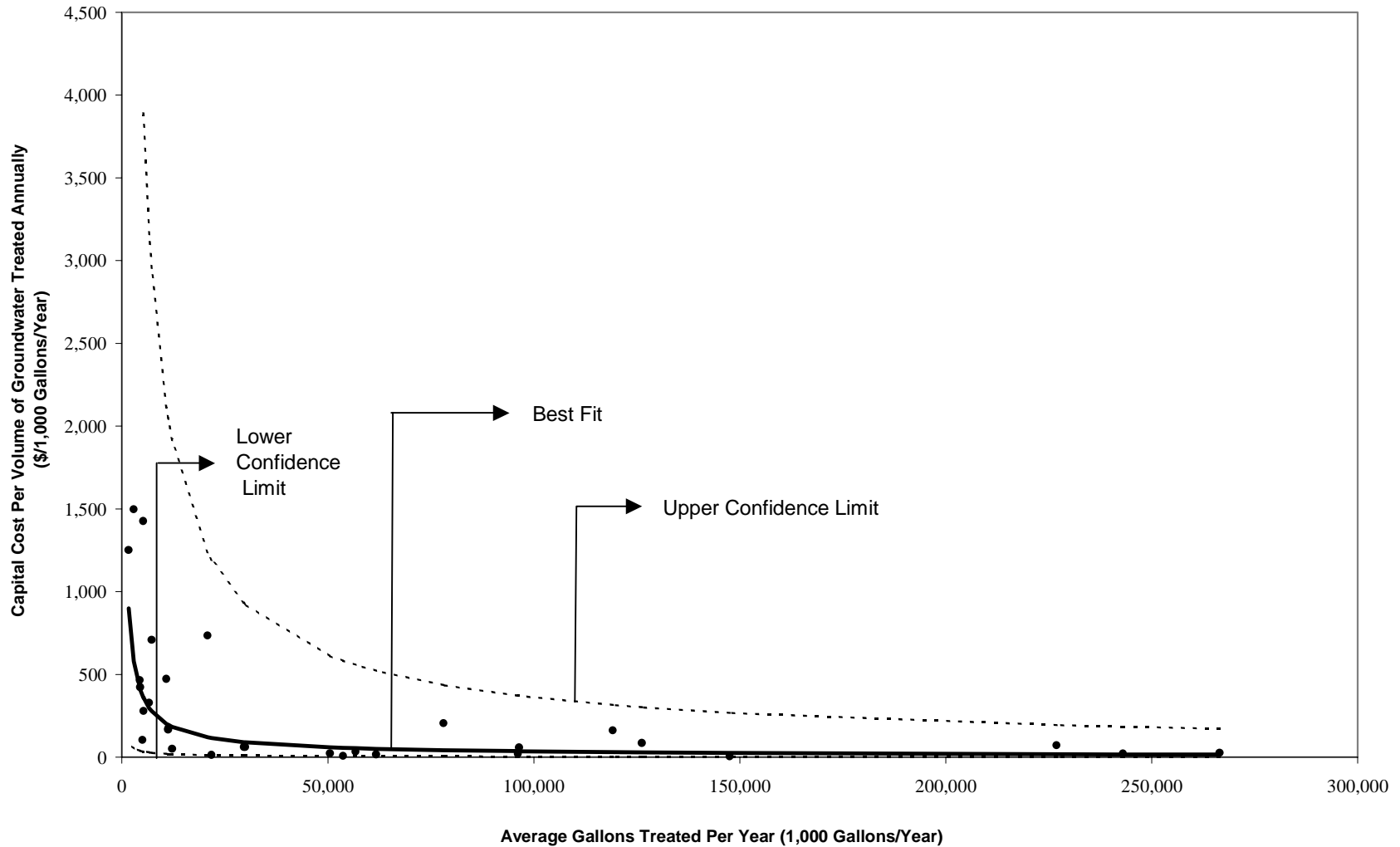
¹ All reported costs were adjusted for site locations and years when costs were incurred, as described in the text.

² The average volume of groundwater treated per year for the 14 sites treating 20 million gallons or less of groundwater annually and the 18 sites treating more than 20 million gallons of groundwater annually are 7,800,000 and 200,000,000 gallons, respectively.

Other Factors - Source control, hydrogeology, extent of contamination, and remedial goals also can have a significant effect on remediation costs; however, insufficient data were available to develop quantitative conclusions about the effects of those factors on the costs for the sites included in the analysis.¹ Several site-specific examples are presented below to demonstrate how each of those factors increase or decrease costs for a particular site. The examples listed below compare remediation costs for P&T sites at which the groundwater is contaminated with chlorinated solvents, alone or with other VOCs. The examples also are presented in Exhibits 10 and 11, which include costs and information about the factors that affect the costs for all 48 sites included in the analysis.

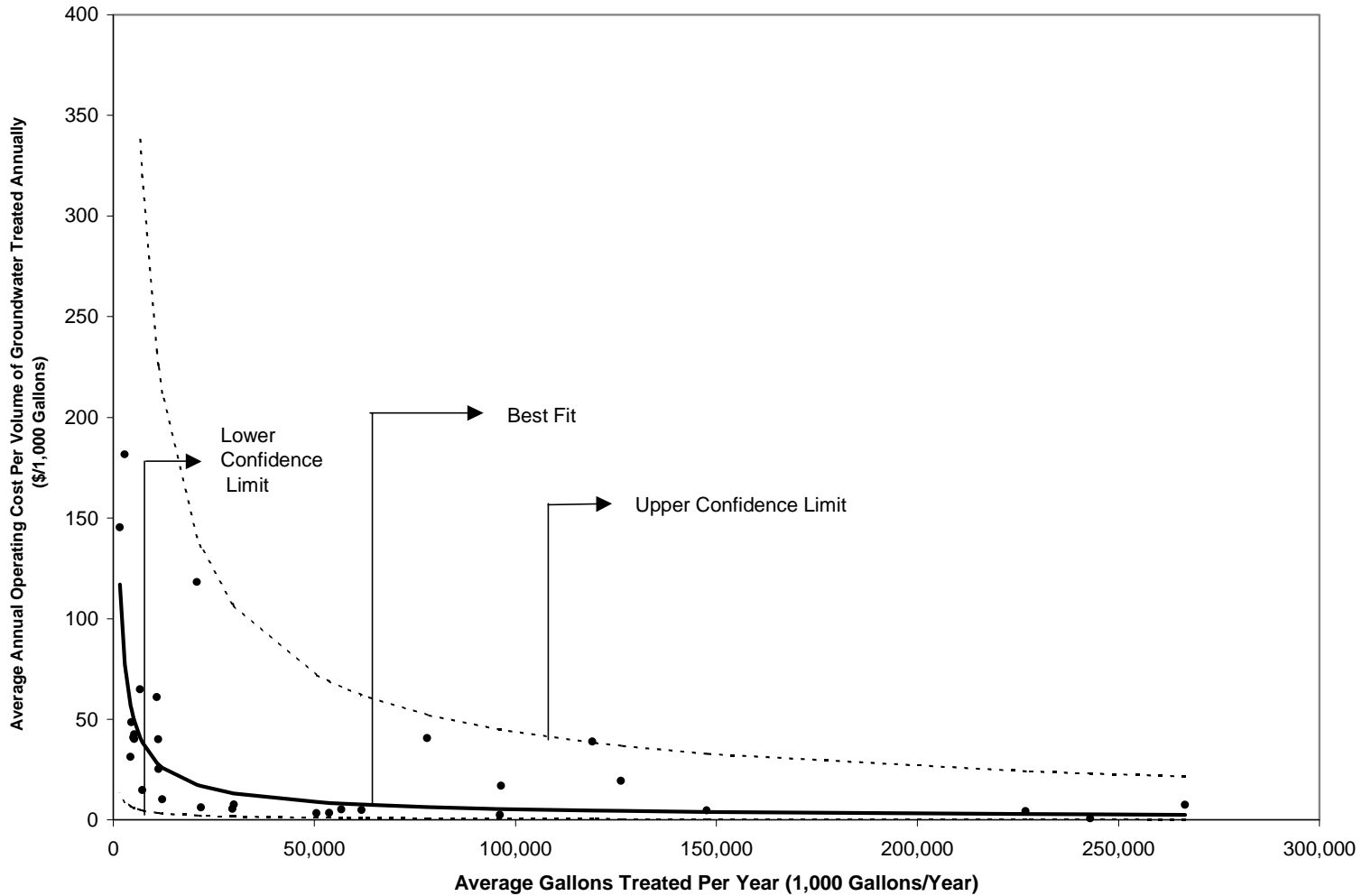
¹ There are several tools available that are used to estimate the costs for use of groundwater (and other) cleanup technologies, and that address these types of factors. Tools include products such as RACER and RS Means®. Additional information on these products is available through the RACER and RS Means® web sites, at <www.talpart.com/products/racer/racerabout.html> and <www.rsmeans.com>, respectively.

EXHIBIT 8. CAPITAL COST FOR PUMP AND TREAT SYSTEMS AS A FUNCTION OF QUANTITY TREATED PER YEAR



1. All reported costs were adjusted for site locations and years when costs were incurred, as described in the text.
2. This chart shows a solid line based on a best fit of the available data for the 32 P&T sites, and dashed lines for the upper and lower confidence intervals using a 95% degree of confidence. The lines were drawn based on the results from a statistical analysis of the available data, using SAS JMP software; the specific methodology used to draw the lines is described more fully in the EPA report titled "Year 2000 Remediation Technology Cost Compendium" (under preparation by EPA's Technology Innovation Office). This chart shows an expanded view of the data points within the ranges shown, and does not include several sites that are treating more than 300,000 gallons per year.

EXHIBIT 9. ANNUAL OPERATING COST FOR PUMP AND TREAT SYSTEMS AS A FUNCTION OF QUANTITY TREATED PER YEAR



1. All reported costs were adjusted for site locations and years when costs were incurred, as described in the text.
2. This chart shows a solid line based on a best fit of the available data for the 32 P&T sites, and dashed lines for the upper and lower confidence intervals using a 95% degree of confidence. The lines were drawn based on the results from a statistical analysis of the available data, using SAS JMP software; the specific methodology used to draw the lines is described more fully in the EPA report titled "Year 2000 Remediation Technology Cost Compendium" (under preparation by EPA's Technology Innovation Office). This chart shows an expanded view of the data points within the ranges shown, and does not include several sites that are treating more than 300,000 gallons per year.

Source control factors:

The method, timing of application, and success of source controls in mitigating contact of non-aqueous phase liquids (NAPLs) or other sources of contaminants, such as highly contaminated soil, with groundwater affect the cost of groundwater remediation systems. At several sites, efforts were made to remove NAPL or isolate the NAPL from contact with the groundwater. Such efforts often involved significant capital expenditures. For example, at Western Processing, both dense non-aqueous phase liquids (DNAPLs) and light non-aqueous phase liquids (LNAPLs) were observed in the groundwater. A slurry wall was constructed around the site to contain the plume and NAPLs and help achieve the cleanup goals in a limited amount of time. Capital costs for construction of the slurry wall were approximately \$1.8 million.

Hydrogeologic factors:

The cost of groundwater remediation systems is affected by the properties of the aquifer. These properties include hydraulic connection of aquifers that allows for contamination of more than one aquifer, aquifer flow parameters, influences of adjacent surface water bodies on the aquifer system, and influences of adjacent groundwater production wells on the aquifer system. The following example illustrates a specific case in which hydrogeological factors affected the cost of the groundwater remediation technology implemented at the site. At JMT, the hydraulic conductivity in the contaminated bedrock aquifer was relatively low (0.65 feet per day). To increase the hydraulic conductivity, controlled blasting was carried out to create an artificial fracture zone, which served as an interceptor drain in the bedrock around the extraction well. While that approach increased the capital cost of the system, it allowed effective extraction of the groundwater from the bedrock aquifer by one well screened in the new fracture zone.

Extent of contamination factors:

The magnitude of the contaminated groundwater plume, including the area and depth of the plume and the concentration of contaminants within the plume, affect the cost of groundwater remediation systems. Typically, groundwater contamination that is limited in area and depth is easier and cheaper to remediate than the same mass of contaminant when it extends deeper and spreads out over a larger area. This factor affects the size of the extraction and treatment system and the complexity of the system in terms of the quantity of groundwater to be extracted from the aquifer and treated *ex situ*. For example, at Gold Coast, the initial areal extent of the contaminated plume was estimated to be 0.87 acre, and the initial volume of the plume was estimated to be less than 3 million gallons. The site was remediated at a total cost of less than \$800,000.

Remedial goal factors:

Regulatory factors affect the design of a remedial system or the period of time it must be operated. These factors include aquifer restoration or treatment system performance goals, and specific system design requirements (such as disallowing reinjection of treated groundwater or specifying the treatment technology to be used). For example, at Western Processing, a P&T system, consisting of more than 200 groundwater extraction points pumping approximately 265 gpm, was installed. After approximately seven years of operation, an ESD was issued to change the focus of remediation efforts from restoration to containment. Because of that change, the system was modified to a system pumping approximately 80 gpm, which significantly reduced operating costs for the system.

NOTICE AND DISCLAIMER

This report was prepared by EPA's Technology Innovation Office with support provided under Contract Number 68-W-99-003. Information in this report is derived from a variety of references (including personal communications with experts in the field), some of which have been peer-reviewed. This report has undergone EPA and external review by experts in the field. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. For more information about this report, please contact: Linda Fiedler, U.S. EPA, Technology Innovation Office, Ariel Rios Building, 1200 Pennsylvania Ave., N.W. (MS 5102G), Washington, D.C., 20460; (703) 603-7194; e-mail: fiedler.linda@epa.gov.

EXHIBIT 10. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED P&T SITES

Site Name and Location	Contaminants With Remedial Cleanup Goals ¹	Remediation Technology ²										Years of Operation/Status ^{3,4}	Gallons Treated Per Year (1,000 Gallons)	Adjusted Capital Cost (Reported Capital Cost) ⁵	Adjusted Av. Ann. Oper. Cost (Reported Av. Ann. Oper. Cost) ^{5,6}	Adjusted Capital Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons/Year) ⁵	Adjusted Av. Ann. Oper. Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons) ^{5,6}	Cost Highlights		
		P&T (with <i>ex situ</i> treatment) ⁷					AS	FPR	ISB	PRB	VCB									
		BIO	GAC	PHYS/CHEM	OXID	STRIP														
CHLORINATED SOLVENTS ALONE OR WITH OTHER VOCs																				
French, Ltd., TX	benzene, toluene, chloroform, 1,2-DCA, VC	●	●	●						●				3.9/A	78,000	\$16,000,000 (\$15,000,000)	\$3,200,000 (\$3,300,000)	\$200	\$41	Oversight costs were high because this is a large system. Costs include those for P&T, ISB, and two VCBs. <i>Ex situ</i> metals treatment was added after it was determined that the biological treatment unit failed to sufficiently remove metals. Costs for VCBs are included in the capital costs because they were an integral part of containing the groundwater plume.
TCAAP, MN	1,2-DCE, 1,1,1-TCA, TCE, PCE					●								4.9/O	1,400,000	\$12,000,000 (\$8,000,000)	\$810,000 (\$590,000)	\$8.4	\$0.58	Complex hydrogeology (multilayer aquifer system) increased remediation costs.
Firestone, CA	1,1-DCE, TCE, PCE, 1,1-DCA, benzene, toluene, xylene		●			●								6.8/C	270,000	\$6,900,000 (\$4,100,000)	\$2,000,000 (\$1,300,000)	\$26	\$7.3	Frequent modifications to system increased costs. Cost of analysis and data management were high.
McClellan AFB, OU B/C, CA	None, primary contaminants of concern are TCE, cis-1,2-DCE, PCE, 1,2-DCA					●								6.8/O	96,000	\$5,600,000 (\$4,000,000)	\$1,600,000 (\$1,200,000)	\$58	\$17	Frequent modifications to system increased costs. Excess treatment capacity required internal groundwater recycling to sustain efficient treatment; this raised operating costs. Small system, unit costs reflect economies of scale. The <i>ex situ</i> treatment system originally included biological treatment. This unit operation was discontinued after influent ketone levels fell below detection limits. A second smaller groundwater treatment system was installed at the site in 1991; costs for this system are not included.
U.S. DOE, Savannah River, SC	TCE, PCE, 1,1,1-TCA					●								8.3/O	240,000	\$5,200,000 (\$4,100,000)	\$170,000 (\$150,000)	\$21	\$0.71	Complex hydrogeology and presence of DNAPLs increased remediation costs.
Des Moines, IA	TCE					●								8.8/O	550,000	\$2,200,000 (\$1,600,000)	\$140,000 (\$110,000)	\$3.9	\$0.25	Large treatment system; unit costs reflect economies of scale.
Old Mill, OH	TCE, PCE, 1,2-DCE, ethylbenzene		●			●								7.8/O	1,700	\$2,100,000 (\$1,600,000)	\$240,000 (\$210,000)	\$1,300	\$150	Modifications to the system increased capital costs by 22 percent. Relatively small volume of groundwater treated annually; increased unit cost relative to larger systems.

EXHIBIT 10. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED P&T SITES (CONTINUED)

Site Name and Location	Contaminants With Remedial Cleanup Goals ¹	Remediation Technology ²							Years of Operation/Status ^{3,4}	Gallons Treated Per Year (1,000 Gallons)	Adjusted Capital Cost (Reported Capital Cost) ⁵	Adjusted Av. Ann. Oper. Cost (Reported Av. Ann. Oper. Cost) ^{5,6}	Adjusted Capital Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons/Year) ⁵	Adjusted Av. Ann. Oper. Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons) ^{5,6}	Cost Highlights			
		P&T (with <i>ex situ</i> treatment) ⁷					AS	FPR								ISB	PRB	VCB
		BIO	GAC	PHYS/CHEM	OXID	STRIP												
Sol Lynn, TX	TCE		●	●		●						3.0/S	4,000	\$2,000,000 (\$2,100,000)	\$130,000 (\$150,000)	\$460	\$31	Complex hydrogeology increased capital costs. An iron filter was added to the <i>ex situ</i> treatment train to minimize fouling in the air stripper packing.
U.S. Aviox, MI	1,1,1-TCA, 1,2-DCA, DEE, 1,1-DCE, TCE, PCE, BTEX					●						3.4/O	96,000	\$1,900,000 (\$1,400,000)	\$230,000 (\$180,000)	\$20	\$2.4	Optimization of interim P&T system before final remedy reduced costs. All contaminants with remedial cleanup goals except diethyl ether are chlorinated solvents or BTEX. All contaminants are VOCs, as reflected in the relatively simple <i>ex situ</i> treatment system.
U.S. DOE, Kansas City, MO	None, contaminants of greatest concern at the site are PCE, TCE, cis-1,2-DCE, trans-1,2-DCE, and VC.				●							5.8/O	11,000	\$1,900,000 (\$1,400,000)	\$450,000 (\$360,000)	\$170	\$40	Remediation costs was high for the following reasons: frequent fouling of the extraction wells required well treatment/redevelopment; and initial oxidation system was undersized and was replaced with larger system.
Keefe, NH	PCE, TCE, 1,1-DCE, benzene, 1,2-DCA			●		●						4.1/O	11,000	\$1,900,000 (\$1,600,000)	\$280,000 (\$240,000)	\$170	\$25	Optimization of the system pumping rates increased mass removal efficiency.
SCRDI Dixiana, SC	PCE, TCE, 1,1,1-TCA, 1,1-DCE, 1,1,2-TCA, 1,1,2,2-PCA, chloroform, carbon tetrachloride, benzene, dichloromethane					●						4.6/O	4,500	\$1,900,000 (\$1,800,000)	\$220,000 (\$220,000)	\$420	\$48	PRP made major modifications to the remedial system, which increased costs. Relatively low contaminant concentration resulted in lower remediation costs. <i>Ex situ</i> treatment system originally included a metal media filter unit before the original air stripper. The metal removal unit was discontinued when the original packed-column air stripper was replaced with a shallow stacked tray air stripper.
JMT, NY	TCE, cis-1,2-DCE, TCA, VC					●						9.6/O	5,200	\$1,400,000 (\$880,000)	\$220,000 (\$150,000)	\$280	\$42	Modifications of treatment system increased capital costs 35 percent; system consisted of one extraction well, which reduced remediation costs.
City Industries, FL	1,1-DCA, 1,1-DCE, MC, VC, PCE, TCE, 1,1,1-TCA, benzene, toluene, ethylbenzene, acetone, MEK, MIBK, phthalates, cis-1,2-DCE, trans-1,2-DCE					●						3.0/O	51,000	\$1,200,000 (\$1,200,000)	\$160,000 (\$170,000)	\$23	\$3.2	Optimized pump rates; biofouling of air stripper increased system downtime and likely increased remediation costs. All contaminants with remedial cleanup goals except acetone, MEK, MIBK, and phthalates are chlorinated solvents or BTEX. All contaminants are VOCs, as reflected in the relatively simple <i>ex situ</i> treatment system.

EXHIBIT 10. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED P&T SITES (CONTINUED)

Site Name and Location	Contaminants With Remedial Cleanup Goals ¹	Remediation Technology ²										Years of Operation/Status ^{3,4}	Gallons Treated Per Year (1,000 Gallons)	Adjusted Capital Cost (Reported Capital Cost) ⁵	Adjusted Av. Ann. Oper. Cost (Reported Av. Ann. Oper. Cost) ^{5,6}	Adjusted Capital Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons/Year) ⁵	Adjusted Av. Ann. Oper. Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons) ^{5,6}	Cost Highlights									
		P&T (with <i>ex situ</i> treatment) ⁷					AS	FPR	ISB	PRB	VCB																
		BIO	GAC	PHYS/CHEM	OXID	STRIP																					
Solid State, MO	TCE					●							4.2/O	62,000	\$1,000,000 (\$930,000)	\$300,000 (\$280,000)	\$17	\$4.9	Capital costs do not include costs for installation of four deep extraction wells installed as part of RI/FS.								
Intersil (P&T), CA	TCE, cis-1,2-DCE, VC, Freon 113@					●						●		7.2/D	5,000	\$510,000 (\$320,000)	\$200,000 (\$140,000)	\$100	\$41	Groundwater extraction system was expanded after three years of operation, likely increasing operating costs. Costs for the PRB are not included.							
Mystery Bridge, WY	trans-1,2-DCE, cis-1,2-DCE, TCE, PCE, 1,1,1-TCA, 1,1-DCE					●								3.6/O	54,000	\$340,000 (\$310,000)	\$180,000 (\$170,000)	\$6.3	\$3.4	Low concentrations in groundwater result in lower remediation costs.							
Gold Coast, FL	MC, 1,1-DCA, trans-1,2-DCE, TCE, PCE, toluene					●	●							3.7/C	22,000	\$290,000 (\$250,000)	\$130,000 (\$120,000)	\$13	\$6.2	Optimized extraction wells resulted in lower remediation costs; P&T system required less than four years to clean up site. Costs for the AS are not included.							
BTEX ONLY																											
Site A, NY	BTEX					●	●					●								2.3/O	6,700	\$2,200,000 (\$1,400,000)	\$430,000 (\$290,000)	\$330	\$65	Use of skid-mounted modular equipment reduced capital costs. The capital cost includes the cost of SVE wells because this cost could not be separated from the groundwater system costs.	
Amoco, MI	None, contaminants of concern are BTEX and MTBE		●																		5.7/O	150,000	\$470,000 (\$300,000)	\$700,000 (\$480,000)	\$3.2	\$4.7	Leasing GAC and GAC system provided flexibility to modify treatment system, likely reducing remediation costs. Costs for AS are not included.
METALS ONLY																											
United Chrome, OR	Cr			●																	8.6/O	7,200	\$5,100,000 (\$3,300,000)	\$110,000 (\$74,000)	\$710	\$15	Modular treatment system used initially, reducing costs.
Odessa I, TX	Cr			●																	4.2/O	30,000	\$1,900,000 (\$2,000,000)	\$220,000 (\$250,000)	\$62	\$7.5	ROD required that ferrous iron be produced onsite electrochemically, limiting number of appropriate vendors and increasing capital costs.
Odessa II, TX	Cr			●																	4.1/O	30,000	\$1,800,000 (\$1,900,000)	\$160,000 (\$180,000)	\$62	\$5.4	ROD required that ferrous iron be produced onsite electrochemically, limiting number of appropriate vendors and increasing capital costs.

EXHIBIT 10. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED P&T SITES (CONTINUED)

Site Name and Location	Contaminants With Remedial Cleanup Goals ¹	Remediation Technology ²										Years of Operation/Status ^{3,4}	Gallons Treated Per Year (1,000 Gallons)	Adjusted Capital Cost (Reported Capital Cost) ⁵	Adjusted Av. Ann. Oper. Cost (Reported Av. Ann. Oper. Cost) ^{5,6}	Adjusted Capital Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons/Year) ⁵	Adjusted Av. Ann. Oper. Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons) ^{5,6}	Cost Highlights		
		P&T (with <i>ex situ</i> treatment) ⁷					AS	FPR	ISB	PRB	VCB									
		BIO	GAC	PHYS/CHEM	OXID	STRIP														
OTHER COMBINATIONS OF CONTAMINANTS																				
Western Processing, WA	Cd, Cr, Cu, Ni, Pb, Zn, Hg, Ag, cyanide, trans-1,2-DCE, cis-1,2-DCE					●							●	8.2/O	120,000	\$19,000,000 (\$14,000,000)	\$4,600,000 (\$3,600,000)	\$160	\$39	Remediation cost was high for the following reasons: large complex system with over 200 vacuum well points was initially used, 24-hour oversight was required; frequent maintenance was required to control iron precipitate buildup; treatment system originally included metals precipitation, oxidation, air stripping, and granular activated carbon treatment. In 1995, remedial goal was changed from aquifer restoration to plume containment; metals precipitation, oxidation, and granular activated carbon treatment were subsequently discontinued. The capital cost includes the cost of a slurry wall because it is an integral part of containing the groundwater plume.
Bofors Nobel, OU 1, MI	Remedial goals set for analine, 2-chloroaniline, selected purgeable halocarbons, and selected purgeable aromatics. Key specific contaminants are benzene, benzidine, 2-chloroaniline, 1,2-DCE, TCE, 3,3-dichlorobenzidene, aniline, VC.		●		●	●								3.1/O	230,000	\$16,000,000 (\$12,000,000)	\$970,000 (\$770,000)	\$70	\$4.3	Preventative maintenance program ensured uninterrupted operation of extraction system, which likely reduced remediation costs. A metals precipitation unit that was operated during the first two years of system operation was taken out of service after it was determined to be unnecessary.
Baird and McGuire, MA	BTEX, acenaphthene, naphthalene, 2,4-dimethyl phenol, dieldrin, chlordane, Pb, As		●	●		●								3.8/O	21,000	\$15,000,000 (\$11,000,000)	\$2,500,000 (\$2,000,000)	\$730	\$120	Operating costs increased due to the need to monitor for a wide range of contaminants and for several full-time operators to be onsite. Originally, <i>ex situ</i> system included biological treatment. This step was eventually discontinued. Historical data indicate that sufficient organic removal rates are attained without the use of biological treatment.

EXHIBIT 10. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED P&T SITES (CONTINUED)

Site Name and Location	Contaminants With Remedial Cleanup Goals ¹	Remediation Technology ²										Years of Operation/Status ^{3,4}	Gallons Treated Per Year (1,000 Gallons)	Adjusted Capital Cost (Reported Capital Cost) ⁵	Adjusted Av. Ann. Oper. Cost (Reported Av. Ann. Oper. Cost) ^{5,6}	Adjusted Capital Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons/Year) ⁵	Adjusted Av. Ann. Oper. Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons) ^{5,6}	Cost Highlights	
		P&T (with <i>ex situ</i> treatment) ⁷					AS	FPR	ISB	PRB	VCB								
		BIO	GAC	PHYS/CHEM	OXID	STRIP													
Sylvester/ Gilson Road, NH	MC, chloroform, MEK, toluene, phenols, Se, methyl methacrylate, 1,1,1-TCA, trans-1,2-DCA, 1,1-DCA, chlorobenzene, 1,1,2-TCA, VC, benzene	●		●		●							9.5/E	130,000	\$11,000,000 (\$7,200,000)	\$2,400,000 (\$1,800,000)	\$85	\$19	Remediation cost was high for the following reasons: several full-time operators were on site 24 hours per day, high costs for fuel oil to operate the vapor incinerator used for air emission control.
LaSalle, IL	PCBs, TCE, 1,2-DCE, 1,1,1-TCA, VC, 1,1-DCA, PCE		●			●							4.4/O	5,200	\$7,400,000 (\$5,300,000)	\$210,000 (\$160,000)	\$1,400	\$40	Complex mixture of contaminants and DNAPL contributed to elevated capital costs. Relatively small volume of groundwater treated annually; increased unit cost relative to larger systems.
Solvent Recovery Service, CT	None, contaminants at the site include TCE, cis-1,2-DCE, 1,1,1-TCA, PCBs, Ba, Cd, Ch, Pb, Mn		●	●	●								3.0/O	11,000	\$5,100,000 (\$4,400,000)	\$660,000 (\$580,000)	\$470	\$61	Presence of DNAPL contributed to elevated capital and operating costs. The capital cost includes the cost of a sheet pile wall because it was an integral part of containing the groundwater plume.
Libby, MT	napthalene, acenaphthene, fluorene, anthracene, pyrene, fluoranthene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene, As, benzene, PCP	●											5.3/O	3,000	\$4,300,000 (\$3,000,000)	\$520,000 (\$400,000)	\$1,500	\$180	Chemical costs (e.g., hydrogen peroxide) were high for <i>in situ</i> bioremediation; monitoring, sampling, and analysis costs were high at the beginning of the project. Relatively small volume of groundwater treated annually; increased unit cost relative to larger systems.
King of Prussia, NJ	1,1-DCA, trans-1,2-DCE, 1,1,1-TCA, TCE, PCA, PCE, benzene, toluene, ethylbenzene, Be, Cr, Cu, Ni, Cd, Hg., Zn		●	●		●							2.7/O	57,000	\$1,800,000 (\$2,000,000)	\$290,000 (\$330,000)	\$32	\$5.1	Electrochemical treatment to remove metals from the groundwater increased costs.

EXHIBIT 10. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED P&T SITES (CONTINUED)

Site Name and Location	Contaminants With Remedial Cleanup Goals ¹	Remediation Technology ²							Years of Operation/Status ^{3,4}	Gallons Treated Per Year (1,000 Gallons)	Adjusted Capital Cost (Reported Capital Cost) ⁵	Adjusted Av. Ann. Oper. Cost (Reported Av. Ann. Oper. Cost) ^{5,6}	Adjusted Capital Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons/Year) ⁵	Adjusted Av. Ann. Oper. Cost Per Volume of Groundwater Treated Per Year (\$/1,000 Gallons) ^{5,6}	Cost Highlights			
		P&T (with <i>ex situ</i> treatment) ⁷					AS	FPR								ISB	PRB	VCB
		BIO	GAC	PHYS/CHEM	OXID	STRIP												
MSWP, AR	PCP, Cr, As, benzo(a)anthracene, benzo(a)pyrene, benzo(b+k)fluoranthene, chrysene		●						8.3/O	12,000	\$600,000 (\$470,000)	\$120,000 (\$110,000)	\$49	\$10	Use of fabric filters increased operating life of GAC units and therefore reduced remediation costs. During a slowdown in plant operations, an additional carbon treatment system was operated briefly to treat metal-contaminated groundwater from one extraction well. Before and after this slowdown, the water from this well was used as makeup water for plant operations.			

Source: FRTR case studies of ongoing and completed groundwater remediation projects.

¹Contaminant Key: As = arsenic, Ba = barium, Be = beryllium, BTEX = benzene, toluene, ethylbenzene, and xylenes, Cd = cadmium, Cr = chromium, Cu = copper, DCA = dichloroethane, DCE = dichloroethene, DEE = diethyl ether, MC = methylene chloride, MEK = methyl ethyl ketone, MIBK = methyl isobutyl ketone, Mn = manganese, MTBE = methyl tert butyl ether, NH-SVOLs = nonhalogenated semivolatiles, Ni = nickel, PAH = polycyclic aromatic hydrocarbons, Pb = lead, PCA = tetrachloroethane, PCB = polychlorinated biphenyls, PCE = tetrachloroethene, PCP = pentachlorophenol, TCA = tetrachloroethane, TCE = tetrachloroethene, VC = vinyl chloride, Zn = zinc.

²Remediation Technology Key: AS = air sparging, BIO = biological treatment, FPR = free product recovery, GAC = granular activated carbon adsorption, ISB = *in situ* bioremediation, PHYS/CHEM = physical or chemical removal of metal, OXID = Oxidation, PRB = permeable reactive barrier, STRIP = air stripping, VCB = vertical containment barrier.

³If cost data are not available for the entire period of treatment system operation, then the number of years for which cost data are available is presented.

⁴Status Key: A = monitored natural attenuation, C = complete, D = P&T discontinued, PRB ongoing, E = shut down pending explanation of significant difference, O = ongoing, S = shut down pending study.

⁵All reported costs were adjusted for site locations and years when costs were incurred, as described in the text. All unadjusted (reported) costs are presented in parentheses. Adjusted costs are not presented in parentheses.

⁶Av. Ann. Oper. Cost = Average Annual Operating Cost

⁷The *ex situ* treatment systems presented in these columns include the treatment units in operation at the time that the case studies were prepared (for systems with and ongoing status) or the treatment units most recently in operation before system shutdown (for systems with any status other than ongoing).

EXHIBIT 11. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED PRB SITES

Site Name and Location	Contaminants ¹	Adjusted Cap. Cost ² (Reported Cap. Cost)	Cost Components						Installation Date	Installation Method ³	Number of PRBs/Gates	PRB Location or Function	Reactive Media Material ⁴	Reactive Media Dimensions				Cost Highlights
			Design	Construction	Materials	Reactive Media	Engineering	Haz. Waste T&D						Unspecified	Total Mass	Width	Length	
CHLORINATED SOLVENTS																		
Kansas City Plant, MO	1,2-DCE, VC	\$1,600,000 (\$1,500,000) Design = \$200,000 Other = \$1,300,000	●	●	●	●			Apr. 1998	CT	1	Top half of trench	2 ft Fe ^o , 4 ft sand	370 tons of iron	6 ft	130 ft	13-27 ft ⁹	Contractor had difficulty using 1-pass deep trenching machine (wet, heavy clay). Resorted to conventional sheet pile construction. This likely increased remediation costs.
												Bottom half of trench	100% Fe ^o				27-33 ft	
Caldwell Trucking, NJ	TCE	\$1,400,000 (\$1,120,000)	●	●	●	●			Apr. 1998	HF	2	Permeation infill	Fe ^o	250 tons	3 in	150 ft	15-50 ft	Permeation infill wall cost \$531,000
												Hydrofracture	Fe ^o				3 in	90 ft
Former Manf. Site, NJ	1,1,1-TCA; PCE; TCE; DNAPL	\$1,100,000 (\$875,000) Design = \$180,000 Iron = \$360,000* Other = \$560,000	●	●	●	●			Sept. 1998	DE, CT, SPC	1	DNAPL excavation	1:1 Fe ^o /sand	720 tons of iron	5 ft	127 ft	25 ft	Below grade sewer line permitted water to enter excavation. Therefore, subaqueous excavation was required for that portion of the wall, increasing remediation costs.
												Top 4 to 7 ft of CT ⁹	3:2 Fe ^o /sand					
												Bottom 7 to 21 ft of CT ⁹	4:1 Fe ^o /sand					
FHA Facility, CO	TCA; 1,1-DCE; TCE; cis-1,2-DCE	\$1,100,000 (\$1,000,000) Iron = \$210,000 ⁹ Other = \$890,000	●	●	●	●			Oct. 1996	F&G	4	All 4 PRBs	Fe ^o	476 tons of iron*	varies	Each gate is 40 ft wide	25 ft ⁹	1,040-ft funnel section. Use of multiple gates increased remediation costs.
Industrial Site, NY	TCE, cis-1,2-DCE, VC	\$1,000,000 (\$797,000) Iron = \$360,000 ⁹ Other = \$640,000		●	●	●			Dec. 1997	CT	2	Main trench	Fe ^o	742 tons	1 ft	370 ft	18 ft	Capital cost includes cost of site improvements to allow access by the trenching equipment.
												Upgradient trench					1 ft	

EXHIBIT 11. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED PRB SITES (CONTINUED)

Site Name and Location	Contaminants ¹	Adjusted Cap. Cost ² (Reported Cap. Cost)	Cost Components						Installation Date	Installation Method ³	Number of PRBs/Gates	PRB Location or Function	Reactive Media Material ⁴	Reactive Media Dimensions				Cost Highlights
			Design	Construction	Materials	Reactive Media	Engineering	Haz. Waste T&D						Unspecified	Total Mass	Width	Length	
Intersil, CA ⁵	TCE, cis-1,2-DCE, VC, Freon 113 [®]	\$760,000 (\$600,000) ¹⁰ Iron = \$170,000* Other = \$590,000	●	●	●				Feb. 1995	F&G	1	NA	Fe ^o	220 tons	4 ft	36 ft	11-31 ft	Two slurry walls: 300 ft and 235 ft long. Average annual operating costs are \$120,000 ¹⁰ .
Aircraft Facility, OR	TCE	\$710,000 (\$600,000)					●	Mar. 1998	F&G	2	Gate 1	Fe ^o	324 tons of iron ⁹	Two 9-in thick layers	50 ft	to 24-34 ft	2-ft. thick funnel walls, 650-ft. long funnel.	
											Gate 2	Fe ^o , sand		3 ft	60 ft	to 24-34 ft		
Lowry Air Force Base, CO	TCE	\$600,000 (\$530,000)	●	●	●	●		Dec. 1995	F&G	1	NA	Fe ^o	NR	5 ft	10 ft	0-17 ft	Two 14-ft. sheet piling funnel walls	
Industrial Site, N. Ireland	TCE; cis-1,2-DCE	\$580,000 ⁶ (\$375,000)		● ⁹	●	●	●	Dec. 1995	F&R	1	NA	Fe ^o	NR	Vessel has 4-ft diam.	Vessel has 4-ft diam.	33-49 ft	Two 100-ft. bentonite/cement slurry walls	
Industrial Site, KS	TCE; 1,1,1-TCA	\$400,000 (\$400,000) Iron = \$50,000* Other = \$350,000		● ⁹	●	●		Jan. 1996	F&G	1	NA	Fe ^o	70 tons	3 ft	20 ft	0-30 ft	Two 490-ft. bentonite slurry walls	
Industrial Site, SC	TCE, cis-1,2-DCE, VC	\$360,000 (\$400,000) Design = \$45,000 Iron = \$130,000* Other = \$180,000	●	●	●	●		Nov. 1997	CT	1	NA	Fe ^o , sand (1:1 ratio)	400 tons of iron	1 ft	375 ft ⁹	0-29 ft	Installation of PRB system being performed in two phases; costs reflect both phases.	

EXHIBIT 11. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED PRB SITES (CONTINUED)

Site Name and Location	Contaminants ¹	Adjusted Cap. Cost ² (Reported Cap. Cost)	Cost Components						Installation Date	Installation Method ³	Number of PRBs/Gates	PRB Location or Function	Reactive Media Material ⁴	Reactive Media Dimensions				Cost Highlights
			Design	Construction	Materials	Reactive Media	Engineering	Haz. Waste T&D						Unspecified	Total Mass	Width	Length	
Former Dryclean Site, Germany	PCE; 1,2-DCE	\$160,000 (\$123,000) Design = \$39,000 Other = \$120,000	●	●	●	●			June 1998	CW	1	NS	1:1 mass ratio Fe/ gravel	69 tons	2-3 ft	33 ft	10 - 33 ft ⁷	The mandrel construction method was chosen because it was determined to be easier and less expensive than continuous sheet piling construction.
												NS	IS	85 tons		41 ft		
METALS AND INORGANICS																		
Nickel Rim Mine Site, Canada	Ni, Fe, Sulfate	\$43,000 (\$30,000)	●	●	●	●			Aug. 1995	C&F	1	NA	OC/ pea gravel	NR	12 ft	50 ft	14 ft deep	12-in clay cap covers PRB to prevent surface water and oxygen entry. Coarse sand buffer zones installed up and downgradient.
COMBINATION OF CONTAMINANTS																		
Y-12 Site, Oak Ridge National Lab, TN	U, Tc, HNO ₃	\$900,000 (\$1,000,000)	●	●	●	●			Nov. 1997	CT	1	NS	100% iron	80 tons iron	2 ft	26 ft	22-30 ft	Did not excavate into confining unit; this may result in lower remediation costs and may permit the groundwater to bypass the reactive media.
									Dec. 1997	F&R	5	All 5 reactors	iron	NR	NR	NR		
Marzone Inc., GA	alpha-HCB, beta-HCB, DDD, DDT, xylene, EB, lindane, methyl parathion	\$650,000 (\$750,000) Design = \$200,000 Other = \$450,000	●	●	●	●			Aug. 1998	F&G	1	NA	AC	0.9 tons	NR	400 ft	NR	System flushing required every 3-4 weeks to reinstate flow; resulting in higher than anticipated operating costs.
U.S. Coast Guard Support Center, NC ⁸	Cr ⁶⁺ , TCE	\$460,000 (\$500,000) ¹⁰ Design = \$160,000 Iron = \$150,000 Other = \$150,000	●	●	●	●			June 1996	CT	1	NA	Fe ⁰	450 tons	2 ft	150 ft	3-24 ft	Total trench is 225 ft long. The exact location of the 26-ft iron portion is unspecified.

Primary Source: EPA, Office of Solid Waste and Emergency Response. 1999. *Field Applications of In Situ Remediation Technologies: Permeable Reactive Barriers*. EPA 542-R-99-002. June.

EXHIBIT 11. SUMMARY OF COST AND TECHNICAL INFORMATION FOR SELECTED PRB SITES (CONTINUED)

Additional Sources: Fax Transmittal from Mr. Robert Puls, EPA to Susan Guenther, TTEMI. March 8, 2000. Comments on Exhibit 10: Summary of Cost and Technical Information for Selected Permeable Reactive Barrier Sites. EPA. 1998. *Remediation Case Studies: Innovative Groundwater Treatment Technologies*. Volume 11. EPA 542-R-98-015. September.

¹ Contaminant Key: As = arsenic, HCB = hexachlorobenzene, Cd = cadmium, Cu = copper, Cr⁺⁶ = hexavalent chromium, DCE = dichloroethene, DDD = dichlorodiphenyldichloroethane, DDT = dichlorodiphenyltrichloroethane, DNAPL = dense nonaqueous-phase liquid, EB = ethylbenzene, Fe = Iron, HNO₃ = nitric acid, Ni = Nickel, Pb = lead, PCE = tetrachloroethene, Tc = technetium, TCA = trichloroethane, TCE = trichloroethene, U = uranium, VC = vinyl chloride, Zn = zinc.

² All reported capital costs were adjusted for site locations and years when costs were incurred, as described in the text. All unadjusted (reported) costs are presented in parentheses. Adjusted costs are not presented in parentheses.

³ Installation Method Key: C&F = cut and fill, CT = continuous trencher, CW = continuous wall, DE = dense nonaqueous-phase liquid (DNAPL) extraction, F&G = funnel and gate, F&R = funnel and reaction vessel, HF = hydraulic fracturing, SPC = Sheet piling construction.

⁴ Reactive Media Material Key: AC = activated carbon, AFO = amorphous ferric oxyhydroxide, Fe^o = zero-valent iron, IS = iron sponge (wood shavings or chips impregnated with hydrated iron oxide), LM = limestone, OC = organic carbon (municipal/leaf compost and wood chips), PO₄ = bone char phosphate.

⁵ Adjusted average annual operating costs for Intersil are \$120,000. Information was obtained from EPA 542-R-98-015.

⁶ An adjustment factor for Northern Ireland is not available. Therefore, an adjustment factor for the United Kingdom was used.

⁷ The lower boundary of the continuous wall was not reported. However, the aquifer extends to 33 ft.

⁸ Adjusted average annual operating costs for the U.S. Coast Guard Support Center are \$78,000. Information was obtained from EPA 542-R-98-015.

⁹ Information provided by Mr Robert Puls, EPA.

¹⁰ Information obtained from EPA 542-R-98-015.

NA = Not applicable, NR = Not reported, NS = Not specified

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APPENDIX A. COST EQUATIONS AND EXAMPLE CALCULATIONS

The equations used to normalize the total capital and total annual operating costs and to calculate the average annual operating costs are presented below.

$$\begin{aligned} \text{Adjusted Total Capital Cost} &= (\text{Total Capital Cost})(\text{ACF})(\text{IF}) \\ \text{Adjusted Total Annual Operating Cost} &= (\text{Total Annual Operating Cost})(\text{ACF})(\text{IF}) \\ \text{Average Annual Operating Cost} &= (\text{Adjusted Total Annual Operating Cost})/(\# \text{ of Years}) \end{aligned}$$

Example calculations are presented below for the Former Firestone Superfund Site, which is one of the 32 P&T sites included in the analysis. The site is located in Salinas, California (California ACF = 1.15). The groundwater treatment system at the Former Firestone Superfund Site was installed in 1985 (IF = 1.44). Annual costs were incurred from 1986 to 1992, for a total of 6.8 years. 1989 was used as the median year in which annual costs were incurred (IF = 1.31). The total unadjusted capital cost and total annual operating cost for the site are \$4,100,000 and \$8,800,000, respectively.

$$\begin{aligned} \text{Adjusted Total Capital Cost} &= (\$4,100,000)(1.15)(1.44) &= & \$6,900,000 \\ \text{Adjusted Total Annual Cost} &= (\$8,800,000)(1.15)(1.31) &= & \$13,000,000 \\ \text{Average Annual Operating Cost} &= (\$13,000,000)/(6.8) &= & \$2,000,000 \end{aligned}$$

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