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Section 4

R1640

H

APPENDIX H

H.E.L.P. OUTPUT FILES

ANDREWS ENGINEERING INC	TITLE:	Existing Unit HELP		Calc No.	Rev. No.
	Project:	Landfill 33		Date:	08/29/2018
	Job No.:	180130		Sheet 1 of 8	
	Prepared By:	MTH	Checked:	Reviewed:	

OBJECTIVE:

Determine the estimated leachate head over the base liner to ensure compliance with Section 811.317 of the Illinois Administrative Code and determine estimated leachate head over the composite liner system for the Groundwater Impact Assessment (GIA).

DESIGN CRITERIA:

1. The liner configuration for the Existing Unit consists of 10-ft of in situ low permeability (i.e., $K<1.0 \times 10^{-7}$ cm/s) silty clay.
2. The final cover configuration for the Existing Unit from the base to the surface will consist of 12 inches of recompacted clay cover overlain by a 40 mil Linear Low Density Polyethylene (LLDPE) geomembrane liner, a 200 mil double sided geocomposite drainage layer, 30 inches of general cover soils and 6 inches of soil material capable of supporting vegetation.
3. The 12 inches of recompacted clay cover will be constructed with a maximum hydraulic conductivity of 1.0×10^{-7} cm/s.
4. It is assumed that the 40 mil LLDPE geomembrane cover liner layer will have 15 installation defects per acre each retaining a cross-sectional area of 1 cm^2.
5. The 200 mil double sided geocomposite drainage layer will have a hydraulic conductivity of 10 cm/s.
6. The maximum waste depth upon closure of the landfill will be approximately 936 inches in depth.

METHOD:

1. Determine HELP input data for weather, precipitation, evapotranspiration, etc. for Effingham, Illinois or other cities located within the region surrounding Effingham, Illinois.
2. The in situ liner and final cover system for the Existing Unit design will be used as HELP input values.
3. HELP run scenarios evaluated over a one (1) acre area for the estimated 75 year design period (45 years of active life and 30 years of post-closure care) and 70 years after the design period. One run completed during the estimated 45 year active life of the landfill; one run will be conducted for the 30 year post closure care period; and one run will be completed for 70 years after post closure.
4. Utilize the HELP output data for use in the GIA.

Assumptions:

Input Data for all HELP Simulations

- Synthetically generated temperature and rainfall inputs developed using actual monthly mean temperature and rainfall data from the St. Louis, Missouri weather station and synthetically generated based on St. Louis, Missouri simulations.
- Synthetically generated solar radiation and evapotranspiration inputs were developed using the latitude for Effingham, IL and synthetically generated based on St. Louis, Missouri simulations.
- The cover geomembrane installation defect density of 15 holes/acre has been utilized based on the HELP Model guidance and typical applications submitted and approved by the Illinois EPA.

Input Data for Individual HELP Simulations

H.E.L.P. Model Design Setup (Active Life Period - Years 1 through 45)

Layer	Depth	Description	Notes
1	12"	Daily Cover Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #11

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2	936"	Waste	Layer 2: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
3	120"	In Situ Silty Clay	Layer 3: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for Active Life Period - Years 1 through 45

- 12 inches of daily/intermediate cover was assumed for this HELP run.
- Average waste depth of 936 inches was assumed for the entire active life.
- A subsurface outflow of -6 inches/year has been imposed on the waste layer to simulate leachate pumping.
- HELP was allowed to generate the initial moisture content and snow water.
- A Leaf Area Index of 3.0 was utilized to represent a fair to good stand of grass over the landfill cover.
- The SCS Runoff Curve Number is based on an assumed top grade of 10% with a fair stand of grass and a slope length of 445 feet.
- Fractional area allowing runoff is presumed to be 75% assuming that the waste has been placed and there is a fair stand of grass.
- The evaporative zone depth is presumed to be 12 inches, the minimum value for a clay as recommended in the HELP documentation.

H.E.L.P. Model Design Setup (Post-Closure Care Period - Years 46 through 75)

Layer	Depth	Description	Notes
1	6"	Vegetative Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #8
2	30"	Protective Layer	Layer 2: Vertical Percolation Layer (1) Soil Texture #11
3	0.20"	Geosynthetic Drainage Layer	Layer 3: Lateral Drainage Layer (2) Soil Texture #20 Average Slope 10% Drainage Length 445 feet
4	0.04"	40-mil LLDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #36 Pinhole-1, Defects-15, Installation Quality-4 (Poor)
5	12"	Recompacted Clay Cover Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16
6	936"	Waste	Layer 6: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
7	120"	In Situ Silty Clay	Layer 7: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for Post Closure Care Period - Years 46 through 75

- The Layer 1 thickness of 6 inches and HELP model default soil texture #8 used is based on the assumption that loamy soil will be placed as the final lift of the final cover system to promote vegetative growth.
- The Layer 2 HELP Model default soil texture #11 was used based on the assumption that the use of general site soils classified as lean clay (CL).
- The Layer 3 HELP model default soil texture #20 was used based on the standard geocomposite drainage material attributes.
- The full waste depth of 936 inches was used for the post closure care period years 46 to 75 and the final soil water content specifications from the previous 1 through 45 year HELP run were input.
- Initial soil water and snow water content was specified for layers 6 and 7 based on the final water storage of the 1 to 45 year HELP run. The initial soil water content specified for layers 1 through 5 was assumed to be at field capacity for all layers except Layer 5, the initial water content was specified at the layers porosity to indicate a fully compacted clay material.
- A Leaf Area Index of 4.0 was utilized to represent the presence of well-established stand of grass over the landfill cover.
- The SCS Runoff Curve Number is based on an assumed worst case grade of 10% (top of landfill slope) composed of areas with good stands of grass with a maximum flow distance of 445 feet based on the final cover configuration.
- Fractional area allowing runoff is presumed to be 90% assuming that the waste will be graded to the final approved contours and all areas will be closed.
- Evaporative zone depth is presumed to be 24 inches, larger than the minimum recommended 8 inches recommended by HELP and well below the maximum of 36 inches.

H.E.L.P. Model Design Setup (After Post-Closure Care Period - Years 76 to 145)

Layer	Depth	Description	Notes
1	6"	Vegetative Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #8
2	30"	Protective Layer	Layer 2: Vertical Percolation Layer (1) Soil Texture #11
3	0.20"	Geosynthetic Drainage Layer	Layer 3: Lateral Drainage Layer (2) Soil Texture #20 Average Slope 10% Drainage Length 445 feet
4	0.04"	40-mil LLDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #36 Pinhole-1, Defects-15, Installation Quality-4 (Poor)
5	12"	Recompacted Clay Cover Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16
6	936"	Waste	Layer 6: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
9	120"	Recompacted Clay Liner	Layer 13: Barrier Soil Liner Layer (3) Soil Texture #16

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Notes for After Post Closure Care Period - Years 76 to 145

- Reduction of the final cover drainage layer (Layer 3) hydraulic conductivity to 1.0 cm/sec is based on the assumption of potential sediment fouling of the geosynthetics.
- An increase in final cover recompacted clay cover liner (Layer 5) hydraulic conductivity to 1.0 X 10^{-5} cm/sec is based on the assumption that potential settlement may occur and result in a higher hydraulic conductivity.
- Initial soil water and snow water content was specified for layers 1 through 7 based on the final water storage of the 46 through 75 year HELP run.
- A Leaf Area Index of 5.0 was utilized to represent the presence of an excellent stand of grass over the landfill cover.
- The SCS Runoff Curve Number is based on an assumed worst case grade of 10% (top of landfill slope) composed of areas with excellent stands of grass with a maximum flow distance of 445 feet based on the final cover configuration.
- Fractional area allowing runoff is presumed to be 95% for the potential of settlement in the final cover system.
- Evaporative zone depth is presumed to be 24 inches, larger than the minimum recommended 8 inches recommended by HELP and below the maximum of 36 inches.

CONCLUSION:

Results of the HELP Model simulations indicate that the average annual leachate heads will remain below the surrounding piezometric groundwater elevation throughout the 45 year Design Period and the 70 year after post closure period resulting in an inward gradient. Final results for each of the three simulation runs are as follows:

HELP Model Output Liner Head Information	
HELP Run Scenario	**Average Annual Leachate Head**
Intermediate Cover Years 1 through 45	**0.199 - Inches**
Post Closure Care Period Years 46 through 75	**0.00 - Inches**
After Post Closure Care Period Years 76 through 145	**0.00 - Inches**

REFERENCES:

Koerner, Robert M. "Designing with Geosynthetics." Upper Saddle River, NJ: Pearson Prentice Hall, 2005.

National Environmental Satellite, Data, and Information Service, National Oceanic & Atmospheric Administration http://hurricane.ncdc.noaa.gov/climatenormals/clim20/il/113320.pdf (accessed August 1, 2011)

Schroeder, Paul R., Tamsen S. Dozier, Paul A. Zappi, Bruce M. McEnroe, John W. Sjostrom, and R. Lee Peyton. *The Hydrologic Evaluation of Landfill Performance (HELP) Model; Engineering Documentation for Version 3.* Vols. EPA/600/R-94/168b. Environmental Laboratory, U.S. Army Corps of Engineers, Vicksburg, MS: U.S. Environmental Protection Agency: Office of Research and Development, 1994.

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OBJECTIVE:

Determine the estimated leachate head over the base liner to ensure compliance with Section 811.317 of the Illinois Administrative Code and determine estimated leachate head over the composite liner system for the Groundwater Impact Assessment (GIA).

DESIGN CRITERIA:

1. The liner configuration for the South Unit consists of 3-ft of recompacted clay liner material overlain by a 60-mil High Density Polyethylene (HDPE) geomembrane liner and a 12 inches of granular drainage layer.
2. The 36 inches of recompacted clay liner will be constructed with a maximum hydraulic conductivity of 1.0 X 10^{-7} cm/s.
3. It is assumed that the 60-mil HDPE geomembrane liner layer will have 10 installation defects per acre each retaining a cross-sectional area of 1 cm^2.
4. The 12 inch granular drainage layer has a minimum hydraulic conductivity of 5.0 X 10^{-2} cm/s.
5. The final cover configuration for the South Unit from the base to the surface will consist of 12 inches of recompacted clay cover overlain by a 40-mil Linear Low Density Polyethylene (LLDPE) geomembrane liner, a 200-mil double sided geocomposite drainage layer, 30 inches of general cover soils and 6 inches of soil material capable of supporting vegetation.
6. The 12 inches of recompacted clay cover will be constructed with a maximum hydraulic conductivity of 1.0 X 10^{-7} cm/s.
7. It is assumed that the 40-mil LLDPE geomembrane cover liner layer will have 15 installation defects per acre each retaining a cross-sectional area of 1 cm^2.
8. The 200-mil double sided geocomposite drainage layer will have a hydraulic conductivity of 3.5 cm/s. per the geocomposite flow calculation.
9. The maximum waste depth upon closure of the landfill will be approximately 1152 inches in depth.

METHOD:

1. Determine HELP input data for weather, precipitation, evapotranspiration, etc. for Effingham, Illinois or other cities located within the region surrounding Effingham, Illinois.
2. Utilize the South Unit design attributes for the composite liner system, leachate collection system, waste depth and final cover system for use as HELP input.
3. Complete three HELP run scenarios over a one (1) acre area for the estimated 61year design period (31 years of active life and 30 years of post-closure care) and 70 years after the design period. One run will be completed during the estimated 31 year active life of the landfill; one run will be conducted for the 30 year post closure care period; and one run will be completed for 70 years after post closure.
4. Utilize the HELP output data for use in the GIA.

Assumptions:

Input Data for all HELP Simulations

- Synthetically generated temperature and rainfall inputs were developed using actual monthly mean temperature and rainfall data from the St. Louis, Missouri weather station and synthetically generated based on St. Louis, Missouri simulations.
- Synthetically generated solar radiation and evapotranspiration inputs were developed using the latitude for Effingham, Illinois and synthetically generated based on St. Louis, Missouri simulations.
- The liner geomembrane pinhole density of 1 is utilized per the recommendations from the HELP Model 3.07 guidance information which notes that pinhole density of 0.5 to 1 may be typical based on current manufacturing process.
- The liner geomembrane installation defect density of 10 holes/acre has been utilized based on the HELP Model guidance and typical applications submitted and approved by the Illinois EPA.

- The cover geomembrane installation defect density of 15 holes/acre has been utilized based on the HELP Model guidance and typical applications submitted and approved by the Illinois EPA.

Input Data for Individual HELP Simulations

H.E.L.P. Model Design Setup (Active Life Period – Years 1 through 31)

Layer	Depth	Description	Notes
1	12"	Daily Cover Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #11
2	1152"	Waste	Layer 2: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
3	12"	Pea Gravel/Coarse Sand OR Sand and 300 mil Double Sided Geocomposite	Layer 3: Lateral Drainage Layer (2) Soil Texture #21 K = 5.0 X 10^{-2} cm/sec Average Slope 2.2% Drainage Length 615 feet
4	0.06"	60 mil HDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #35 Pinhole-1, Defects-10, Installation Quality-4 (Poor)
5	36"	Recompacted Clay Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for Active Life Period – Years 1 through 31

- 12 inches of intermediate cover was assumed for this HELP run.
- An initial average waste depth of 1,152 inches was assumed for years 1 through 31.
- HELP was allowed to generate the initial moisture content and snow water.
- A Leaf Area Index of 3.0 was utilized to represent the presence of a fair stand of grass.
- The SCS Runoff Curve Number is based on an assumed top grade of 14% composed of vegetated soils with a maximum flow distance of 630 feet.
- Fractional area allowing runoff is presumed to be 75% assuming that the waste is in place and runoff potential is limited.
- The evaporative zone depth is presumed to be the minimum recommended by the HELP program of 12 inches.

H.E.L.P. Model Design Setup (Post-Closure Care Period – Years 32 through 61)

Layer	Depth	Description	Notes
1	6"	Vegetative Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #8

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2	30"	Protective Layer	Layer 2: Vertical Percolation Layer (1) Soil Texture #11
3	0.20"	Geosynthetic Drainage Layer	Layer 3: Lateral Drainage Layer (2) Soil Texture #20 Average Slope 14.5% Drainage Length 630 feet
4	0.04"	40 mil LLDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #36 Pinhole-1, Defects-15, Installation Quality-4 (Poor)
5	12"	Recompacted Clay Cover Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16 (shown as 0 due to conductivity amendment) K = 1.0 X 10^{-7} cm/sec
6	1,152"	Waste	Layer 6: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
7	12"	Pea Gravel/Coarse Sand OR Sand and 300 mil Double Sided Geocomposite	Layer 7: Lateral Drainage Layer (2) Soil Texture #21 (shown as 0 due to conductivity amendment) K = 5.0 X 10^{-2} cm/sec Average Slope 2.2% Drainage Length 615 feet
8	0.06"	60 mil HDPE Geomembrane	Layer 8: Flexible Membrane Liner Layer (4) Material Texture #35 Pinhole-1, Defects-10, Installation Quality-4 (Poor)
9	36"	Recompacted Clay Liner	Layer 9: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for Post-Closure Care Period – Years 32 through 61

- The Layer 1 thickness of 6 inches and HELP Model default soil texture #8 used is based on the assumption that 6 inches of loamy soil will be placed as the final lift of the final cover system to promote vegetative growth.
- The Layer 2 HELP Model default soil texture #11 was used based on the assumption that the use of general site soils classified as lean clay (CL).
- The Layer 3 HELP Model default soil texture #20 was used based on the standard geocomposite drainage material attributes.
- The full waste depth of 1,152 inches was used for the post closure care period years 32 through 61 and the final soil water content specifications from the previous 1 through 31 year HELP run were input.
- Initial soil water and snow water content was specified for layers 6 through 9 based on the final water storage of the 1 through 31 year HELP run. The initial soil water content specified for layers 1 through 5 was assumed to be at field capacity for all layers except Layer 5, the initial water content was specified at the layers porosity to indicate a fully compacted clay material.
- A Leaf Area Index of 4.0 was utilized to represent the presence of significant vegetation over the landfill cover.

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- The SCS Runoff Curve Number is based on an assumed worst case grade of 14% (top of landfill slope) composed of areas with good stands of grass with a maximum flow distance of 630 feet based on the final cover configuration.
- Fractional area allowing runoff is presumed to be 90% assuming that the waste will be graded to the final approved contours and all areas will be closed.
- Evaporative zone depth is presumed to be 24-inches, larger than the minimum recommended 8-inches recommended by HELP and well below the maximum of 36-inches.

H.E.L.P. Model Design Setup (After Post-Closure Care Period - Year 62 through 131)

Layer	Depth	Description	Notes
1	6"	Vegetative Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #8
2	30"	Protective Layer	Layer 2: Vertical Percolation Layer (1) Soil Texture #11
3	0.20"	Geosynthetic Drainage Layer	Layer 3: Lateral Drainage Layer (2) Soil Texture #20 (shown as 0 due to conductivity amendment) K = 1.0 cm/sec Average Slope 5% Drainage Length 178 Ft (Longest)
4	0.04"	40-mil LLDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #36 Pinhole-1, Defects-15, Installation Quality-Poor
5	12"	Recompacted Clay Cover Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16 (shown as 0 due to conductivity amendment) K = 1.0 X 10^{-5} cm/sec
6	1,512"	Waste	Layer 2: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
7	12"	Pea Gravel/Coarse Sand OR Sand and 300 mil Double Sided Geocomposite	Layer 3: Vertical Percolation Layer (1) Soil Texture #21 (shown as 0 due to conductivity amendment) K = 5.0 X 10^{-2} cm/sec Subsurface Inflow = 0.35 Inches/Year
8	0.06"	60-mil HDPE Geomembrane	Layer 9: Flexible Membrane Liner Layer (4) Material Texture #35 Pinhole-1, Defects-10, Installation Quality -Poor
9	36"	Recompacted Clay Liner	Layer 13: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for After Post Closure Care Period – Years 62 through 131

- Reduction of the final cover drainage layer (Layer 3) hydraulic conductivity to 1.0 cm/sec is based on the assumption of potential sediment fouling of the geosynthetics.

- An increase in final cover recompacted clay cover liner (Layer 5) hydraulic conductivity to 1.0 X 10^{-5} cm/sec is based on the assumption that potential settlement may occur and result in a higher hydraulic conductivity.
- Revision to the leachate drainage layer (Layer 7) from a lateral drainage layer designation layer type 2 to a vertical percolation layer type 1 is based on the assumption that leachate collection will cease after completion of the 30 year post closure care period.
- Initial soil water and snow water content was specified for layers 1 through 9 based on the final water storage of the 31 through 61year HELP run.
- A Leaf Area Index of 5.0 was utilized to represent an excellent stand of grass over the landfill cover.
- The SCS Runoff Curve Number is based on an assumed worst case grade of 14% (top of landfill slope) composed of areas with excellent stands of grass with a maximum flow distance of 630 feet based on the final cover configuration.
- Fractional area allowing runoff is presumed to be 95%.
- Evaporative zone depth is presumed to be 24-inches, larger than the minimum recommended 8-inches recommended by HELP and below the maximum of 36-inches.

CONCLUSION:

Results of the HELP Model simulations indicate that the average annual leachate heads will remain below the surrounding piezometric groundwater elevation throughout the 67-year Design Period and the 70-year after post closure period resulting in an inward gradient. Final results for each of the four simulation runs are as follows:

HELP Model Output Liner Head Information

HELP Run Scenario	Average Annual Leachate Head
Active Life Years 1 through 31	1.548 - Inches
Post Closure Care Period Years 32 through 61	0 - Inches
After Post Closure Care Period Years 62 through 131	2.252 Inches

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Koerner, Robert M. "Designing with Geosynthetics." Upper Saddle River, NJ: Pearson Prentice Hall, 2005.

National Environmental Satellite, Data, and Information Service, National Oceanic & Atmospheric Administration http://hurricane.ncdc.noaa.gov/climatenormals/clim20/il/113320.pdf (accessed August 1, 2011)

Schroeder, Paul R., Tamsen S. Dozier, Paul A. Zappi, Bruce M. McEnroe, John W. Sjostrom, and R. Lee Peyton. *The Hydrologic Evaluation of Landfill Performance (HELP) Model; Engineering Documentation for Version 3*. Vols. EPA/600/R-94/168b. Environmental Laboratory, U.S. Army Corps of Engineers, Vicksburg, MS: U.S. Environmental Protection Agency: Office of Research and Development, 1994.

Google Maps http://maps.google.com/maps?f=q&source=s_q&hl=en&geocode=&q=2150+North,+Oneida,+IL&aq=0&vps=1&sll=41.028154,-90.250111&sspn=0.0225,0.036221&ie=UTF8&hq=&hnear=2150+N,+Oneida,+Knox,+Illinois+61467 (accessed August 1, 2011).

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OBJECTIVE:

Determine the estimated leachate head over the base liner to ensure compliance with Section 811.317 of the Illinois Administrative Code and determine estimated leachate head over the composite liner system for the Groundwater Impact Assessment (GIA).

DESIGN CRITERIA:

1. The liner configuration for the South Unit consists of 3-ft of recompacted clay liner material overlain by a 60-mil High Density Polyethylene (HDPE) geomembrane liner and a 12 inches of granular drainage layer.
2. The 36 inches of recompacted clay liner will be constructed with a maximum hydraulic conductivity of 1.0 X 10^{-7} cm/s.
3. It is assumed that the 60-mil HDPE geomembrane liner layer will have 10 installation defects per acre each retaining a cross-sectional area of 1 cm^2.
4. The 12 inch granular drainage layer has a minimum hydraulic conductivity of 5.0 X 10^{-2} cm/s.
5. The final cover configuration for the South Unit from the base to the surface will consist of 12 inches of recompacted clay cover overlain by a 40-mil Linear Low Density Polyethylene (LLDPE) geomembrane liner, a 200-mil double sided geocomposite drainage layer, 30 inches of general cover soils and 6 inches of soil material capable of supporting vegetation.
6. The 12 inches of recompacted clay cover will be constructed with a maximum hydraulic conductivity of 1.0 X 10^{-7} cm/s.
7. It is assumed that the 40-mil LLDPE geomembrane cover liner layer will have 15 installation defects per acre each retaining a cross-sectional area of 1 cm^2.
8. The 200-mil double sided geocomposite drainage layer will have a hydraulic conductivity of 3.5 cm/s. per the geocomposite flow calculation.
9. The maximum waste depth upon closure of the landfill will be approximately 1152 inches in depth.

METHOD:

1. Determine HELP input data for weather, precipitation, evapotranspiration, etc. for Effingham, Illinois or other cities located within the region surrounding Effingham, Illinois.
2. Utilize the South Unit design attributes for the composite liner system, leachate collection system, waste depth and final cover system for use as HELP input.
3. Complete three HELP run scenarios over a one (1) acre area for the estimated 61year design period (31 years of active life and 30 years of post-closure care) and 70 years after the design period. One run will be completed during the estimated 31 year active life of the landfill; one run will be conducted for the 30 year post closure care period; and one run will be completed for 70 years after post closure.
4. Utilize the HELP output data for use in the GIA.

Assumptions:

Input Data for all HELP Simulations

- Synthetically generated temperature and rainfall inputs were developed using actual monthly mean temperature and rainfall data from the St. Louis, Missouri weather station and synthetically generated based on St. Louis, Missouri simulations.
- Synthetically generated solar radiation and evapotranspiration inputs were developed using the latitude for Effingham, Illinois and synthetically generated based on St. Louis, Missouri simulations.
- The liner geomembrane pinhole density of 1 is utilized per the recommendations from the HELP Model 3.07 guidance information which notes that pinhole density of 0.5 to 1 may be typical based on current manufacturing process.
- The liner geomembrane installation defect density of 10 holes/acre has been utilized based on the HELP Model guidance and typical applications submitted and approved by the Illinois EPA.

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- The cover geomembrane installation defect density of 15 holes/acre has been utilized based on the HELP Model guidance and typical applications submitted and approved by the Illinois EPA.

Input Data for Individual HELP Simulations

H.E.L.P. Model Design Setup (Active Life Period – Years 1 through 31)

Layer	Depth	Description	Notes
1	12"	Daily Cover Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #11
2	1152"	Waste	Layer 2: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
3	12"	Pea Gravel/Coarse Sand OR Sand and 300 mil Double Sided Geocomposite	Layer 3: Lateral Drainage Layer (2) Soil Texture #21 K = 5.0 X 10^{-2} cm/sec Average Slope 2.2% Drainage Length 615 feet
4	0.06"	60 mil HDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #35 Pinhole-1, Defects-10, Installation Quality-4 (Poor)
5	36"	Recompacted Clay Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for Active Life Period – Years 1 through 31

- 12 inches of intermediate cover was assumed for this HELP run.
- An initial average waste depth of 1,152 inches was assumed for years 1 through 31.
- HELP was allowed to generate the initial moisture content and snow water.
- A Leaf Area Index of 3.0 was utilized to represent the presence of a fair stand of grass.
- The SCS Runoff Curve Number is based on an assumed top grade of 14% composed of vegetated soils with a maximum flow distance of 630 feet.
- Fractional area allowing runoff is presumed to be 75% assuming that the waste is in place and runoff potential is limited.
- The evaporative zone depth is presumed to be the minimum recommended by the HELP program of 12 inches.

H.E.L.P. Model Design Setup (Post-Closure Care Period – Years 32 through 61)

Layer	Depth	Description	Notes
1	6"	Vegetative Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #8

2	30"	Protective Layer	Layer 2: Vertical Percolation Layer (1) Soil Texture #11
3	0.20"	Geosynthetic Drainage Layer	Layer 3: Lateral Drainage Layer (2) Soil Texture #20 Average Slope 14.5% Drainage Length 630 feet
4	0.04"	40 mil LLDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #36 Pinhole-1, Defects-15, Installation Quality-4 (Poor)
5	12"	Recompacted Clay Cover Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16 (shown as 0 due to conductivity amendment) K = 1.0 X 10^{-7} cm/sec
6	1,152"	Waste	Layer 6: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
7	12"	Pea Gravel/Coarse Sand OR Sand and 300 mil Double Sided Geocomposite	Layer 7: Lateral Drainage Layer (2) Soil Texture #21 (shown as 0 due to conductivity amendment) K = 5.0 X 10^{-2} cm/sec Average Slope 2.2% Drainage Length 615 feet
8	0.06"	60 mil HDPE Geomembrane	Layer 8: Flexible Membrane Liner Layer (4) Material Texture #35 Pinhole-1, Defects-10, Installation Quality-4 (Poor)
9	36"	Recompacted Clay Liner	Layer 9: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for Post-Closure Care Period – Years 32 through 61

- The Layer 1 thickness of 6 inches and HELP Model default soil texture #8 used is based on the assumption that 6 inches of loamy soil will be placed as the final lift of the final cover system to promote vegetative growth.
- The Layer 2 HELP Model default soil texture #11 was used based on the assumption that the use of general site soils classified as lean clay (CL).
- The Layer 3 HELP Model default soil texture #20 was used based on the standard geocomposite drainage material attributes.
- The full waste depth of 1,152 inches was used for the post closure care period years 32 through 61 and the final soil water content specifications from the previous 1 through 31 year HELP run were input.
- Initial soil water and snow water content was specified for layers 6 through 9 based on the final water storage of the 1 through 31 year HELP run. The initial soil water content specified for layers 1 through 5 was assumed to be at field capacity for all layers except Layer 5, the initial water content was specified at the layers porosity to indicate a fully compacted clay material.
- A Leaf Area Index of 4.0 was utilized to represent the presence of significant vegetation over the landfill cover.

- The SCS Runoff Curve Number is based on an assumed worst case grade of 14% (top of landfill slope) composed of areas with good stands of grass with a maximum flow distance of 630 feet based on the final cover configuration.
- Fractional area allowing runoff is presumed to be 90% assuming that the waste will be graded to the final approved contours and all areas will be closed.
- Evaporative zone depth is presumed to be 24-inches, larger than the minimum recommended 8-inches recommended by HELP and well below the maximum of 36-inches.

H.E.L.P. Model Design Setup (After Post-Closure Care Period - Year 62 through 131)

Layer	Depth	Description	Notes
1	6"	Vegetative Layer	Layer 1: Vertical Percolation Layer (1) Soil Texture #8
2	30"	Protective Layer	Layer 2: Vertical Percolation Layer (1) Soil Texture #11
3	0.20"	Geosynthetic Drainage Layer	Layer 3: Lateral Drainage Layer (2) Soil Texture #20 (shown as 0 due to conductivity amendment) K = 1.0 cm/sec Average Slope 5% Drainage Length 178 Ft (Longest)
4	0.04"	40-mil LLDPE Geomembrane	Layer 4: Flexible Membrane Liner Layer (4) Material Texture #36 Pinhole-1, Defects-15, Installation Quality-Poor
5	12"	Recompacted Clay Cover Liner	Layer 5: Barrier Soil Liner Layer (3) Soil Texture #16 (shown as 0 due to conductivity amendment) K = 1.0 X 10^{-5} cm/sec
6	1,512"	Waste	Layer 2: Vertical Percolation Layer (1) Soil Texture #18 for municipal solid waste
7	12"	Pea Gravel/Coarse Sand OR Sand and 300 mil Double Sided Geocomposite	Layer 3: Vertical Percolation Layer (1) Soil Texture #21 (shown as 0 due to conductivity amendment) K = 5.0 X 10^{-2} cm/sec Subsurface Inflow = 0.35 Inches/Year
8	0.06"	60-mil HDPE Geomembrane	Layer 9: Flexible Membrane Liner Layer (4) Material Texture #35 Pinhole-1, Defects-10, Installation Quality -Poor
9	36"	Recompacted Clay Liner	Layer 13: Barrier Soil Liner Layer (3) Soil Texture #16

Notes for After Post Closure Care Period – Years 62 through 131

- Reduction of the final cover drainage layer (Layer 3) hydraulic conductivity to 1.0 cm/sec is based on the assumption of potential sediment fouling of the geosynthetics.

ANDREWS ENGINEERING INC	**TITLE:**	South Unit HELP			Calc No.	Rev. No.
	Project:	Landfill 33			**Date:**	08/29/2018
	Job No.:	180130			**Sheet** 5 of 8	
	Prepared By:	MTH	**Checked:**		**Reviewed:**	

- An increase in final cover recompacted clay cover liner (Layer 5) hydraulic conductivity to 1.0 X 10^{-5} cm/sec is based on the assumption that potential settlement may occur and result in a higher hydraulic conductivity.
- Revision to the leachate drainage layer (Layer 7) from a lateral drainage layer designation layer type 2 to a vertical percolation layer type 1 is based on the assumption that leachate collection will cease after completion of the 30 year post closure care period.
- Initial soil water and snow water content was specified for layers 1 through 9 based on the final water storage of the 31 through 61year HELP run.
- A Leaf Area Index of 5.0 was utilized to represent an excellent stand of grass over the landfill cover.
- The SCS Runoff Curve Number is based on an assumed worst case grade of 14% (top of landfill slope) composed of areas with excellent stands of grass with a maximum flow distance of 630 feet based on the final cover configuration.
- Fractional area allowing runoff is presumed to be 95%.
- Evaporative zone depth is presumed to be 24-inches, larger than the minimum recommended 8-inches recommended by HELP and below the maximum of 36-inches.

CONCLUSION:

Results of the HELP Model simulations indicate that the average annual leachate heads will remain below the surrounding piezometric groundwater elevation throughout the 67-year Design Period and the 70-year after post closure period resulting in an inward gradient. Final results for each of the four simulation runs are as follows:

HELP Model Output Liner Head Information

HELP Run Scenario	Average Annual Leachate Head
Active Life Years 1 through 31	1.548 - Inches
Post Closure Care Period Years 32 through 61	0 - Inches
After Post Closure Care Period Years 62 through 131	2.252 Inches

REFERENCES:

Koerner, Robert M. "Designing with Geosynthetics." Upper Saddle River, NJ: Pearson Prentice Hall, 2005.

National Environmental Satellite, Data, and Information Service, National Oceanic & Atmospheric Administration http://hurricane.ncdc.noaa.gov/climatenormals/clim20/il/113320.pdf (accessed August 1, 2011)

Schroeder, Paul R., Tamsen S. Dozier, Paul A. Zappi, Bruce M. McEnroe, John W. Sjostrom, and R. Lee Peyton. *The Hydrologic Evaluation of Landfill Performance (HELP) Model; Engineering Documentation for Version 3.* Vols. EPA/600/R-94/168b. Environmental Laboratory, U.S. Army Corps of Engineers, Vicksburg, MS: U.S. Environmental Protection Agency: Office of Research and Development, 1994.

Google Maps http://maps.google.com/maps?f=q&source=s_q&hl=en&geocode=&q=2150+North,+Oneida,+IL&aq=0&vps=1&sll=41.028154,-90.250111&sspn=0.0225,0.036221&ie=UTF8&hq=&hnear=2150+N,+Oneida,+Knox,+Illinois+61467 (accessed August 1, 2011).

Xuede, Qian, Robert M. Koerner, and Donald H. Gray. "Geotechnical Aspects of Landfill Design and Construction." Upper Saddle River, NJ: Prentice Hall, 2002.

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA4E1.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA7E1.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA13E1.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA11E1.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10E1.D10
OUTPUT DATA FILE:             C:\LF33\E10145.OUT


TIME:  91:12      DATE:   6/29/2018


******************************************************************************

     TITLE:  EXISTING UNIT - ACTIVE LIFE - YEARS 1 TO 45

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
            COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                           MATERIAL TEXTURE NUMBER  11
           THICKNESS                     =    12.00   INCHES
           POROSITY                      =     0.4640 VOL/VOL
           FIELD CAPACITY                =     0.3100 VOL/VOL
           WILTING POINT                 =     0.1870 VOL/VOL
           INITIAL SOIL WATER CONTENT    =     0.3377 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.639999998000E-04 CM/SEC
```

```
                                   LAYER  2
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                           MATERIAL TEXTURE NUMBER  18
           THICKNESS                     =   936.00   INCHES
           POROSITY                      =     0.6710 VOL/VOL
           FIELD CAPACITY                =     0.2920 VOL/VOL
           WILTING POINT                 =     0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT    =     0.2900 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC


                                   LAYER  3
                                   --------

                         TYPE 3 - BARRIER SOIL LINER
                           MATERIAL TEXTURE NUMBER  16
           THICKNESS                     =   120.00   INCHES
           POROSITY                      =     0.4270 VOL/VOL
           FIELD CAPACITY                =     0.4180 VOL/VOL
           WILTING POINT                 =     0.3670 VOL/VOL
           INITIAL SOIL WATER CONTENT    =     0.4270 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.100000001000E-06 CM/SEC


                   GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                   ----------------------------------------

          NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
                 SOIL DATA BASE USING SOIL TEXTURE #11 WITH BARE
                 GROUND CONDITIONS, A SURFACE SLOPE OF 10.% AND
                 A SLOPE LENGTH OF  445. FEET.

        SCS RUNOFF CURVE NUMBER            =    94.60
        FRACTION OF AREA ALLOWING RUNOFF   =    75.0    PERCENT
        AREA PROJECTED ON HORIZONTAL PLANE =     1.000  ACRES
        EVAPORATIVE ZONE DEPTH             =     6.0    INCHES
        INITIAL WATER IN EVAPORATIVE ZONE  =     1.889  INCHES
        UPPER LIMIT OF EVAPORATIVE STORAGE =     2.784  INCHES
        LOWER LIMIT OF EVAPORATIVE STORAGE =     1.122  INCHES
        INITIAL SNOW WATER                 =     0.000  INCHES
        INITIAL WATER IN LAYER MATERIALS   =   326.755  INCHES
        TOTAL INITIAL WATER                =   326.755  INCHES
        TOTAL SUBSURFACE INFLOW            =    -6.00   INCHES/YEAR
```

```
                   EVAPOTRANSPIRATION AND WEATHER DATA
                   -----------------------------------

          NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
                    ST. LOUIS              MISSOURI

               STATION LATITUDE                          =  39.10 DEGREES
               MAXIMUM LEAF AREA INDEX                   =   0.00
               START OF GROWING SEASON (JULIAN DATE)     =     98
               END OF GROWING SEASON (JULIAN DATE)       =    300
               EVAPORATIVE ZONE DEPTH                    =   6.0  INCHES
               AVERAGE ANNUAL WIND SPEED                 =  10.40 MPH
               AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  73.00 %
               AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  67.00 %
               AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  71.00 %
               AVERAGE 4TH QUARTER RELATIVE HUMIDITY     =  74.00 %


          NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
                    COEFFICIENTS FOR     ST. LOUIS              MISSOURI

                    NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

        JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
        -------      -------      -------      -------      -------      -------
          1.72         2.14         3.28         3.55         3.54         3.73
          3.63         2.55         2.70         2.32         2.53         2.22


          NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
                    COEFFICIENTS FOR     ST. LOUIS              MISSOURI

               NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

        JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
        -------      -------      -------      -------      -------      -------
         28.60        33.80        43.20        56.10        65.60        74.80
         78.90        77.00        69.70        57.90        44.60        34.20


          NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                    COEFFICIENTS FOR     ST. LOUIS              MISSOURI
                     AND STATION LATITUDE  =  39.10 DEGREES
```

```
*******************************************************************************

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH    45
------------------------------------------------------------------------------
-

                           JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                           -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                    1.64     2.07     3.24     3.41     3.62     4.21
                             3.57     2.72     2.75     2.20     2.24     2.03

   STD. DEVIATIONS           0.94     1.10     1.22     1.34     1.75     1.99
                             1.88     1.37     1.34     1.30     1.39     1.15

 RUNOFF
 ------
   TOTALS                    0.423    0.800    0.775    0.423    0.575    0.848
                             0.683    0.368    0.422    0.279    0.384    0.263

   STD. DEVIATIONS           0.462    0.647    0.705    0.406    0.542    0.750
                             0.663    0.387    0.300    0.341    0.460    0.397

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                    0.596    0.744    2.077    2.525    2.507    2.793
                             2.275    1.980    1.850    1.376    1.232    0.852

   STD. DEVIATIONS           0.365    0.417    0.519    0.828    0.963    1.063
                             1.027    0.880    0.807    0.628    0.441    0.289

 PERCOLATION/LEAKAGE THROUGH LAYER  3
 ------------------------------------
   TOTALS                    0.0414   0.0392   0.0441   0.0433   0.0446   0.0411
                             0.0422   0.0437   0.0424   0.0425   0.0442   0.0465

   STD. DEVIATIONS           0.0531   0.0486   0.0532   0.0514   0.0538   0.0513
                             0.0524   0.0535   0.0523   0.0524   0.0516   0.0539

------------------------------------------------------------------------------
-
              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
------------------------------------------------------------------------------
-

 DAILY AVERAGE HEAD ON TOP OF LAYER  3
 -------------------------------------
   AVERAGES                  1.4143   1.4226   1.5577   1.7990   1.8481   1.7592
```

```
                         1.7182   1.7049   1.6942   1.6420   1.6770   1.7093

   STD. DEVIATIONS       2.7319   2.7596   2.9404   3.4172   3.4384   3.3517
                         3.2419   3.2502   3.2182   3.1938   3.2115   3.2101

*******************************************************************************


*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   45
  -----------------------------------------------------------------------------
-
                                   INCHES              CU. FEET         PERCENT
                              -------------------    -------------    ---------
 PRECIPITATION                 33.70   (   4.999)     122337.5        100.00

 RUNOFF                         6.244  (  1.8170)      22664.17        18.526

 EVAPOTRANSPIRATION            20.805  (  2.5041)      75523.41        61.734

 PERCOLATION/LEAKAGE THROUGH    0.51531 (  0.56111)      1870.562       1.52902
   LAYER  3

 AVERAGE HEAD ON TOP            1.662 (    3.079)
   OF LAYER  3

 CHANGE IN WATER STORAGE        0.134  (  1.8920)        484.73         0.396

*******************************************************************************
```

```
*******************************************************************************

            PEAK DAILY VALUES FOR YEARS    1 THROUGH   45
   ------------------------------------------------------------------------
                                                 (INCHES)      (CU. FT.)
                                                ----------    -------------
     PRECIPITATION                                 3.57        12959.100

     RUNOFF                                        1.963        7127.2856

     PERCOLATION/LEAKAGE THROUGH LAYER  3          0.003830       13.90330

     AVERAGE HEAD ON TOP OF LAYER  3              15.120

     SNOW WATER                                    2.43         8821.5488


     MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.4640

     MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1870

*******************************************************************************
```

```
*******************************************************************************

                FINAL WATER STORAGE AT END OF YEAR   45
   ----------------------------------------------------------------------
              LAYER        (INCHES)       (VOL/VOL)
              -----        --------       ---------
                1             3.6105         0.3009

                2           277.9134         0.2969

                3            51.2400         0.4270

            SNOW WATER        0.000

*******************************************************************************
*******************************************************************************
```

```
*******************************************************************************
*******************************************************************************
**                                                                           **
**                                                                           **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**              HELP MODEL VERSION 3.07   (1 NOVEMBER 1997)                  **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                        **
**              USAE WATERWAYS EXPERIMENT STATION                            **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                           **
**                                                                           **
*******************************************************************************
*******************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA42.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA72.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA132.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA112.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10E2.D10
OUTPUT DATA FILE:            C:\LF33\E14675.OUT


TIME:  92:35     DATE:   6/29/2018


*******************************************************************************

    TITLE:  EXISTING UNIT - 30 YEAR POST CLOSURE - YEARS 46 TO 75

*******************************************************************************


    NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
             WERE SPECIFIED BY THE USER.


                                 LAYER  1
                                 --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   8
         THICKNESS                    =     6.00   INCHES
         POROSITY                     =     0.4630 VOL/VOL
         FIELD CAPACITY               =     0.2320 VOL/VOL
         WILTING POINT                =     0.1160 VOL/VOL
         INITIAL SOIL WATER CONTENT   =     0.2320 VOL/VOL
         EFFECTIVE SAT. HYD. COND.    = 0.369999994000E-03 CM/SEC
```

R1661

```
NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.20
       FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                          LAYER  2
                          --------

                TYPE 1 - VERTICAL PERCOLATION LAYER
                    MATERIAL TEXTURE NUMBER  11
  THICKNESS                      =    30.00   INCHES
  POROSITY                       =     0.4640 VOL/VOL
  FIELD CAPACITY                 =     0.3100 VOL/VOL
  WILTING POINT                  =     0.1870 VOL/VOL
  INITIAL SOIL WATER CONTENT     =     0.3100 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.639999998000E-04 CM/SEC


                          LAYER  3
                          --------

                  TYPE 2 - LATERAL DRAINAGE LAYER
                    MATERIAL TEXTURE NUMBER  20
  THICKNESS                      =     0.20   INCHES
  POROSITY                       =     0.8500 VOL/VOL
  FIELD CAPACITY                 =     0.0100 VOL/VOL
  WILTING POINT                  =     0.0050 VOL/VOL
  INITIAL SOIL WATER CONTENT     =     0.0100 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =   10.0000000000      CM/SEC
  SLOPE                          =    10.00   PERCENT
  DRAINAGE LENGTH                =   445.0    FEET


                          LAYER  4
                          --------

                  TYPE 4 - FLEXIBLE MEMBRANE LINER
                    MATERIAL TEXTURE NUMBER  36
  THICKNESS                      =     0.04   INCHES
  POROSITY                       =     0.0000 VOL/VOL
  FIELD CAPACITY                 =     0.0000 VOL/VOL
  WILTING POINT                  =     0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT     =     0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.399999993000E-12 CM/SEC
  FML PINHOLE DENSITY            =     1.00   HOLES/ACRE
  FML INSTALLATION DEFECTS       =    15.00   HOLES/ACRE
  FML PLACEMENT QUALITY          =  4 - POOR
```

```
                          LAYER  5
                          --------

                  TYPE 3 - BARRIER SOIL LINER
                    MATERIAL TEXTURE NUMBER  16
  THICKNESS                      =    12.00   INCHES
  POROSITY                       =     0.4270 VOL/VOL
  FIELD CAPACITY                 =     0.4180 VOL/VOL
  WILTING POINT                  =     0.3670 VOL/VOL
  INITIAL SOIL WATER CONTENT     =     0.4270 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


                          LAYER  6
                          --------

                TYPE 1 - VERTICAL PERCOLATION LAYER
                    MATERIAL TEXTURE NUMBER  18
  THICKNESS                      =   936.00   INCHES
  POROSITY                       =     0.6710 VOL/VOL
  FIELD CAPACITY                 =     0.2920 VOL/VOL
  WILTING POINT                  =     0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT     =     0.2969 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.100000005000E-02 CM/SEC


                          LAYER  7
                          --------

                  TYPE 3 - BARRIER SOIL LINER
                    MATERIAL TEXTURE NUMBER  16
  THICKNESS                      =   120.00   INCHES
  POROSITY                       =     0.4270 VOL/VOL
  FIELD CAPACITY                 =     0.4180 VOL/VOL
  WILTING POINT                  =     0.3670 VOL/VOL
  INITIAL SOIL WATER CONTENT     =     0.4270 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------

NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
       SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
       FAIR STAND OF GRASS, A SURFACE SLOPE OF 10.%
```

```
           AND A SLOPE LENGTH OF  445. FEET.

   SCS RUNOFF CURVE NUMBER               =      79.70
   FRACTION OF AREA ALLOWING RUNOFF      =      90.0    PERCENT
   AREA PROJECTED ON HORIZONTAL PLANE    =       1.000  ACRES
   EVAPORATIVE ZONE DEPTH                =      24.0    INCHES
   INITIAL WATER IN EVAPORATIVE ZONE     =       6.972  INCHES
   UPPER LIMIT OF EVAPORATIVE STORAGE    =      11.130  INCHES
   LOWER LIMIT OF EVAPORATIVE STORAGE    =       4.062  INCHES
   INITIAL SNOW WATER                    =       0.000  INCHES
   INITIAL WATER IN LAYER MATERIALS      =     344.956  INCHES
   TOTAL INITIAL WATER                   =     344.956  INCHES
   TOTAL SUBSURFACE INFLOW               =       0.00   INCHES/YEAR


               EVAPOTRANSPIRATION AND WEATHER DATA
               -----------------------------------

NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
          ST. LOUIS            MISSOURI

       STATION LATITUDE                         =  39.10 DEGREES
       MAXIMUM LEAF AREA INDEX                  =   3.00
       START OF GROWING SEASON (JULIAN DATE)    =     98
       END OF GROWING SEASON (JULIAN DATE)      =    300
       EVAPORATIVE ZONE DEPTH                   =  24.0  INCHES
       AVERAGE ANNUAL WIND SPEED                =  10.40 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  71.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  74.00 %


NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR     ST. LOUIS             MISSOURI

          NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
  1.72        2.14        3.28        3.55        3.54        3.73
  3.63        2.55        2.70        2.32        2.53        2.22


NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR     ST. LOUIS             MISSOURI

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
```

```
-------     -------     -------     -------     -------     -------
 28.60       33.80       43.20       56.10       65.60       74.80
 78.90       77.00       69.70       57.90       44.60       34.20


NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR     ST. LOUIS             MISSOURI
           AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   30
-------------------------------------------------------------------------------

                       JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                       -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                1.56     2.15     3.09     3.37     3.44     4.42
                         3.38     2.66     2.75     2.18     2.16     2.06

   STD. DEVIATIONS       0.95     1.09     0.92     1.36     1.56     2.04
                         1.87     1.38     1.45     1.28     1.38     1.14

 RUNOFF
 ------
   TOTALS                0.180    0.498    0.318    0.025    0.021    0.070
                         0.027    0.005    0.005    0.006    0.018    0.016

   STD. DEVIATIONS       0.320    0.565    0.602    0.098    0.048    0.167
                         0.081    0.025    0.018    0.027    0.045    0.033

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                0.512    0.636    2.140    3.263    4.408    4.824
                         3.531    2.597    2.122    1.267    0.899    0.676

   STD. DEVIATIONS       0.277    0.371    0.568    0.766    0.840    1.655
                         1.477    1.178    1.021    0.288    0.279    0.195

 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                0.3953   0.5492   1.4808   1.0612   0.5327   0.1967
                         0.0652   0.0162   0.0004   0.0201   0.2833   0.5459

   STD. DEVIATIONS       0.4584   0.8242   0.7987   0.7111   0.5504   0.2367
```

```
                        0.1475  0.0452  0.0009  0.1048  0.7912  0.7943

 PERCOLATION/LEAKAGE THROUGH LAYER  5
 ------------------------------------
   TOTALS               0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
                        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

   STD. DEVIATIONS      0.0000  0.0000  0.0000  0.0000  0.0000  0.0000
                        0.0000  0.0000  0.0000  0.0000  0.0000  0.0000

 PERCOLATION/LEAKAGE THROUGH LAYER  7
 ------------------------------------
   TOTALS               0.0146  0.0135  0.0148  0.0143  0.0147  0.0142
                        0.0122  0.0111  0.0107  0.0111  0.0107  0.0110

   STD. DEVIATIONS      0.0379  0.0349  0.0384  0.0370  0.0382  0.0369
                        0.0341  0.0339  0.0327  0.0338  0.0326  0.0336

-----------------------------------------------------------------------------
-
            AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-----------------------------------------------------------------------------
-

 DAILY AVERAGE HEAD ON TOP OF LAYER  4
 -------------------------------------
   AVERAGES             0.0010  0.0015  0.0038  0.0028  0.0014  0.0005
                        0.0002  0.0000  0.0000  0.0001  0.0007  0.0014

   STD. DEVIATIONS      0.0012  0.0023  0.0020  0.0019  0.0014  0.0006
                        0.0004  0.0001  0.0000  0.0003  0.0021  0.0020

 DAILY AVERAGE HEAD ON TOP OF LAYER  7
 -------------------------------------
   AVERAGES             0.6385  0.8316  0.8231  0.7848  0.7466  0.7084
                        0.6725  0.6427  0.6139  0.5851  0.5565  0.5279

   STD. DEVIATIONS      1.8869  2.5324  2.5698  2.4860  2.4036  2.3226
                        2.2426  2.1603  2.0800  2.0004  1.9218  1.8441

******************************************************************************


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    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   30
-----------------------------------------------------------------------------
-
                                      INCHES           CU. FEET      PERCENT
                                 -------------------  -------------  ---------
 PRECIPITATION                    33.21    (   4.731)    120562.0     100.00

 RUNOFF                            1.190   (  1.0105)     4317.89      3.581

 EVAPOTRANSPIRATION               26.875   (  2.9462)    97555.70     80.917

 LATERAL DRAINAGE COLLECTED        5.14694 (  2.06383)   18683.408   15.49693
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH       0.00004 (  0.00001)       0.133    0.00011
   LAYER  5

 AVERAGE HEAD ON TOP               0.001 (    0.000)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH       0.15292 (  0.41021)     555.089    0.46042
   LAYER  7

 AVERAGE HEAD ON TOP               0.678 (    2.177)
   OF LAYER  7

 CHANGE IN WATER STORAGE          -0.152   (  1.3347)     -550.09     -0.456

******************************************************************************


******************************************************************************

          PEAK DAILY VALUES FOR YEARS     1 THROUGH   30
------------------------------------------------------------------------
                                               (INCHES)    (CU. FT.)
                                              ----------  -------------
   PRECIPITATION                                 3.44       12487.200

   RUNOFF                                        1.962       7120.3486

   DRAINAGE COLLECTED FROM LAYER  3              0.62284     2260.91333

   PERCOLATION/LEAKAGE THROUGH LAYER  5          0.000003       0.01149

   AVERAGE HEAD ON TOP OF LAYER  4               0.049

   MAXIMUM HEAD ON TOP OF LAYER  4               0.113

   LOCATION OF MAXIMUM HEAD IN LAYER  3
          (DISTANCE FROM DRAIN)                  0.0 FEET

   PERCOLATION/LEAKAGE THROUGH LAYER  7          0.003732      13.54868

   AVERAGE HEAD ON TOP OF LAYER  7              11.674

   SNOW WATER                                    2.43        8821.5488


   MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.4278

   MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1693

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

******************************************************************************


******************************************************************************

              FINAL WATER STORAGE AT END OF YEAR   30
 ----------------------------------------------------------------------
              LAYER        (INCHES)       (VOL/VOL)
              -----        --------       ---------
                1            1.6417         0.2736

                2            9.0904         0.3030

                3            0.0020         0.0100

                4            0.0000         0.0000

                5            5.1240         0.4270

                6          273.3120         0.2920

                7           51.2400         0.4270

           SNOW WATER        0.000

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******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07   (1 NOVEMBER 1997)                  **
**             DEVELOPED BY ENVIRONMENTAL LABORATORY                        **
**                 USAE WATERWAYS EXPERIMENT STATION                        **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:    C:\LF33\DATA43.D4
TEMPERATURE DATA FILE:      C:\LF33\DATA73.D7
SOLAR RADIATION DATA FILE:  C:\LF33\DATA133.D13
EVAPOTRANSPIRATION DATA:    C:\LF33\DATA113.D11
SOIL AND DESIGN DATA FILE:  C:\LF33\DATA10E3.D10
OUTPUT DATA FILE:           C:\LF33\E176145.OUT


TIME:  92:59     DATE:   6/29/2018


******************************************************************************

     TITLE:  EXISTING UNIT - 70 YEAR AFTER POST CLOSURE - YEARS 76 TO 145

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
            WERE SPECIFIED BY THE USER.


                                 LAYER  1
                                 --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  8
          THICKNESS                  =     6.00   INCHES
          POROSITY                   =     0.4630 VOL/VOL
          FIELD CAPACITY             =     0.2320 VOL/VOL
          WILTING POINT              =     0.1160 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.2736 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.369999994000E-03 CM/SEC
```

```
     NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
            FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                 LAYER  2
                                 --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  11
          THICKNESS                  =    30.00   INCHES
          POROSITY                   =     0.4640 VOL/VOL
          FIELD CAPACITY             =     0.3100 VOL/VOL
          WILTING POINT              =     0.1870 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.3030 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.639999998000E-04 CM/SEC


                                 LAYER  3
                                 --------

                       TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER  0
          THICKNESS                  =     0.20   INCHES
          POROSITY                   =     0.8500 VOL/VOL
          FIELD CAPACITY             =     0.0100 VOL/VOL
          WILTING POINT              =     0.0050 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.0100 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  1.00000000000      CM/SEC
          SLOPE                      =    10.00   PERCENT
          DRAINAGE LENGTH            =   445.0    FEET


                                 LAYER  4
                                 --------

                      TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  36
          THICKNESS                  =     0.04   INCHES
          POROSITY                   =     0.0000 VOL/VOL
          FIELD CAPACITY             =     0.0000 VOL/VOL
          WILTING POINT              =     0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.399999993000E-12 CM/SEC
          FML PINHOLE DENSITY        =     1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS   =    15.00   HOLES/ACRE
          FML PLACEMENT QUALITY      =  4 - POOR
```

```
                                 LAYER  5
                                 --------

                         TYPE 3 - BARRIER SOIL LINER
                         MATERIAL TEXTURE NUMBER  0
          THICKNESS                  =    12.00   INCHES
          POROSITY                   =     0.4270 VOL/VOL
          FIELD CAPACITY             =     0.4180 VOL/VOL
          WILTING POINT              =     0.3670 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.4270 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-05 CM/SEC


                                 LAYER  6
                                 --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  18
          THICKNESS                  =   936.00   INCHES
          POROSITY                   =     0.6710 VOL/VOL
          FIELD CAPACITY             =     0.2920 VOL/VOL
          WILTING POINT              =     0.0770 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.2920 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.100000005000E-02 CM/SEC


                                 LAYER  7
                                 --------

                         TYPE 3 - BARRIER SOIL LINER
                         MATERIAL TEXTURE NUMBER  16
          THICKNESS                  =   120.00   INCHES
          POROSITY                   =     0.4270 VOL/VOL
          FIELD CAPACITY             =     0.4180 VOL/VOL
          WILTING POINT              =     0.3670 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.4270 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.100000001000E-06 CM/SEC


                 GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                 ----------------------------------------

     NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
            SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
            GOOD STAND OF GRASS, A SURFACE SLOPE OF 10.%
```

```
            AND A SLOPE LENGTH OF  445. FEET.

          SCS RUNOFF CURVE NUMBER            =    72.90
          FRACTION OF AREA ALLOWING RUNOFF   =    95.0    PERCENT
          AREA PROJECTED ON HORIZONTAL PLANE =     1.000  ACRES
          EVAPORATIVE ZONE DEPTH             =    24.0    INCHES
          INITIAL WATER IN EVAPORATIVE ZONE  =     7.096  INCHES
          UPPER LIMIT OF EVAPORATIVE STORAGE =    11.130  INCHES
          LOWER LIMIT OF EVAPORATIVE STORAGE =     4.062  INCHES
          INITIAL SNOW WATER                 =     0.000  INCHES
          INITIAL WATER IN LAYER MATERIALS   =   340.410  INCHES
          TOTAL INITIAL WATER                =   340.410  INCHES
          TOTAL SUBSURFACE INFLOW            =     0.00   INCHES/YEAR


                    EVAPOTRANSPIRATION AND WEATHER DATA
                    -----------------------------------

     NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
               ST. LOUIS               MISSOURI

            STATION LATITUDE                         =  39.10 DEGREES
            MAXIMUM LEAF AREA INDEX                  =   4.00
            START OF GROWING SEASON (JULIAN DATE)    =     98
            END OF GROWING SEASON (JULIAN DATE)      =    300
            EVAPORATIVE ZONE DEPTH                   =  24.0  INCHES
            AVERAGE ANNUAL WIND SPEED                =  10.40 MPH
            AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
            AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  67.00 %
            AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  71.00 %
            AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  74.00 %


     NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR     ST. LOUIS             MISSOURI

                   NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
   1.72        2.14        3.28        3.55        3.54        3.73
   3.63        2.55        2.70        2.32        2.53        2.22


     NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR     ST. LOUIS             MISSOURI

               NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
```

```
      -------     -------     -------     -------     -------     -------
       28.60       33.80       43.20       56.10       65.60       74.80
       78.90       77.00       69.70       57.90       44.60       34.20


           NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                    COEFFICIENTS FOR    ST. LOUIS           MISSOURI
                     AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

          AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH   70
-------------------------------------------------------------------------------
-

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                  1.81     2.12     3.31     3.55     3.59     4.08
                           3.43     2.58     2.65     2.29     2.30     2.10

   STD. DEVIATIONS         0.97     1.03     1.40     1.37     1.65     2.04
                           1.79     1.41     1.34     1.39     1.36     1.22

 RUNOFF
 ------
   TOTALS                 0.267    0.517    0.364    0.010    0.003    0.011
                          0.008    0.001    0.000    0.001    0.009    0.057

   STD. DEVIATIONS        0.447    0.584    0.677    0.054    0.012    0.043
                          0.035    0.006    0.001    0.004    0.047    0.224

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                 0.525    0.648    2.080    3.304    4.847    4.168
                          3.525    2.585    2.260    1.222    0.850    0.669

   STD. DEVIATIONS        0.240    0.352    0.551    0.706    0.992    1.914
                          1.664    1.232    0.985    0.350    0.235    0.195

 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                0.4837   0.6781   1.7594   1.1389   0.5813   0.2267
                         0.0614   0.0214   0.0028   0.0196   0.2850   0.5874

   STD. DEVIATIONS       0.5390   0.8087   1.0704   0.7561   0.5689   0.3628
```

```
                         0.1433   0.0759   0.0144   0.1049   0.6772   0.9662

 PERCOLATION/LEAKAGE THROUGH LAYER  5
 ------------------------------------
   TOTALS                0.0011   0.0061   0.0218   0.0072   0.0030   0.0011
                         0.0001   0.0000   0.0000   0.0001   0.0029   0.0067

   STD. DEVIATIONS       0.0026   0.0123   0.0369   0.0189   0.0092   0.0045
                         0.0003   0.0001   0.0000   0.0004   0.0153   0.0352

 PERCOLATION/LEAKAGE THROUGH LAYER  7
 ------------------------------------
   TOTALS                0.0032   0.0065   0.0178   0.0101   0.0047   0.0011
                         0.0001   0.0000   0.0000   0.0001   0.0028   0.0036

   STD. DEVIATIONS       0.0134   0.0141   0.0242   0.0213   0.0132   0.0045
                         0.0003   0.0001   0.0000   0.0004   0.0146   0.0145

-------------------------------------------------------------------------------
-
               AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------
-

 DAILY AVERAGE HEAD ON TOP OF LAYER  4
 -------------------------------------
   AVERAGES              0.0209   0.1627   0.5374   0.1734   0.0657   0.0240
                         0.0016   0.0005   0.0001   0.0013   0.0725   0.1648

   STD. DEVIATIONS       0.0640   0.3425   0.9447   0.4993   0.2304   0.1152
                         0.0037   0.0019   0.0004   0.0086   0.4038   0.9025

 DAILY AVERAGE HEAD ON TOP OF LAYER  7
 -------------------------------------
   AVERAGES              0.0051   0.0025   0.0097   0.0076   0.0021   0.0002
                         0.0000   0.0000   0.0000   0.0000   0.0024   0.0054

   STD. DEVIATIONS       0.0406   0.0104   0.0226   0.0272   0.0089   0.0009
                         0.0000   0.0000   0.0000   0.0000   0.0153   0.0406

*******************************************************************************


*******************************************************************************

    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS     1 THROUGH   70
-------------------------------------------------------------------------------
-
                                            INCHES          CU. FEET     PERCENT
```

```
                                      -------------------  -------------  ---------
 PRECIPITATION                          33.82     (   4.892)     122761.4     100.00

 RUNOFF                                  1.248    (  0.9984)      4530.15      3.690

 EVAPOTRANSPIRATION                     26.682    (  3.2810)     96856.61     78.898

 LATERAL DRAINAGE COLLECTED              5.84570 (  2.17258)    21219.875   17.28546
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH             0.05012 (  0.05154)      181.931    0.14820
   LAYER  5

 AVERAGE HEAD ON TOP                     0.102 (    0.110)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH             0.05012 (  0.04491)      181.931    0.14820
   LAYER  7

 AVERAGE HEAD ON TOP                     0.003 (    0.006)
   OF LAYER  7

 CHANGE IN WATER STORAGE                -0.007    (  1.3942)       -27.16     -0.022

*******************************************************************************
```

```
*******************************************************************************

          PEAK DAILY VALUES FOR YEARS     1 THROUGH   70
------------------------------------------------------------------------
                                                  (INCHES)      (CU. FT.)
                                                 ----------   -------------
   PRECIPITATION                                   3.57        12959.100

   RUNOFF                                          2.660        9656.1279

   DRAINAGE COLLECTED FROM LAYER  3                0.25421       922.79926

   PERCOLATION/LEAKAGE THROUGH LAYER  5            0.030329      110.09521

   AVERAGE HEAD ON TOP OF LAYER  4                24.255

   MAXIMUM HEAD ON TOP OF LAYER  4                40.935

   LOCATION OF MAXIMUM HEAD IN LAYER  3
         (DISTANCE FROM DRAIN)                    65.7 FEET

   PERCOLATION/LEAKAGE THROUGH LAYER  7            0.003416       12.39872

   AVERAGE HEAD ON TOP OF LAYER  7                 0.498

   SNOW WATER                                      3.24        11767.4912


   MAXIMUM VEG. SOIL WATER (VOL/VOL)                     0.4227

   MINIMUM VEG. SOIL WATER (VOL/VOL)                     0.1692

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

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```

```
******************************************************************************

              FINAL WATER STORAGE AT END OF YEAR   70
     ----------------------------------------------------------------------
              LAYER         (INCHES)         (VOL/VOL)
              -----         --------         ---------
                1            1.5429            0.2571

                2            8.6649            0.2888

                3            0.0020            0.0100

                4            0.0000            0.0000

                5            5.1240            0.4270

                6          273.3120            0.2920

                7           51.2400            0.4270

             SNOW WATER      0.000

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******************************************************************************
```

```
 NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.20
          FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                             LAYER  2
                             --------

                  TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER  18
    THICKNESS                   =     936.00    INCHES
    POROSITY                    =       0.6710 VOL/VOL
    FIELD CAPACITY              =       0.2920 VOL/VOL
    WILTING POINT               =       0.0770 VOL/VOL
    INITIAL SOIL WATER CONTENT  =       0.2894 VOL/VOL
    EFFECTIVE SAT. HYD. COND.   =  0.100000005000E-02 CM/SEC


                             LAYER  3
                             --------

                      TYPE 3 - BARRIER SOIL LINER
                      MATERIAL TEXTURE NUMBER  16
    THICKNESS                   =     120.00    INCHES
    POROSITY                    =       0.4270 VOL/VOL
    FIELD CAPACITY              =       0.4180 VOL/VOL
    WILTING POINT               =       0.3670 VOL/VOL
    INITIAL SOIL WATER CONTENT  =       0.4270 VOL/VOL
    EFFECTIVE SAT. HYD. COND.   =  0.100000001000E-06 CM/SEC


              GENERAL DESIGN AND EVAPORATIVE ZONE DATA
              ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #11 WITH A
          FAIR STAND OF GRASS, A SURFACE SLOPE OF 10.%
          AND A SLOPE LENGTH OF  445. FEET.

   SCS RUNOFF CURVE NUMBER             =     87.10
   FRACTION OF AREA ALLOWING RUNOFF    =     75.0    PERCENT
   AREA PROJECTED ON HORIZONTAL PLANE  =      1.000  ACRES
   EVAPORATIVE ZONE DEPTH              =     12.0    INCHES
   INITIAL WATER IN EVAPORATIVE ZONE   =      3.855  INCHES
   UPPER LIMIT OF EVAPORATIVE STORAGE  =      5.568  INCHES
   LOWER LIMIT OF EVAPORATIVE STORAGE  =      2.244  INCHES
   INITIAL SNOW WATER                  =      0.000  INCHES
   INITIAL WATER IN LAYER MATERIALS    =    326.005  INCHES
```

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                   **
**             DEVELOPED BY ENVIRONMENTAL LABORATORY                        **
**               USAE WATERWAYS EXPERIMENT STATION                          **
**          FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                 **
**                                                                          **
**                                                                          **
******************************************************************************
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PRECIPITATION DATA FILE:     C:\LF33\DATA4EA.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA7EA.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA13EA.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA11EA.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10EA.D10
OUTPUT DATA FILE:            C:\LF33\EA0145.OUT


TIME:  66:12     DATE:   6/29/2018


******************************************************************************

     TITLE:  EXISTING UNIT - ACTIVE LIFE - YEARS 1 TO 45

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                           MATERIAL TEXTURE NUMBER  11
         THICKNESS                   =     12.00    INCHES
         POROSITY                    =      0.4640 VOL/VOL
         FIELD CAPACITY              =      0.3100 VOL/VOL
         WILTING POINT               =      0.1870 VOL/VOL
         INITIAL SOIL WATER CONTENT  =      0.3212 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.639999998000E-04 CM/SEC


        TOTAL INITIAL WATER                  =    326.005  INCHES
        TOTAL SUBSURFACE INFLOW              =     -6.00   INCHES/YEAR


                      EVAPOTRANSPIRATION AND WEATHER DATA
                      -----------------------------------

        NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
                  ST. LOUIS              MISSOURI

            STATION LATITUDE                         =  39.10 DEGREES
            MAXIMUM LEAF AREA INDEX                  =   3.00
            START OF GROWING SEASON (JULIAN DATE)    =    98
            END OF GROWING SEASON (JULIAN DATE)      =   300
            EVAPORATIVE ZONE DEPTH                   =  12.0  INCHES
            AVERAGE ANNUAL WIND SPEED                =  10.40 MPH
            AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
            AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  67.00 %
            AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  71.00 %
            AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  74.00 %


        NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
                  COEFFICIENTS FOR    ST. LOUIS            MISSOURI

                  NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

     JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
     -------      -------      -------      -------      -------      -------
       1.72         2.14         3.28         3.55         3.54         3.73
       3.63         2.55         2.70         2.32         2.53         2.22


        NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
                  COEFFICIENTS FOR    ST. LOUIS            MISSOURI

            NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

     JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
     -------      -------      -------      -------      -------      -------
      28.60        33.80        43.20        56.10        65.60        74.80
      78.90        77.00        69.70        57.90        44.60        34.20


        NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                  COEFFICIENTS FOR    ST. LOUIS            MISSOURI
                    AND STATION LATITUDE  =  39.10 DEGREES
```

```
******************************************************************************

          AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH    45
------------------------------------------------------------------------------

                              JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                              -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                       1.64     2.07     3.24     3.41     3.62     4.21
                                3.57     2.72     2.75     2.20     2.24     2.03

   STD. DEVIATIONS              0.94     1.10     1.22     1.34     1.75     1.99
                                1.88     1.37     1.34     1.30     1.39     1.15

 RUNOFF
 ------
   TOTALS                      0.339    0.624    0.456    0.071    0.093    0.187
                               0.130    0.048    0.061    0.040    0.101    0.127

   STD. DEVIATIONS             0.422    0.607    0.670    0.142    0.138    0.282
                               0.231    0.106    0.080    0.079    0.200    0.360

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                      0.587    0.753    2.299    3.222    3.331    3.885
                               3.285    2.570    2.168    1.395    1.137    0.798

   STD. DEVIATIONS             0.308    0.440    0.513    0.910    1.080    1.512
                               1.439    1.140    0.913    0.419    0.318    0.216

 PERCOLATION/LEAKAGE THROUGH LAYER  3
 ------------------------------------
   TOTALS                     0.0069   0.0065   0.0073   0.0072   0.0073   0.0072
                              0.0072   0.0072   0.0070   0.0072   0.0069   0.0072

   STD. DEVIATIONS            0.0254   0.0239   0.0273   0.0264   0.0275   0.0265
                              0.0274   0.0274   0.0264   0.0272   0.0263   0.0271

------------------------------------------------------------------------------
-
                AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
------------------------------------------------------------------------------
-

 DAILY AVERAGE HEAD ON TOP OF LAYER  3
```

```
 -------------------------------------
   AVERAGES                   0.1256   0.1278   0.2170   0.2424   0.2700   0.2521
                              0.2324   0.2246   0.2048   0.1850   0.1652   0.1455

   STD. DEVIATIONS            0.6922   0.6493   0.9843   1.1758   1.1702   1.1067
                              1.0418   0.9910   0.9269   0.8645   0.8043   0.7470

******************************************************************************


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     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS     1 THROUGH    45
------------------------------------------------------------------------------
-
                                      INCHES            CU. FEET      PERCENT
                                ------------------    -------------   ---------
 PRECIPITATION                   33.70     (   4.999)    122337.5     100.00

 RUNOFF                           2.278    (  1.1769)      8268.44      6.759

 EVAPOTRANSPIRATION              25.431    (  2.9371)     92312.91     75.458

 PERCOLATION/LEAKAGE THROUGH      0.08513 (  0.28720)      309.016     0.25259
   LAYER  3

 AVERAGE HEAD ON TOP              0.199 (     0.866)
   OF LAYER  3

 CHANGE IN WATER STORAGE         -0.096    (  2.5282)      -347.49     -0.284

******************************************************************************
```

```
******************************************************************************

                PEAK DAILY VALUES FOR YEARS     1 THROUGH    45
------------------------------------------------------------------------
                                                  (INCHES)     (CU. FT.)
                                                 ----------   -------------
    PRECIPITATION                                   3.57       12959.100

    RUNOFF                                          1.895       6878.5874

    PERCOLATION/LEAKAGE THROUGH LAYER  3          0.003609        13.10205

    AVERAGE HEAD ON TOP OF LAYER  3                 7.333

    SNOW WATER                                      2.43        8821.5488

    MAXIMUM VEG. SOIL WATER (VOL/VOL)                     0.4640

    MINIMUM VEG. SOIL WATER (VOL/VOL)                     0.1870

******************************************************************************
```

```
******************************************************************************

               FINAL WATER STORAGE AT END OF YEAR   45
    -----------------------------------------------------------------------
               LAYER        (INCHES)      (VOL/VOL)
               -----        --------      ---------
                 1            3.6030        0.3002

                 2          266.8546        0.2851

                 3           51.2400        0.4270

               SNOW WATER     0.000

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R1667

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******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                   **
**             DEVELOPED BY ENVIRONMENTAL LABORATORY                        **
**               USAE WATERWAYS EXPERIMENT STATION                          **
**        FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                   **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA4EB.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA7EB.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA13EB.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA11EB.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10EB.D10
OUTPUT DATA FILE:             C:\LF33\EB4675.OUT


TIME:  66:50      DATE:   6/29/2018


******************************************************************************

     TITLE:  EXISTING UNIT - 30 YEAR POST CLOSURE - YEARS 46 TO 75

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
            WERE SPECIFIED BY THE USER.


                                 LAYER  1
                                 --------

                   TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER   8
          THICKNESS                  =     6.00   INCHES
          POROSITY                   =     0.4630 VOL/VOL
          FIELD CAPACITY             =     0.2320 VOL/VOL
          WILTING POINT              =     0.1160 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.2320 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.369999994000E-03 CM/SEC
```

```
NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
       FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                            LAYER  2
                            --------

                  TYPE 1 - VERTICAL PERCOLATION LAYER
                       MATERIAL TEXTURE NUMBER  11
   THICKNESS                  =    30.00   INCHES
   POROSITY                   =     0.4640 VOL/VOL
   FIELD CAPACITY             =     0.3100 VOL/VOL
   WILTING POINT              =     0.1870 VOL/VOL
   INITIAL SOIL WATER CONTENT =     0.3100 VOL/VOL
   EFFECTIVE SAT. HYD. COND.  =  0.639999998000E-04 CM/SEC


                            LAYER  3
                            --------

                   TYPE 2 - LATERAL DRAINAGE LAYER
                       MATERIAL TEXTURE NUMBER  20
   THICKNESS                  =     0.20   INCHES
   POROSITY                   =     0.8500 VOL/VOL
   FIELD CAPACITY             =     0.0100 VOL/VOL
   WILTING POINT              =     0.0050 VOL/VOL
   INITIAL SOIL WATER CONTENT =     0.0100 VOL/VOL
   EFFECTIVE SAT. HYD. COND.  =  10.0000000000     CM/SEC
   SLOPE                      =    10.00   PERCENT
   DRAINAGE LENGTH            =   445.0    FEET


                            LAYER  4
                            --------

                   TYPE 4 - FLEXIBLE MEMBRANE LINER
                       MATERIAL TEXTURE NUMBER  36
   THICKNESS                  =     0.04   INCHES
   POROSITY                   =     0.0000 VOL/VOL
   FIELD CAPACITY             =     0.0000 VOL/VOL
   WILTING POINT              =     0.0000 VOL/VOL
   INITIAL SOIL WATER CONTENT =     0.0000 VOL/VOL
   EFFECTIVE SAT. HYD. COND.  =  0.399999993000E-12 CM/SEC
   FML PINHOLE DENSITY        =     1.00   HOLES/ACRE
   FML INSTALLATION DEFECTS   =    15.00   HOLES/ACRE
   FML PLACEMENT QUALITY      =   4 - POOR
```

```
                                 LAYER  5
                                 --------

                      TYPE 3 - BARRIER SOIL LINER
                        MATERIAL TEXTURE NUMBER  16
          THICKNESS                  =    12.00   INCHES
          POROSITY                   =     0.4270 VOL/VOL
          FIELD CAPACITY             =     0.4180 VOL/VOL
          WILTING POINT              =     0.3670 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.4270 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.100000001000E-06 CM/SEC


                                 LAYER  6
                                 --------

                   TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  18
          THICKNESS                  =   936.00   INCHES
          POROSITY                   =     0.6710 VOL/VOL
          FIELD CAPACITY             =     0.2920 VOL/VOL
          WILTING POINT              =     0.0770 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.2851 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.100000005000E-02 CM/SEC


                                 LAYER  7
                                 --------

                      TYPE 3 - BARRIER SOIL LINER
                        MATERIAL TEXTURE NUMBER  16
          THICKNESS                  =   120.00   INCHES
          POROSITY                   =     0.4270 VOL/VOL
          FIELD CAPACITY             =     0.4180 VOL/VOL
          WILTING POINT              =     0.3670 VOL/VOL
          INITIAL SOIL WATER CONTENT =     0.4270 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.100000001000E-06 CM/SEC


               GENERAL DESIGN AND EVAPORATIVE ZONE DATA
               ----------------------------------------

     NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
            SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
            GOOD STAND OF GRASS, A SURFACE SLOPE OF 10.%
```

```
           AND A SLOPE LENGTH OF  445. FEET.

   SCS RUNOFF CURVE NUMBER            =    72.90
   FRACTION OF AREA ALLOWING RUNOFF   =    90.0    PERCENT
   AREA PROJECTED ON HORIZONTAL PLANE =     1.000  ACRES
   EVAPORATIVE ZONE DEPTH             =    24.0    INCHES
   INITIAL WATER IN EVAPORATIVE ZONE  =     6.972  INCHES
   UPPER LIMIT OF EVAPORATIVE STORAGE =    11.130  INCHES
   LOWER LIMIT OF EVAPORATIVE STORAGE =     4.062  INCHES
   INITIAL SNOW WATER                 =     0.000  INCHES
   INITIAL WATER IN LAYER MATERIALS   =   333.912  INCHES
   TOTAL INITIAL WATER                =   333.912  INCHES
   TOTAL SUBSURFACE INFLOW            =     0.00   INCHES/YEAR


                 EVAPOTRANSPIRATION AND WEATHER DATA
                 -----------------------------------

     NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
            ST. LOUIS                MISSOURI

        STATION LATITUDE                        =  39.10 DEGREES
        MAXIMUM LEAF AREA INDEX                 =   4.00
        START OF GROWING SEASON (JULIAN DATE)   =     98
        END OF GROWING SEASON (JULIAN DATE)     =    300
        EVAPORATIVE ZONE DEPTH                  =  24.0  INCHES
        AVERAGE ANNUAL WIND SPEED               =  10.40 MPH
        AVERAGE 1ST QUARTER RELATIVE HUMIDITY   =  73.00 %
        AVERAGE 2ND QUARTER RELATIVE HUMIDITY   =  67.00 %
        AVERAGE 3RD QUARTER RELATIVE HUMIDITY   =  71.00 %
        AVERAGE 4TH QUARTER RELATIVE HUMIDITY   =  74.00 %


     NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR     ST. LOUIS              MISSOURI

                 NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

  JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
  -------      -------      -------      -------      -------      -------
   1.72         2.14         3.28         3.55         3.54         3.73
   3.63         2.55         2.70         2.32         2.53         2.22


     NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
               COEFFICIENTS FOR     ST. LOUIS              MISSOURI

             NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
```

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```
      -------      -------      -------      -------      -------      -------
       28.60        33.80        43.20        56.10        65.60        74.80
       78.90        77.00        69.70        57.90        44.60        34.20

    NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR      ST. LOUIS              MISSOURI
               AND STATION LATITUDE  =   39.10 DEGREES
```

```
*******************************************************************************

       AVERAGE MONTHLY VALUES IN INCHES FOR YEARS      1 THROUGH    30
-------------------------------------------------------------------------------
-

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                   1.56     2.15     3.09     3.37     3.44     4.42
                            3.38     2.66     2.75     2.18     2.16     2.06

   STD. DEVIATIONS          0.95     1.09     0.92     1.36     1.56     2.04
                            1.87     1.38     1.45     1.28     1.38     1.14

 RUNOFF
 ------
   TOTALS                   0.179    0.492    0.311    0.015    0.002    0.018
                            0.005    0.001    0.000    0.001    0.003    0.009

   STD. DEVIATIONS          0.320    0.568    0.601    0.077    0.006    0.061
                            0.017    0.003    0.002    0.007    0.009    0.023

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                   0.502    0.630    2.105    3.244    4.742    4.570
                            3.521    2.599    2.180    1.209    0.836    0.647

   STD. DEVIATIONS          0.272    0.362    0.574    0.752    0.868    1.709
                            1.511    1.181    1.071    0.279    0.258    0.197

 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                   0.4256   0.5622   1.5404   1.0885   0.5643   0.2120
                            0.0500   0.0191   0.0032   0.0177   0.2979   0.6035

   STD. DEVIATIONS          0.4830   0.8325   0.8285   0.7293   0.5525   0.3098
                            0.1145   0.0633   0.0165   0.0960   0.8215   0.8671

 PERCOLATION/LEAKAGE THROUGH LAYER  5
 ------------------------------------
   TOTALS                   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

 PERCOLATION/LEAKAGE THROUGH LAYER  7
 ------------------------------------
   TOTALS                   0.0000 . 0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------
-
        AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------
-

 DAILY AVERAGE HEAD ON TOP OF LAYER  4
 -------------------------------------
   AVERAGES                 0.0011   0.0016   0.0039   0.0029   0.0014   0.0006
                            0.0001   0.0000   0.0000   0.0000   0.0008   0.0015

   STD. DEVIATIONS          0.0012   0.0023   0.0021   0.0019   0.0014   0.0008
                            0.0003   0.0002   0.0000   0.0002   0.0022   0.0022

 DAILY AVERAGE HEAD ON TOP OF LAYER  7
 -------------------------------------
   AVERAGES                 0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

*******************************************************************************


*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS   1 THROUGH   30
-------------------------------------------------------------------------------
-
                                           INCHES          CU. FEET      PERCENT


                              -------------------    -------------    ---------
 PRECIPITATION                  33.21     (   4.731)     120562.0       100.00

 RUNOFF                          1.036    (  0.9739)       3761.52        3.120

 EVAPOTRANSPIRATION             26.786    (  3.0181)      97233.41       80.650

 LATERAL DRAINAGE COLLECTED      5.38445 (  2.11883)     19545.566     16.21205
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH     0.00004 (  0.00001)         0.138      0.00011
   LAYER  5

 AVERAGE HEAD ON TOP             0.001 (    0.000)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH     0.00000 (  0.00000)         0.000      0.00000
   LAYER  7

 AVERAGE HEAD ON TOP             0.000 (    0.000)
   OF LAYER  7

 CHANGE IN WATER STORAGE         0.006    (  1.2913)         21.49        0.018

*******************************************************************************
```

```
*******************************************************************************

         PEAK DAILY VALUES FOR YEARS      1 THROUGH    30
------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
    PRECIPITATION                                3.44         12487.200

    RUNOFF                                       1.958         7107.4639

    DRAINAGE COLLECTED FROM LAYER  3             0.75217       2730.36450

    PERCOLATION/LEAKAGE THROUGH LAYER  5         0.000004         0.01369

    AVERAGE HEAD ON TOP OF LAYER  4              0.060

    MAXIMUM HEAD ON TOP OF LAYER  4              0.131

    LOCATION OF MAXIMUM HEAD IN LAYER  3
          (DISTANCE FROM DRAIN)                  0.0 FEET

    PERCOLATION/LEAKAGE THROUGH LAYER  7         0.000000         0.00000

    AVERAGE HEAD ON TOP OF LAYER  7              0.000

    SNOW WATER                                   2.43          8821.5488


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.4282

    MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1693

      ***  Maximum heads are computed using McEnroe's equations.  ***

           Reference:  Maximum Saturated Depth over Landfill Liner
                       by Bruce M. McEnroe, University of Kansas
                       ASCE Journal of Environmental Engineering
                       Vol. 119, No. 2, March 1993, pp. 262-270.

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******************************************************************************

          FINAL WATER STORAGE AT END OF YEAR   30
    ----------------------------------------------------------------------
                  LAYER         (INCHES)        (VOL/VOL)
                  -----         --------        ---------
                    1             1.6233          0.2705

                    2             9.2451          0.3082

                    3             0.0020          0.0100

                    4             0.0000          0.0000

                    5             5.1240          0.4270

                    6           266.8547          0.2851

                    7            51.2400          0.4270

                 SNOW WATER       0.000

******************************************************************************
******************************************************************************
```

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                   **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                       **
**                 USAE WATERWAYS EXPERIMENT STATION                        **
**           FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA4EC.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA7EC.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA13EC.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA11EC.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10EC.D10
OUTPUT DATA FILE:             C:\LF33\EC76145.OUT


TIME:  68:53     DATE:   6/29/2018


******************************************************************************

    TITLE:  EXISTING UNIT - 70 YEAR AFTER POST CLOSURE - YEARS 76 TO 145

******************************************************************************


    NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
             WERE SPECIFIED BY THE USER.


                                      LAYER  1
                                      --------

                         TYPE 1 - VERTICAL PERCOLATION LAYER
                              MATERIAL TEXTURE NUMBER  8
           THICKNESS                      =      6.00    INCHES
           POROSITY                       =      0.4630 VOL/VOL
           FIELD CAPACITY                 =      0.2320 VOL/VOL
           WILTING POINT                  =      0.1160 VOL/VOL
           INITIAL SOIL WATER CONTENT     =      0.2705 VOL/VOL
           EFFECTIVE SAT. HYD. COND.      =  0.369999994000E-03 CM/SEC
```

```
   NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  5.00
            FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                      LAYER  2
                                      --------

                         TYPE 1 - VERTICAL PERCOLATION LAYER
                              MATERIAL TEXTURE NUMBER  11
           THICKNESS                      =     30.00    INCHES
           POROSITY                       =      0.4640 VOL/VOL
           FIELD CAPACITY                 =      0.3100 VOL/VOL
           WILTING POINT                  =      0.1870 VOL/VOL
           INITIAL SOIL WATER CONTENT     =      0.3082 VOL/VOL
           EFFECTIVE SAT. HYD. COND.      =  0.639999998000E-04 CM/SEC


                                      LAYER  3
                                      --------

                          TYPE 2 - LATERAL DRAINAGE LAYER
                              MATERIAL TEXTURE NUMBER  0
           THICKNESS                      =      0.20    INCHES
           POROSITY                       =      0.8500 VOL/VOL
           FIELD CAPACITY                 =      0.0100 VOL/VOL
           WILTING POINT                  =      0.0050 VOL/VOL
           INITIAL SOIL WATER CONTENT     =      0.0100 VOL/VOL
           EFFECTIVE SAT. HYD. COND.      =  1.00000000000      CM/SEC
           SLOPE                          =     10.00    PERCENT
           DRAINAGE LENGTH                =    445.0     FEET


                                      LAYER  4
                                      --------

                          TYPE 4 - FLEXIBLE MEMBRANE LINER
                              MATERIAL TEXTURE NUMBER  36
           THICKNESS                      =      0.04    INCHES
           POROSITY                       =      0.0000 VOL/VOL
           FIELD CAPACITY                 =      0.0000 VOL/VOL
           WILTING POINT                  =      0.0000 VOL/VOL
           INITIAL SOIL WATER CONTENT     =      0.0000 VOL/VOL
           EFFECTIVE SAT. HYD. COND.      =  0.399999993000E-12 CM/SEC
           FML PINHOLE DENSITY            =      1.00    HOLES/ACRE
           FML INSTALLATION DEFECTS       =     15.00    HOLES/ACRE
           FML PLACEMENT QUALITY          =  4 - POOR
```

```
                                      LAYER  5
                                      --------

                            TYPE 3 - BARRIER SOIL LINER
                              MATERIAL TEXTURE NUMBER  0
           THICKNESS                      =     12.00    INCHES
           POROSITY                       =      0.4270 VOL/VOL
           FIELD CAPACITY                 =      0.4180 VOL/VOL
           WILTING POINT                  =      0.3670 VOL/VOL
           INITIAL SOIL WATER CONTENT     =      0.4270 VOL/VOL
           EFFECTIVE SAT. HYD. COND.      =  0.999999975000E-05 CM/SEC


                                      LAYER  6
                                      --------

                         TYPE 1 - VERTICAL PERCOLATION LAYER
                              MATERIAL TEXTURE NUMBER  18
           THICKNESS                      =    936.00    INCHES
           POROSITY                       =      0.6710 VOL/VOL
           FIELD CAPACITY                 =      0.2920 VOL/VOL
           WILTING POINT                  =      0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT     =      0.2851 VOL/VOL
           EFFECTIVE SAT. HYD. COND.      =  0.100000005000E-02 CM/SEC


                                      LAYER  7
                                      --------

                            TYPE 3 - BARRIER SOIL LINER
                              MATERIAL TEXTURE NUMBER  16
           THICKNESS                      =    120.00    INCHES
           POROSITY                       =      0.4270 VOL/VOL
           FIELD CAPACITY                 =      0.4180 VOL/VOL
           WILTING POINT                  =      0.3670 VOL/VOL
           INITIAL SOIL WATER CONTENT     =      0.4270 VOL/VOL
           EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


                    GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                    ----------------------------------------

   NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
            SOIL DATA BASE USING SOIL TEXTURE # 8 WITH AN
            EXCELLENT STAND OF GRASS, A SURFACE SLOPE OF 10.
```

```
               AND A SLOPE LENGTH OF  445. FEET.

        SCS RUNOFF CURVE NUMBER                  =     70.30
        FRACTION OF AREA ALLOWING RUNOFF         =     95.0    PERCENT
        AREA PROJECTED ON HORIZONTAL PLANE       =      1.000  ACRES
        EVAPORATIVE ZONE DEPTH                   =     24.0    INCHES
        INITIAL WATER IN EVAPORATIVE ZONE        =      7.171  INCHES
        UPPER LIMIT OF EVAPORATIVE STORAGE       =     11.130  INCHES
        LOWER LIMIT OF EVAPORATIVE STORAGE       =      4.062  INCHES
        INITIAL SNOW WATER                       =      0.000  INCHES
        INITIAL WATER IN LAYER MATERIALS         =    334.089  INCHES
        TOTAL INITIAL WATER                      =    334.089  INCHES
        TOTAL SUBSURFACE INFLOW                  =      0.00   INCHES/YEAR


                 EVAPOTRANSPIRATION AND WEATHER DATA
                 -----------------------------------

         NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
                 ST. LOUIS            MISSOURI

              STATION LATITUDE                         =  39.10 DEGREES
             .MAXIMUM LEAF AREA INDEX                  =   5.00
              START OF GROWING SEASON (JULIAN DATE)    =    98
              END OF GROWING SEASON (JULIAN DATE)      =   300
              EVAPORATIVE ZONE DEPTH                   =  24.0  INCHES
              AVERAGE ANNUAL WIND SPEED                =  10.40 MPH
              AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
              AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  67.00 %
              AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  71.00 %
              AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  74.00 %


         NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
                  COEFFICIENTS FOR    ST. LOUIS           MISSOURI

                  NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

      JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
      -------      -------      -------      -------      -------      -------
        1.72         2.14         3.28         3.55         3.54         3.73
        3.63         2.55         2.70         2.32         2.53         2.22


         NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
                  COEFFICIENTS FOR    ST. LOUIS           MISSOURI

              NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

      JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
      -------      -------      -------      -------      -------      -------
       28.60        33.80        43.20        56.10        65.60        74.80
       78.90        77.00        69.70        57.90        44.60        34.20


         NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                  COEFFICIENTS FOR    ST. LOUIS           MISSOURI
                   AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

        AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   70
-------------------------------------------------------------------------------

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                  1.81     2.12     3.31     3.55     3.59     4.08
                           3.43     2.58     2.65     2.29     2.30     2.10

   STD. DEVIATIONS         0.97     1.03     1.40     1.37     1.65     2.04
                           1.79     1.41     1.34     1.39     1.36     1.22

 RUNOFF
 ------
   TOTALS                 0.267    0.518    0.362    0.008    0.001    0.006
                          0.004    0.000    0.000    0.000    0.006    0.056

   STD. DEVIATIONS        0.448    0.585    0.678    0.051    0.005    0.026
                          0.022    0.002    0.000    0.001    0.035    0.223

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                 0.521    0.643    2.061    3.335    4.893    4.129
                          3.530    2.586    2.301    1.192    0.806    0.648

   STD. DEVIATIONS        0.236    0.346    0.553    0.690    1.048    1.907
                          1.665    1.233    1.018    0.348    0.228    0.194

 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                0.5006   0.6939   1.7829   1.1589   0.5761   0.2046
                         0.0530   0.0202   0.0026   0.0170   0.2868   0.6069

   STD. DEVIATIONS       0.5435   0.8086   1.0785   0.7569   0.5505   0.3443
                         0.1383   0.0806   0.0152   0.0961   0.6811   0.9855

 PERCOLATION/LEAKAGE THROUGH LAYER  5
 ------------------------------------
   TOTALS                0.0012   0.0063   0.0222   0.0074   0.0026   0.0009
                         0.0001   0.0000   0.0000   0.0001   0.0031   0.0071

   STD. DEVIATIONS       0.0027   0.0127   0.0377   0.0202   0.0082   0.0038
                         0.0002   0.0001   0.0000   0.0004   0.0164   0.0373

 PERCOLATION/LEAKAGE THROUGH LAYER  7
 ------------------------------------
   TOTALS                0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-------------------------------------------------------------------------------

              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------


 DAILY AVERAGE HEAD ON TOP OF LAYER  4
 -------------------------------------
   AVERAGES              0.0221   0.1688   0.5476   0.1796   0.0577   0.0208
                         0.0014   0.0005   0.0001   0.0012   0.0775   0.1753

   STD. DEVIATIONS       0.0653   0.3537   0.9642   0.5352   0.2060   0.0980
                         0.0035   0.0021   0.0004   0.0084   0.4333   0.9562

 DAILY AVERAGE HEAD ON TOP OF LAYER  7
 -------------------------------------
   AVERAGES              0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS       0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

*******************************************************************************


*******************************************************************************

      AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   70
-------------------------------------------------------------------------------

                                       INCHES           CU. FEET      PERCENT
                                  ----------------   -----------   ---------
 PRECIPITATION                     33.82    (   4.892)   122761.4     100.00

 RUNOFF                             1.228   (  0.9967)    4456.16      3.630

 EVAPOTRANSPIRATION                26.645   (  3.3178)   96722.35     78.789

 LATERAL DRAINAGE COLLECTED         5.90334 (  2.17455)  21429.107   17.45590
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH        0.05118 (  0.05391)    185.769    0.15133
   LAYER  5

 AVERAGE HEAD ON TOP                0.104 (    0.116)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH        0.00000 (  0.00000)      0.000    0.00000
   LAYER  7

 AVERAGE HEAD ON TOP                0.000 (    0.000)
   OF LAYER  7

 CHANGE IN WATER STORAGE            0.042   (  1.3700)     153.78      0.125

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******************************************************************************

              PEAK DAILY VALUES FOR YEARS     1 THROUGH    70
   ------------------------------------------------------------------------
                                             (INCHES)      (CU. FT.)
                                            ----------   -------------
     PRECIPITATION                             3.57        12959.100

     RUNOFF                                    2.659        9653.2158

     DRAINAGE COLLECTED FROM LAYER  3          0.25435       923.29694

     PERCOLATION/LEAKAGE THROUGH LAYER  5      0.032530      118.08403

     AVERAGE HEAD ON TOP OF LAYER  4          25.953

     MAXIMUM HEAD ON TOP OF LAYER  4          43.485

     LOCATION OF MAXIMUM HEAD IN LAYER  3
           (DISTANCE FROM DRAIN)              68.5 FEET

     PERCOLATION/LEAKAGE THROUGH LAYER  7      0.000000        0.00000

     AVERAGE HEAD ON TOP OF LAYER  7           0.000

     SNOW WATER                                3.24        11767.4912


     MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.4248

     MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.1693


      ***  Maximum heads are computed using McEnroe's equations.  ***

           Reference:  Maximum Saturated Depth over Landfill Liner
                       by Bruce M. McEnroe, University of Kansas
                       ASCE Journal of Environmental Engineering
                       Vol. 119, No. 2, March 1993, pp. 262-270.

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******************************************************************************

              FINAL WATER STORAGE AT END OF YEAR    70
   ----------------------------------------------------------------------
              LAYER        (INCHES)      (VOL/VOL)
              -----        --------      ---------
                1            1.5407        0.2568

                2            8.7114        0.2904

                3            0.0020        0.0100

                4            0.0000        0.0000

                5            5.1240        0.4270

                6          270.4359        0.2889

                7           51.2400        0.4270

           SNOW WATER        0.000

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******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**               HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                 **
**               DEVELOPED BY ENVIRONMENTAL LABORATORY                      **
**                     USAE WATERWAYS EXPERIMENT STATION                    **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA4N1.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA7N1.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA13N1.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA11N1.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10N1.D10
OUTPUT DATA FILE:             C:\LF33\N10116.OUT


TIME:  95:22      DATE:   6/29/2018


******************************************************************************

      TITLE:  NORTHWESTERN AREA - ACTIVE LIFE - YEARS 1 TO 16

******************************************************************************


      NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
               COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                   LAYER  1
                                   --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  11
          THICKNESS                      =     12.00    INCHES
          POROSITY                       =      0.4640 VOL/VOL
          FIELD CAPACITY                 =      0.3100 VOL/VOL
          WILTING POINT                  =      0.1870 VOL/VOL
          INITIAL SOIL WATER CONTENT     =      0.3363 VOL/VOL
          EFFECTIVE SAT. HYD. COND.      =  0.639999998000E-04 CM/SEC
```

```
                                   LAYER  2
                                   --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  18
          THICKNESS                      =   1152.00    INCHES
          POROSITY                       =      0.6710 VOL/VOL
          FIELD CAPACITY                 =      0.2920 VOL/VOL
          WILTING POINT                  =      0.0770 VOL/VOL
          INITIAL SOIL WATER CONTENT     =      0.2929 VOL/VOL
          EFFECTIVE SAT. HYD. COND.      =  0.100000005000E-02 CM/SEC


                                   LAYER  3
                                   --------

                         TYPE 2 - LATERAL DRAINAGE LAYER
                          MATERIAL TEXTURE NUMBER   0
          THICKNESS                      =     12.00    INCHES
          POROSITY                       =      0.3970 VOL/VOL
          FIELD CAPACITY                 =      0.0320 VOL/VOL
          WILTING POINT                  =      0.0130 VOL/VOL
          INITIAL SOIL WATER CONTENT     =      0.0736 VOL/VOL
          EFFECTIVE SAT. HYD. COND.      =  0.500000007000E-01 CM/SEC
          SLOPE                          =      2.20    PERCENT
          DRAINAGE LENGTH                =    653.0     FEET


                                   LAYER  4
                                   --------

                         TYPE 4 - FLEXIBLE MEMBRANE LINER
                          MATERIAL TEXTURE NUMBER  35
          THICKNESS                      =      0.06    INCHES
          POROSITY                       =      0.0000 VOL/VOL
          FIELD CAPACITY                 =      0.0000 VOL/VOL
          WILTING POINT                  =      0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT     =      0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.      =  0.199999996000E-12 CM/SEC
          FML PINHOLE DENSITY            =      1.00    HOLES/ACRE
          FML INSTALLATION DEFECTS       =     10.00    HOLES/ACRE
          FML PLACEMENT QUALITY          =  4 - POOR
```

```
                           LAYER  5
                           --------

                  TYPE 3 - BARRIER SOIL LINER
                  MATERIAL TEXTURE NUMBER  16
      THICKNESS                    =    36.00   INCHES
      POROSITY                     =     0.4270 VOL/VOL
      FIELD CAPACITY               =     0.4180 VOL/VOL
      WILTING POINT                =     0.3670 VOL/VOL
      INITIAL SOIL WATER CONTENT   =     0.4270 VOL/VOL
      EFFECTIVE SAT. HYD. COND.    =  0.100000001000E-06 CM/SEC


               GENERAL DESIGN AND EVAPORATIVE ZONE DATA
               ----------------------------------------

     NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
              SOIL DATA BASE USING SOIL TEXTURE #11 WITH BARE
              GROUND CONDITIONS, A SURFACE SLOPE OF 19.% AND
              A SLOPE LENGTH OF  380. FEET.

    SCS RUNOFF CURVE NUMBER                =     94.70
    FRACTION OF AREA ALLOWING RUNOFF       =     75.0    PERCENT
    AREA PROJECTED ON HORIZONTAL PLANE     =      1.000  ACRES
    EVAPORATIVE ZONE DEPTH                 =      6.0    INCHES
    INITIAL WATER IN EVAPORATIVE ZONE      =      1.883  INCHES
    UPPER LIMIT OF EVAPORATIVE STORAGE     =      2.784  INCHES
    LOWER LIMIT OF EVAPORATIVE STORAGE     =      1.122  INCHES
    INITIAL SNOW WATER                     =      0.000  INCHES
    INITIAL WATER IN LAYER MATERIALS       =    357.736  INCHES
    TOTAL INITIAL WATER                    =    357.736  INCHES
    TOTAL SUBSURFACE INFLOW                =      0.00   INCHES/YEAR


                EVAPOTRANSPIRATION AND WEATHER DATA
                -----------------------------------

     NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
              ST. LOUIS              MISSOURI

          STATION LATITUDE                          =  39.10 DEGREES
          MAXIMUM LEAF AREA INDEX                   =   0.00
          START OF GROWING SEASON (JULIAN DATE)     =     98
          END OF GROWING SEASON (JULIAN DATE)       =    300
          EVAPORATIVE ZONE DEPTH                    =   6.0  INCHES
          AVERAGE ANNUAL WIND SPEED                 =  10.40 MPH
          AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  73.00 %
          AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  67.00 %
          AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  71.00 %
```

```
RUNOFF
------
  TOTALS                 0.487    0.822    0.606    0.415    0.505    0.897
                         0.718    0.288    0.393    0.270    0.385    0.208

  STD. DEVIATIONS        0.445    0.545    0.686    0.381    0.553    0.935
                         0.844    0.315    0.290    0.261    0.378    0.210

EVAPOTRANSPIRATION
------------------
  TOTALS                 0.513    0.726    2.053    2.682    2.324    2.819
                         2.060    1.974    1.864    1.523    1.244    0.786

  STD. DEVIATIONS        0.298    0.477    0.469    0.889    1.229    1.002
                         0.983    0.924    0.816    0.719    0.485    0.269

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                 0.5687   0.4110   0.5559   0.7416   0.5879   0.5173
                         0.5921   0.5292   0.4306   0.4296   0.3859   0.5005

  STD. DEVIATIONS        0.2267   0.1951   0.2542   0.3278   0.2459   0.2493
                         0.2938   0.2380   0.2125   0.1806   0.1730   0.2458

PERCOLATION/LEAKAGE THROUGH LAYER  5
------------------------------------
  TOTALS                 0.0019   0.0014   0.0018   0.0024   0.0019   0.0017
                         0.0019   0.0017   0.0014   0.0014   0.0013   0.0016

  STD. DEVIATIONS        0.0007   0.0006   0.0008   0.0009   0.0007   0.0007
                         0.0009   0.0007   0.0006   0.0006   0.0005   0.0007

-----------------------------------------------------------------------------
-
          AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-----------------------------------------------------------------------------
-

DAILY AVERAGE HEAD ON TOP OF LAYER  4
-------------------------------------
  AVERAGES               1.9220   1.5218   1.8786   2.5898   1.9868   1.8066
                         2.0009   1.7884   1.5037   1.4517   1.3475   1.6915

  STD. DEVIATIONS        0.7660   0.7185   0.8591   1.1447   0.8310   0.8706
                         0.9929   0.8043   0.7422   0.6104   0.6040   0.8307

*****************************************************************************
```

```
          AVERAGE 4TH QUARTER RELATIVE HUMIDITY  =  74.00 %


     NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR    ST. LOUIS           MISSOURI

              NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

   JAN/JUL    FEB/AUG    MAR/SEP    APR/OCT    MAY/NOV    JUN/DEC
   -------    -------    -------    -------    -------    -------
     1.72       2.14       3.28       3.55       3.54       3.73
     3.63       2.55       2.70       2.32       2.53       2.22


     NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR    ST. LOUIS           MISSOURI

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

   JAN/JUL    FEB/AUG    MAR/SEP    APR/OCT    MAY/NOV    JUN/DEC
   -------    -------    -------    -------    -------    -------
    28.60      33.00      43.20      56.10      65.60      74.80
    78.90      77.00      69.70      57.90      44.60      34.20


     NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR    ST. LOUIS           MISSOURI
                AND STATION LATITUDE  =  39.10 DEGREES


*****************************************************************************

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   16
-----------------------------------------------------------------------------
-

                    JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                    -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS             1.46     2.03     2.96     3.47     3.27     4.37
                      3.32     2.54     2.69     2.19     2.32     2.10

   STD. DEVIATIONS    0.80     1.14     0.87     1.49     1.89     2.09
                      2.15     1.37     1.17     1.09     1.55     1.06


*****************************************************************************

    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   16
-----------------------------------------------------------------------------
-
                                   INCHES            CU. FEET      PERCENT
                             -----------------    -------------  ---------
 PRECIPITATION               32.72    (   3.658)    118782.7     100.00

 RUNOFF                       5.993   (  1.8188)     21755.57     18.315

 EVAPOTRANSPIRATION          20.567   (  2.1396)     74658.98     62.853

 LATERAL DRAINAGE COLLECTED   6.25029 (  1.58814)    22688.562   19.10090
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH  0.02047 (  0.00474)       74.301     0.06255
   LAYER  5

 AVERAGE HEAD ON TOP          1.791 (    0.456)
   OF LAYER  4

 CHANGE IN WATER STORAGE     -0.109   (  1.0390)      -394.74     -0.332

*****************************************************************************
```

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*******************************************************************************

            PEAK DAILY VALUES FOR YEARS     1 THROUGH   16
-------------------------------------------------------------------------
                                              (INCHES)      (CU. FT.)
                                             ----------    -------------
     PRECIPITATION                              3.44         12487.200

     RUNOFF                                     1.810         6570.7866

     DRAINAGE COLLECTED FROM LAYER  3           0.06229        226.09923

     PERCOLATION/LEAKAGE THROUGH LAYER  5       0.000183         0.66518

     AVERAGE HEAD ON TOP OF LAYER  4            6.525

     MAXIMUM HEAD ON TOP OF LAYER  4           11.212

     LOCATION OF MAXIMUM HEAD IN LAYER  3
            (DISTANCE FROM DRAIN)              91.7 FEET

     SNOW WATER                                 1.92          6955.1221


     MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.4640

     MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1870

      ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

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*******************************************************************************

               FINAL WATER STORAGE AT END OF YEAR   16
----------------------------------------------------------------------
              LAYER          (INCHES)          (VOL/VOL)
              -----          --------          ---------
                1              3.6118            0.3010

                2            336.3840            0.2920

                3              0.6279            0.0523

                4              0.0000            0.0000

                5             15.3720            0.4270

            SNOW WATER         0.000

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*******************************************************************************
*******************************************************************************
**                                                                           **
**                                                                           **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                 **
**                DEVELOPED BY ENVIRONMENTAL LABORATORY                      **
**                   USAE WATERWAYS EXPERIMENT STATION                       **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                           **
**                                                                           **
*******************************************************************************
*******************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA42.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA72.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA132.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA112.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10N2.D10
OUTPUT DATA FILE:            C:\LF33\N11746.OUT


TIME:  95:39     DATE:   6/29/2018


*******************************************************************************

     TITLE:  NORTHWESTERN AREA-30 YEAR POST CLOSURE CARE-YEARS 17 TO 46

*******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                  LAYER  1
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER   8
          THICKNESS                   =      12.00   INCHES
          POROSITY                    =       0.4630 VOL/VOL
          FIELD CAPACITY              =       0.2320 VOL/VOL
          WILTING POINT               =       0.1160 VOL/VOL
          INITIAL SOIL WATER CONTENT  =       0.2320 VOL/VOL
          EFFECTIVE SAT. HYD. COND.   =  0.369999994000E-03 CM/SEC
```

```
NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.20
         FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                  LAYER  2
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  11
          THICKNESS                   =      30.00   INCHES
          POROSITY                    =       0.4640 VOL/VOL
          FIELD CAPACITY              =       0.3100 VOL/VOL
          WILTING POINT               =       0.1870 VOL/VOL
          INITIAL SOIL WATER CONTENT  =       0.3100 VOL/VOL
          EFFECTIVE SAT. HYD. COND.   =  0.639999998000E-04 CM/SEC


                                  LAYER  3
                                  --------

                        TYPE 2 - LATERAL DRAINAGE LAYER
                          MATERIAL TEXTURE NUMBER  20
          THICKNESS                   =       0.20   INCHES
          POROSITY                    =       0.8500 VOL/VOL
          FIELD CAPACITY              =       0.0100 VOL/VOL
          WILTING POINT               =       0.0050 VOL/VOL
          INITIAL SOIL WATER CONTENT  =       0.0100 VOL/VOL
          EFFECTIVE SAT. HYD. COND.   =   10.0000000000      CM/SEC
          SLOPE                       =      19.00   PERCENT
          DRAINAGE LENGTH             =     380.0    FEET


                                  LAYER  4
                                  --------

                        TYPE 4 - FLEXIBLE MEMBRANE LINER
                          MATERIAL TEXTURE NUMBER  36
          THICKNESS                   =       0.04   INCHES
          POROSITY                    =       0.0000 VOL/VOL
          FIELD CAPACITY              =       0.0000 VOL/VOL
          WILTING POINT               =       0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT  =       0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.   =  0.399999993000E-12 CM/SEC
          FML PINHOLE DENSITY         =       1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS    =      15.00   HOLES/ACRE
          FML PLACEMENT QUALITY       =  4 - POOR
```

```
                         LAYER  5
                         --------

                TYPE 3 - BARRIER SOIL LINER
                 MATERIAL TEXTURE NUMBER  16
THICKNESS                      =     12.00    INCHES
POROSITY                       =      0.4270 VOL/VOL
FIELD CAPACITY                 =      0.4180 VOL/VOL
WILTING POINT                  =      0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


                         LAYER  6
                         --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER  18
THICKNESS                      =   1152.00    INCHES
POROSITY                       =      0.6710 VOL/VOL
FIELD CAPACITY                 =      0.2920 VOL/VOL
WILTING POINT                  =      0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.2920 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.100000005000E-02 CM/SEC


                         LAYER  7
                         --------

              TYPE 2 - LATERAL DRAINAGE LAYER
                 MATERIAL TEXTURE NUMBER   0
THICKNESS                      =     12.00    INCHES
POROSITY                       =      0.3970 VOL/VOL
FIELD CAPACITY                 =      0.0320 VOL/VOL
WILTING POINT                  =      0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.0523 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.500000007000E-01 CM/SEC
SLOPE                          =      2.20    PERCENT
DRAINAGE LENGTH                =    653.0     FEET


                         LAYER  8
                         --------

              TYPE 4 - FLEXIBLE MEMBRANE LINER
                 MATERIAL TEXTURE NUMBER  35
```

```
THICKNESS                      =      0.06    INCHES
POROSITY                       =      0.0000 VOL/VOL
FIELD CAPACITY                 =      0.0000 VOL/VOL
WILTING POINT                  =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY            =      1.00    HOLES/ACRE
FML INSTALLATION DEFECTS       =     10.00    HOLES/ACRE
FML PLACEMENT QUALITY          =  4 - POOR


                         LAYER  9
                         --------

                TYPE 3 - BARRIER SOIL LINER
                 MATERIAL TEXTURE NUMBER  16
THICKNESS                      =     36.00    INCHES
POROSITY                       =      0.4270 VOL/VOL
FIELD CAPACITY                 =      0.4180 VOL/VOL
WILTING POINT                  =      0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT     =      0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
          FAIR STAND OF GRASS, A SURFACE SLOPE OF 19.%
          AND A SLOPE LENGTH OF  380. FEET.

SCS RUNOFF CURVE NUMBER              =     80.20
FRACTION OF AREA ALLOWING RUNOFF     =     90.0     PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      1.000   ACRES
EVAPORATIVE ZONE DEPTH               =     24.0     INCHES
INITIAL WATER IN EVAPORATIVE ZONE    =      6.504   INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE   =     11.124   INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE   =      3.636   INCHES
INITIAL SNOW WATER                   =      0.000   INCHES
INITIAL WATER IN LAYER MATERIALS     =    369.594   INCHES
TOTAL INITIAL WATER                  =    369.594   INCHES
TOTAL SUBSURFACE INFLOW              =      0.00    INCHES/YEAR


            EVAPOTRANSPIRATION AND WEATHER DATA
            -----------------------------------
```

```
 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
           ST. LOUIS            MISSOURI

       STATION LATITUDE                          =  39.10 DEGREES
       MAXIMUM LEAF AREA INDEX                   =   3.00
       START OF GROWING SEASON (JULIAN DATE)     =     98
       END OF GROWING SEASON (JULIAN DATE)       =    300
       EVAPORATIVE ZONE DEPTH                    =  24.0  INCHES
       AVERAGE ANNUAL WIND SPEED                 =  10.40 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  73.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  71.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY     =  74.00 %


 NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
           COEFFICIENTS FOR    ST. LOUIS           MISSOURI

           NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
  1.72        2.14        3.28        3.55        3.54        3.73
  3.63        2.55        2.70        2.32        2.53        2.22


 NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
           COEFFICIENTS FOR    ST. LOUIS           MISSOURI

        NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
 28.60       33.80       43.20       56.10       65.60       74.80
 78.90       77.00       69.70       57.90       44.60       34.20


 NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
           COEFFICIENTS FOR    ST. LOUIS           MISSOURI
             AND STATION LATITUDE  =  39.10 DEGREES



*******************************************************************************

    AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   30
```

```
-------------------------------------------------------------------------------

                    JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                    -------  -------  -------  -------  -------  -------
PRECIPITATION
-------------
  TOTALS              1.56     2.15     3.09     3.37     3.44     4.42
                      3.38     2.66     2.75     2.18     2.16     2.06

  STD. DEVIATIONS     0.95     1.09     0.92     1.36     1.56     2.04
                      1.87     1.38     1.45     1.28     1.38     1.14

RUNOFF
------
  TOTALS              0.326    0.721    0.387    0.025    0.022    0.075
                      0.031    0.006    0.006    0.005    0.017    0.039

  STD. DEVIATIONS     0.445    0.696    0.674    0.103    0.049    0.173
                      0.088    0.028    0.021    0.024    0.042    0.089

EVAPOTRANSPIRATION
------------------
  TOTALS              0.515    0.638    2.155    3.263    4.373    4.765
                      3.507    2.590    2.133    1.281    0.916    0.686

  STD. DEVIATIONS     0.280    0.374    0.574    0.787    0.854    1.664
                      1.481    1.177    1.025    0.293    0.282    0.195

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS              0.4317   0.4167   1.0309   1.0720   0.6036   0.2727
                      0.1179   0.0310   0.0044   0.0094   0.2551   0.4844

  STD. DEVIATIONS     0.4791   0.6721   0.6490   0.6433   0.5145   0.2197
                      0.1679   0.0729   0.0137   0.0468   0.7667   0.7207

PERCOLATION/LEAKAGE THROUGH LAYER  5
------------------------------------
  TOTALS              0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS     0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER  7
----------------------------------------
  TOTALS              0.0045   0.0019   0.0010   0.0004   0.0002   0.0001
                      0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS     0.0247   0.0102   0.0052   0.0023   0.0010   0.0005
                      0.0002   0.0001   0.0000   0.0000   0.0000   0.0000

PERCOLATION/LEAKAGE THROUGH LAYER  9
```

```
  ------------------------------------
    TOTALS                   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                             0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

    STD. DEVIATIONS          0.0001   0.0000   0.0000   0.0000   0.0000   0.0000
                             0.0000   0.0000   0.0000   0.0000   0.0000   0.0000


 ------------------------------------------------------------------------------
-
               AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
 ------------------------------------------------------------------------------
-

  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES                 0.0005   0.0005   0.0012   0.0013   0.0007   0.0003
                             0.0001   0.0000   0.0000   0.0000   0.0003   0.0006

    STD. DEVIATIONS          0.0006   0.0009   0.0008   0.0008   0.0006   0.0003
                             0.0002   0.0001   0.0000   0.0001   0.0009   0.0008

  DAILY AVERAGE HEAD ON TOP OF LAYER  8
  -------------------------------------
    AVERAGES                 0.0153   0.0070   0.0032   0.0015   0.0007   0.0003
                             0.0001   0.0001   0.0000   0.0000   0.0000   0.0000

    STD. DEVIATIONS          0.0836   0.0382   0.0177   0.0079   0.0035   0.0016
                             0.0007   0.0003   0.0001   0.0001   0.0000   0.0000

*******************************************************************************



*******************************************************************************

      AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   30
 ------------------------------------------------------------------------------
-
                                        INCHES            CU. FEET     PERCENT
                                  -------------------   -------------  ---------
  PRECIPITATION                  33.21     (   4.731)     120562.0     100.00

  RUNOFF                          1.660    (  1.1223)       6025.63      4.998

  EVAPOTRANSPIRATION             26.822    (  2.9548)      97362.76     80.757

  LATERAL DRAINAGE COLLECTED      4.72954 (  2.01001)     17168.242   14.24018
    FROM LAYER  3

  PERCOLATION/LEAKAGE THROUGH     0.00002 (  0.00001)         0.067    0.00006
```

```
    LAYER  5

  AVERAGE HEAD ON TOP            0.000 (    0.000)
    OF LAYER  4

  LATERAL DRAINAGE COLLECTED     0.00810 (  0.04429)        29.417    0.02440
    FROM LAYER  7

  PERCOLATION/LEAKAGE THROUGH    0.00003 (  0.00018)         0.126     0.0001
    LAYER  9

  AVERAGE HEAD ON TOP            0.002 (    0.013)
    OF LAYER  8

  CHANGE IN WATER STORAGE       -0.007   (  1.4517)        -24.18    -0.020

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```

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*******************************************************************************

             PEAK DAILY VALUES FOR YEARS     1 THROUGH   30
 ------------------------------------------------------------------------
                                                (INCHES)     (CU. FT.)
                                               ----------   -------------
    PRECIPITATION                                 3.44       12487.200

    RUNOFF                                        2.123       7708.0542

    DRAINAGE COLLECTED FROM LAYER  3              0.62788     2279.18750

    PERCOLATION/LEAKAGE THROUGH LAYER  5          0.000002       0.00599

    AVERAGE HEAD ON TOP OF LAYER  4               0.023

    MAXIMUM HEAD ON TOP OF LAYER  4               0.089

    LOCATION OF MAXIMUM HEAD IN LAYER  3
           (DISTANCE FROM DRAIN)                  0.0 FEET

    DRAINAGE COLLECTED FROM LAYER  7              0.00631       22.89842

    PERCOLATION/LEAKAGE THROUGH LAYER  9          0.000023       0.08357

    AVERAGE HEAD ON TOP OF LAYER  8               0.661

    MAXIMUM HEAD ON TOP OF LAYER  8               1.282

    LOCATION OF MAXIMUM HEAD IN LAYER  7
           (DISTANCE FROM DRAIN)                 19.2 FEET

    SNOW WATER                                    2.43        8821.5488


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.3879

    MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1515

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

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```

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*******************************************************************************

                 FINAL WATER STORAGE AT END OF YEAR   30
    ----------------------------------------------------------------------
                 LAYER        (INCHES)        (VOL/VOL)
                 -----        --------        ---------
                   1            3.2913          0.2743

                   2            8.8363          0.2945

                   3            0.0020          0.0100

                   4            0.0000          0.0000

                   5            5.1240          0.4270

                   6          336.3840          0.2920

                   7            0.3840          0.0320

                   8            0.0000          0.0000

                   9           15.3720          0.4270

                SNOW WATER      0.000

*******************************************************************************
*******************************************************************************
```

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY             **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA43.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA73.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA133.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA113.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10N3.D10
OUTPUT DATA FILE:             C:\LF33\N147116.OUT


TIME:  96:16      DATE:   6/29/2018


******************************************************************************

    TITLE:  NORTHWESTERN AREA-70 YEAR AFTER POST CLOSURE-YEAR 47 TO 116

******************************************************************************


    NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
             WERE SPECIFIED BY THE USER.


                               LAYER  1
                               --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER   8
         THICKNESS                   =    12.00    INCHES
         POROSITY                    =     0.4630 VOL/VOL
         FIELD CAPACITY              =     0.2320 VOL/VOL
         WILTING POINT               =     0.1160 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.2743 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.369999994000E-03 CM/SEC

    NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
             FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                               LAYER  2
                               --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER  11
         THICKNESS                   =    30.00    INCHES
         POROSITY                    =     0.4640 VOL/VOL
         FIELD CAPACITY              =     0.3100 VOL/VOL
         WILTING POINT               =     0.1870 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.2945 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.639999998000E-04 CM/SEC


                               LAYER  3
                               --------

                     TYPE 2 - LATERAL DRAINAGE LAYER
                      MATERIAL TEXTURE NUMBER   0
         THICKNESS                   =     0.20    INCHES
         POROSITY                    =     0.8500 VOL/VOL
         FIELD CAPACITY              =     0.0100 VOL/VOL
         WILTING POINT               =     0.0050 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.0100 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =   1.00000000000      CM/SEC
         SLOPE                       =    19.00    PERCENT
         DRAINAGE LENGTH             =   380.0     FEET


                               LAYER  4
                               --------

                    TYPE 4 - FLEXIBLE MEMBRANE LINER
                      MATERIAL TEXTURE NUMBER  36
         THICKNESS                   =     0.04    INCHES
         POROSITY                    =     0.0000 VOL/VOL
         FIELD CAPACITY              =     0.0000 VOL/VOL
         WILTING POINT               =     0.0000 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.0000 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.399999993000E-12 CM/SEC
         FML PINHOLE DENSITY         =     1.00    HOLES/ACRE
         FML INSTALLATION DEFECTS    =    15.00    HOLES/ACRE
         FML PLACEMENT QUALITY       =  4 - POOR


                               LAYER  5
                               --------

                       TYPE 3 - BARRIER SOIL LINER
                      MATERIAL TEXTURE NUMBER   0
         THICKNESS                   =    12.00    INCHES
         POROSITY                    =     0.4270 VOL/VOL
         FIELD CAPACITY              =     0.4180 VOL/VOL
         WILTING POINT               =     0.3670 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.4270 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.999999975000E-05 CM/SEC


                               LAYER  6
                               --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER  18
         THICKNESS                   =  1152.00    INCHES
         POROSITY                    =     0.6710 VOL/VOL
         FIELD CAPACITY              =     0.2920 VOL/VOL
         WILTING POINT               =     0.0770 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.2920 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.100000005000E-02 CM/SEC


                               LAYER  7
                               --------

                    TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER   0
         THICKNESS                   =    12.00    INCHES
         POROSITY                    =     0.3970 VOL/VOL
         FIELD CAPACITY              =     0.0320 VOL/VOL
         WILTING POINT               =     0.0130 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.0320 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.500000007000E-01 CM/SEC


                               LAYER  8
                               --------

                    TYPE 4 - FLEXIBLE MEMBRANE LINER
                      MATERIAL TEXTURE NUMBER  35
         THICKNESS                   =     0.06    INCHES
         POROSITY                    =     0.0000 VOL/VOL
         FIELD CAPACITY              =     0.0000 VOL/VOL
         WILTING POINT               =     0.0000 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.0000 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
         FML PINHOLE DENSITY         =     1.00    HOLES/ACRE
         FML INSTALLATION DEFECTS    =    10.00    HOLES/ACRE
         FML PLACEMENT QUALITY       =  4 - POOR


                               LAYER  9
                               --------

                       TYPE 3 - BARRIER SOIL LINER
                      MATERIAL TEXTURE NUMBER  16
         THICKNESS                   =    36.00    INCHES
         POROSITY                    =     0.4270 VOL/VOL
         FIELD CAPACITY              =     0.4180 VOL/VOL
         WILTING POINT               =     0.3670 VOL/VOL
         INITIAL SOIL WATER CONTENT  =     0.4270 VOL/VOL
         EFFECTIVE SAT. HYD. COND.   =  0.100000001000E-06 CM/SEC


           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------

    NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
             SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
             GOOD STAND OF GRASS, A SURFACE SLOPE OF 19.%
             AND A SLOPE LENGTH OF  380. FEET.

  SCS RUNOFF CURVE NUMBER            =      73.70
  FRACTION OF AREA ALLOWING RUNOFF   =      95.0     PERCENT
  AREA PROJECTED ON HORIZONTAL PLANE =       1.000   ACRES
  EVAPORATIVE ZONE DEPTH             =      24.0     INCHES
  INITIAL WATER IN EVAPORATIVE ZONE  =       6.826   INCHES
  UPPER LIMIT OF EVAPORATIVE STORAGE =      11.124   INCHES
  LOWER LIMIT OF EVAPORATIVE STORAGE =       3.636   INCHES
  INITIAL SNOW WATER                 =       0.000   INCHES
  INITIAL WATER IN LAYER MATERIALS   =     369.393   INCHES
  TOTAL INITIAL WATER                =     369.393   INCHES
  TOTAL SUBSURFACE INFLOW            =       0.00    INCHES/YEAR


             EVAPOTRANSPIRATION AND WEATHER DATA
             -----------------------------------

    NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
```

```
          ST. LOUIS              MISSOURI

       STATION LATITUDE                            =  39.10 DEGREES
       MAXIMUM LEAF AREA INDEX                     =   4.00
       START OF GROWING SEASON (JULIAN DATE)       =     98
       END OF GROWING SEASON (JULIAN DATE)         =    300
       EVAPORATIVE ZONE DEPTH                      =  24.0  INCHES
       AVERAGE ANNUAL WIND SPEED                   =  10.40 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY       =  73.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY       =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY       =  71.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY       =  74.00 %


    NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR    ST. LOUIS              MISSOURI

              NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
  1.72        2.14        3.28        3.55        3.54        3.73
  3.63        2.55        2.70        2.32        2.53        2.22


    NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR    ST. LOUIS              MISSOURI

           NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
 28.60       33.80       43.20       56.10       65.60       74.80
 78.90       77.00       69.70       57.90       44.60       34.20


    NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR    ST. LOUIS              MISSOURI
                AND STATION LATITUDE  =  39.10 DEGREES



*******************************************************************************

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH   70
 ------------------------------------------------------------------------------



              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
 ------------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES                  0.0104   0.0389   0.1128   0.0380   0.0090   0.0036
                              0.0013   0.0004   0.0001   0.0001   0.0232   0.0340

    STD. DEVIATIONS           0.0385   0.1273   0.2266   0.1118   0.0151   0.0040
                              0.0020   0.0010   0.0004   0.0007   0.1400   0.2381

  DAILY AVERAGE HEAD ON TOP OF LAYER  8
  -------------------------------------
    AVERAGES                  0.5032   0.5049   0.5130   0.5199   0.5216   0.5212
                              0.5202   0.5188   0.5174   0.5159   0.5165   0.5184

    STD. DEVIATIONS           0.2884   0.2889   0.2923   0.2946   0.2940   0.2932
                              0.2924   0.2916   0.2908   0.2900   0.2879   0.2900

*******************************************************************************


*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   70
 ------------------------------------------------------------------------------

                                    INCHES           CU. FEET      PERCENT
                              ------------------   ------------   ---------
 PRECIPITATION                 33.82    (   4.892)   122761.4      100.00

 RUNOFF                         1.164   (  0.9403)     4225.34       3.442

 EVAPOTRANSPIRATION            26.680   (  3.2479)    96849.79      78.893

 LATERAL DRAINAGE COLLECTED     5.96965 (  2.15506)   21669.834    17.65199
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH    0.01230 (  0.01403)       44.632     0.03636
   LAYER  5

 AVERAGE HEAD ON TOP            0.023 (    0.030)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH    0.00662 (  0.00345)       24.042     0.01958
   LAYER  9

 AVERAGE HEAD ON TOP            0.516 (    0.291)
   OF LAYER  8
```

```
                              JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                              -------  -------  -------  -------  -------  -------
PRECIPITATION
-------------
  TOTALS                        1.81     2.12     3.31     3.55     3.59     4.08
                                3.43     2.58     2.65     2.29     2.30     2.10

  STD. DEVIATIONS               0.97     1.03     1.40     1.37     1.65     2.04
                                1.79     1.41     1.34     1.39     1.36     1.22

RUNOFF
------
  TOTALS                        0.250    0.474    0.340    0.009    0.003    0.013
                                0.010    0.002    0.000    0.001    0.010    0.054

  STD. DEVIATIONS               0.426    0.545    0.637    0.048    0.015    0.048
                                0.039    0.008    0.002    0.003    0.048    0.213

EVAPOTRANSPIRATION
------------------
  TOTALS                        0.530    0.653    2.102    3.344    4.769    4.138
                                3.513    2.581    2.269    1.234    0.867    0.679

  STD. DEVIATIONS               0.242    0.355    0.545    0.712    1.024    1.900
                                1.656    1.229    0.989    0.356    0.239    0.195

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                        0.5156   0.6610   1.7140   1.1696   0.6430   0.2958
                                0.1135   0.0339   0.0080   0.0113   0.2576   0.5464

  STD. DEVIATIONS               0.5456   0.7670   1.0600   0.7260   0.5254   0.3271
                                0.1724   0.0874   0.0342   0.0570   0.6499   0.9446

PERCOLATION/LEAKAGE THROUGH LAYER  5
------------------------------------
  TOTALS                        0.0006   0.0016   0.0049   0.0018   0.0006   0.0003
                                0.0001   0.0000   0.0000   0.0000   0.0009   0.0015

  STD. DEVIATIONS               0.0016   0.0045   0.0089   0.0043   0.0007   0.0002
                                0.0001   0.0001   0.0000   0.0000   0.0053   0.0093

PERCOLATION/LEAKAGE THROUGH LAYER  9
------------------------------------
  TOTALS                        0.0005   0.0005   0.0006   0.0005   0.0006   0.0005
                                0.0006   0.0006   0.0005   0.0006   0.0005   0.0006

  STD. DEVIATIONS               0.0003   0.0003   0.0003   0.0003   0.0003   0.0003
                                0.0003   0.0003   0.0003   0.0003   0.0003   0.0003

 ------------------------------------------------------------------------------



 CHANGE IN WATER STORAGE         -0.002    (  1.4714)          -7.60     -0.006

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R1678

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             PEAK DAILY VALUES FOR YEARS    1 THROUGH   70
  ------------------------------------------------------------------------
                                                 (INCHES)      (CU. FT.)
                                                ----------   -------------
     PRECIPITATION                                 3.57        12959.100

     RUNOFF                                        2.602        9446.6738

     DRAINAGE COLLECTED FROM LAYER  3              0.55069      1999.00513

     PERCOLATION/LEAKAGE THROUGH LAYER  5          0.025314       91.88854

     AVERAGE HEAD ON TOP OF LAYER  4              20.320

     MAXIMUM HEAD ON TOP OF LAYER  4              36.393

     LOCATION OF MAXIMUM HEAD IN LAYER  3
            (DISTANCE FROM DRAIN)                 27.4 FEET

     PERCOLATION/LEAKAGE THROUGH LAYER  9          0.000037        0.13339

     AVERAGE HEAD ON TOP OF LAYER  8               1.110

     SNOW WATER                                    3.24        11767.4912


     MAXIMUM VEG. SOIL WATER (VOL/VOL)                     0.4100

     MINIMUM VEG. SOIL WATER (VOL/VOL)                     0.1515


       ***  Maximum heads are computed using McEnroe's equations.  ***

            Reference:  Maximum Saturated Depth over Landfill Liner
                        by Bruce M. McEnroe, University of Kansas
                        ASCE Journal of Environmental Engineering
                        Vol. 119, No. 2, March 1993, pp. 262-270.

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              FINAL WATER STORAGE AT END OF YEAR   70
    ----------------------------------------------------------------------
               LAYER        (INCHES)        (VOL/VOL)
               -----        --------        ---------
                 1            3.0592          0.2549

                 2            8.5237          0.2841

                 3            0.0020          0.0100

                 4            0.0000          0.0000

                 5            5.1240          0.4270

                 6          336.3840          0.2920

                 7            0.7811          0.0651

                 8            0.0000          0.0000

                 9           15.3720          0.4270

             SNOW WATER       0.000

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*******************************************************************************
*******************************************************************************
**                                                                           **
**                                                                           **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**                  HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)               **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                    USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY               **
**                                                                           **
**                                                                           **
*******************************************************************************
*******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA4NA.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA7NA.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA13NA.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA11NA.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10NA.D10
OUTPUT DATA FILE:             C:\LF33\NA0116.OUT


TIME:  88:29      DATE:   6/29/2018


*******************************************************************************

     TITLE:  NORTHWESTERN AREA - ACTIVE LIFE - YEARS 1 TO 16

*******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
            COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  11
           THICKNESS                     =     12.00   INCHES
           POROSITY                      =      0.4640 VOL/VOL
           FIELD CAPACITY                =      0.3100 VOL/VOL
           WILTING POINT                 =      0.1870 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.3224 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.639999998000E-04 CM/SEC
```

```
 NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.20
        FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                  LAYER  2
                                  --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  18
           THICKNESS                     =   1152.00   INCHES
           POROSITY                      =      0.6710 VOL/VOL
           FIELD CAPACITY                =      0.2920 VOL/VOL
           WILTING POINT                 =      0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.2932 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC


                                  LAYER  3
                                  --------

                        TYPE 2 - LATERAL DRAINAGE LAYER
                          MATERIAL TEXTURE NUMBER   0
           THICKNESS                     =     12.00   INCHES
           POROSITY                      =      0.3970 VOL/VOL
           FIELD CAPACITY                =      0.0320 VOL/VOL
           WILTING POINT                 =      0.0130 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.0472 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.500000007000E-01 CM/SEC
           SLOPE                         =      2.20   PERCENT
           DRAINAGE LENGTH               =    653.0    FEET


                                  LAYER  4
                                  --------

                        TYPE 4 - FLEXIBLE MEMBRANE LINER
                          MATERIAL TEXTURE NUMBER  35
           THICKNESS                     =      0.06   INCHES
           POROSITY                      =      0.0000 VOL/VOL
           FIELD CAPACITY                =      0.0000 VOL/VOL
           WILTING POINT                 =      0.0000 VOL/VOL
           INITIAL SOIL WATER CONTENT    =      0.0000 VOL/VOL
           EFFECTIVE SAT. HYD. COND.     =  0.199999996000E-12 CM/SEC
           FML PINHOLE DENSITY           =      1.00   HOLES/ACRE
           FML INSTALLATION DEFECTS      =     10.00   HOLES/ACRE
           FML PLACEMENT QUALITY         =  4 - POOR
```

```
                          LAYER  5
                          --------

                TYPE 3 - BARRIER SOIL LINER
                MATERIAL TEXTURE NUMBER  16
      THICKNESS                   =     36.00   INCHES
      POROSITY                    =      0.4270 VOL/VOL
      FIELD CAPACITY              =      0.4180 VOL/VOL
      WILTING POINT               =      0.3670 VOL/VOL
      INITIAL SOIL WATER CONTENT  =      0.4270 VOL/VOL
      EFFECTIVE SAT. HYD. COND.   =  0.100000001000E-06 CM/SEC


             GENERAL DESIGN AND EVAPORATIVE ZONE DATA
             ----------------------------------------

   NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
            SOIL DATA BASE USING SOIL TEXTURE #11 WITH A
            FAIR STAND OF GRASS, A SURFACE SLOPE OF 19.%
            AND A SLOPE LENGTH OF  380. FEET.

   SCS RUNOFF CURVE NUMBER              =    87.40
   FRACTION OF AREA ALLOWING RUNOFF     =    75.0    PERCENT
   AREA PROJECTED ON HORIZONTAL PLANE   =     1.000  ACRES
   EVAPORATIVE ZONE DEPTH               =    12.0    INCHES
   INITIAL WATER IN EVAPORATIVE ZONE    =     3.868  INCHES
   UPPER LIMIT OF EVAPORATIVE STORAGE   =     5.568  INCHES
   LOWER LIMIT OF EVAPORATIVE STORAGE   =     2.244  INCHES
   INITIAL SNOW WATER                   =     0.000  INCHES
   INITIAL WATER IN LAYER MATERIALS     =   357.523  INCHES
   TOTAL INITIAL WATER                  =   357.523  INCHES
   TOTAL SUBSURFACE INFLOW              =     0.00   INCHES/YEAR


              EVAPOTRANSPIRATION AND WEATHER DATA
              -----------------------------------

   NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
            ST. LOUIS              MISSOURI

        STATION LATITUDE                           =  39.10 DEGREES
        MAXIMUM LEAF AREA INDEX                    =   3.00
        START OF GROWING SEASON (JULIAN DATE)      =     98.
        END OF GROWING SEASON (JULIAN DATE)        =    300
        EVAPORATIVE ZONE DEPTH                     =  12.0  INCHES
        AVERAGE ANNUAL WIND SPEED                  =  10.40 MPH
        AVERAGE 1ST QUARTER RELATIVE HUMIDITY      =  73.00 %
```

```
        AVERAGE 2ND QUARTER RELATIVE HUMIDITY      =  67.00 %
        AVERAGE 3RD QUARTER RELATIVE HUMIDITY      =  71.00 %
        AVERAGE 4TH QUARTER RELATIVE HUMIDITY      =  74.00 %


   NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR    ST. LOUIS           MISSOURI

             NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

  JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
  -------      -------      -------      -------      -------      -------
    1.72         2.14         3.28         3.55         3.54         3.73
    3.63         2.55         2.70         2.32         2.53         2.22


   NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR    ST. LOUIS           MISSOURI

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
  -------      -------      -------      -------      -------      -------
   28.60        33.80        43.20        56.10        65.60        74.80
   78.90        77.00        69.70        57.90        44.60        34.20


   NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR    ST. LOUIS           MISSOURI
              AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   16
-------------------------------------------------------------------------------

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
  PRECIPITATION
  -------------
    TOTALS                 1.46     2.03     2.96     3.47     3.27     4.37
                           3.32     2.54     2.69     2.19     2.32     2.10

    STD. DEVIATIONS        0.80     1.14     0.87     1.49     1.89     2.09
```

```
                           2.15     1.37     1.17     1.09     1.55     1.06

  RUNOFF
  ------
    TOTALS                 0.399    0.643    0.344    0.057    0.101    0.229
                           0.163    0.015    0.046    0.028    0.085    0.074

    STD. DEVIATIONS        0.414    0.524    0.712    0.081    0.163    0.418
                           0.297    0.030    0.062    0.035    0.124    0.133

  EVAPOTRANSPIRATION
  ------------------
    TOTALS                 0.496    0.746    2.360    3.276    3.046    3.889
                           3.058    2.418    2.244    1.439    1.227    0.776

    STD. DEVIATIONS        0.281    0.498    0.398    0.975    1.313    1.165
                           1.516    1.163    1.046    0.449    0.328    0.179

  LATERAL DRAINAGE COLLECTED FROM LAYER  3
  ----------------------------------------
    TOTALS                 0.6373   0.4525   0.6321   0.9312   0.7078   0.4897
                           0.4392   0.2888   0.1678   0.1591   0.2603   0.5093

    STD. DEVIATIONS        0.3558   0.2428   0.3628   0.4357   0.3947   0.3296
                           0.4141   0.2719   0.1521   0.1524   0.2682   0.3630

  PERCOLATION/LEAKAGE THROUGH LAYER  5
  ------------------------------------
    TOTALS                 0.0020   0.0015   0.0020   0.0029   0.0022   0.0016
                           0.0014   0.0010   0.0006   0.0006   0.0009   0.0017

    STD. DEVIATIONS        0.0011   0.0007   0.0011   0.0013   0.0012   0.0010
                           0.0012   0.0008   0.0005   0.0005   0.0008   0.0011

-------------------------------------------------------------------------------

             AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES               2.1536   1.6750   2.1363   3.2518   2.3919   1.7100
                           1.4844   0.9759   0.5859   0.5376   0.9090   1.7211

    STD. DEVIATIONS        1.2025   0.8937   1.2262   1.5214   1.3338   1.1511
                           1.3994   0.9187   0.5311   0.5151   0.9365   1.2267

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```

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    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   16
-------------------------------------------------------------------------------

                                      INCHES            CU. FEET     PERCENT
                                 -----------------   ------------   ---------
  PRECIPITATION                   32.72    (   3.658)    118782.7    100.00

  RUNOFF                           2.183   (  1.3241)     7925.78      6.673

  EVAPOTRANSPIRATION              24.974   (  2.2259)    90656.17     76.321

  LATERAL DRAINAGE COLLECTED       5.67497 (  2.08367)   20600.150   17.34272
    FROM LAYER  3

  PERCOLATION/LEAKAGE THROUGH      0.01838 (  0.00632)      66.705     0.05616
    LAYER  5

  AVERAGE HEAD ON TOP              1.628 (    0.597)
    OF LAYER  4

  CHANGE IN WATER STORAGE         -0.128   (  1.2454)     -466.14     -0.392

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R1680

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          PEAK DAILY VALUES FOR YEARS     1 THROUGH    16
------------------------------------------------------------------------
                                            (INCHES)     (CU. FT.)
                                           ----------  -------------
  PRECIPITATION                               3.44       12487.200

  RUNOFF                                      1.302       4725.6240

  DRAINAGE COLLECTED FROM LAYER  3            0.07023      254.95059

  PERCOLATION/LEAKAGE THROUGH LAYER  5        0.000205       0.74240

  AVERAGE HEAD ON TOP OF LAYER  4             7.358

  MAXIMUM HEAD ON TOP OF LAYER  4            12.493

  LOCATION OF MAXIMUM HEAD IN LAYER  3
        (DISTANCE FROM DRAIN)                98.4 FEET

  SNOW WATER                                  1.92        6955.1221


  MAXIMUM VEG. SOIL WATER (VOL/VOL)                    0.4640

  MINIMUM VEG. SOIL WATER (VOL/VOL)                    0.1870

   ***  Maximum heads are computed using McEnroe's equations.  ***

        Reference:  Maximum Saturated Depth over Landfill Liner
                    by Bruce M. McEnroe, University of Kansas
                    ASCE Journal of Environmental Engineering
                    Vol. 119, No. 2, March 1993, pp. 262-270.

*******************************************************************************
```

```
*******************************************************************************

               FINAL WATER STORAGE AT END OF YEAR   16
----------------------------------------------------------------------
             LAYER        (INCHES)        (VOL/VOL)
             -----        --------        ---------
               1            3.1519          0.2627

               2          336.3839          0.2920

               3            0.5602          0.0467

               4            0.0000          0.0000

               5           15.3720          0.4270

           SNOW WATER       0.000

*******************************************************************************
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```

```
*******************************************************************************
*******************************************************************************
**                                                                           **
**                                                                           **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                 **
**                DEVELOPED BY ENVIRONMENTAL LABORATORY                      **
**                  USAE WATERWAYS EXPERIMENT STATION                        **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY               **
**                                                                           **
**                                                                           **
*******************************************************************************
*******************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA4EB.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA7EB.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA13EB.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA11EB.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10NB.D10
OUTPUT DATA FILE:            C:\LF33\NB1746.OUT


TIME:  89:21     DATE:   6/29/2018


*******************************************************************************

     TITLE:  NORTHWESTERN AREA-30 YEAR POST CLOSURE CARE-YEARS 17 TO 46

*******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                   LAYER  1
                                   --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                            MATERIAL TEXTURE NUMBER   8
          THICKNESS                    =      12.00   INCHES
          POROSITY                     =       0.4630 VOL/VOL
          FIELD CAPACITY               =       0.2320 VOL/VOL
          WILTING POINT                =       0.1160 VOL/VOL
          INITIAL SOIL WATER CONTENT   =       0.2320 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.369999994000E-03 CM/SEC
```

```
NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
        FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                               LAYER  2
                               --------

                  TYPE 1 - VERTICAL PERCOLATION LAYER
                      MATERIAL TEXTURE NUMBER  11
   THICKNESS                    =       30.00   INCHES
   POROSITY                     =        0.4640 VOL/VOL
   FIELD CAPACITY               =        0.3100 VOL/VOL
   WILTING POINT                =        0.1870 VOL/VOL
   INITIAL SOIL WATER CONTENT   =        0.3100 VOL/VOL
   EFFECTIVE SAT. HYD. COND.    =  0.639999998000E-04 CM/SEC


                               LAYER  3
                               --------

                    TYPE 2 - LATERAL DRAINAGE LAYER
                      MATERIAL TEXTURE NUMBER  20
   THICKNESS                    =        0.20   INCHES
   POROSITY                     =        0.8500 VOL/VOL
   FIELD CAPACITY               =        0.0100 VOL/VOL
   WILTING POINT                =        0.0050 VOL/VOL
   INITIAL SOIL WATER CONTENT   =        0.0100 VOL/VOL
   EFFECTIVE SAT. HYD. COND.    =   10.0000000000       CM/SEC
   SLOPE                        =       19.00   PERCENT
   DRAINAGE LENGTH              =      380.0    FEET


                               LAYER  4
                               --------

                    TYPE 4 - FLEXIBLE MEMBRANE LINER
                      MATERIAL TEXTURE NUMBER  36
   THICKNESS                    =        0.04   INCHES
   POROSITY                     =        0.0000 VOL/VOL
   FIELD CAPACITY               =        0.0000 VOL/VOL
   WILTING POINT                =        0.0000 VOL/VOL
   INITIAL SOIL WATER CONTENT   =        0.0000 VOL/VOL
   EFFECTIVE SAT. HYD. COND.    =  0.399999993000E-12 CM/SEC
   FML PINHOLE DENSITY          =        1.00   HOLES/ACRE
   FML INSTALLATION DEFECTS     =       15.00   HOLES/ACRE
   FML PLACEMENT QUALITY        =  4 - POOR
```

```
                          LAYER  5
                          --------

                TYPE 3 - BARRIER SOIL LINER
                 MATERIAL TEXTURE NUMBER  16
THICKNESS                    =      12.00   INCHES
POROSITY                     =       0.4270 VOL/VOL
FIELD CAPACITY               =       0.4180 VOL/VOL
WILTING POINT                =       0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT   =       0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000001000E-06 CM/SEC


                          LAYER  6
                          --------

             TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER  18
THICKNESS                    =    1152.00   INCHES
POROSITY                     =       0.6710 VOL/VOL
FIELD CAPACITY               =       0.2920 VOL/VOL
WILTING POINT                =       0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT   =       0.2920 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC


                          LAYER  7
                          --------

               TYPE 2 - LATERAL DRAINAGE LAYER
                 MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      12.00   INCHES
POROSITY                     =       0.3970 VOL/VOL
FIELD CAPACITY               =       0.0320 VOL/VOL
WILTING POINT                =       0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT   =       0.0467 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.500000007000E-01 CM/SEC
SLOPE                        =       2.20   PERCENT
DRAINAGE LENGTH              =     653.0    FEET


                          LAYER  8
                          --------

               TYPE 4 - FLEXIBLE MEMBRANE LINER
                 MATERIAL TEXTURE NUMBER  35
```

```
THICKNESS                    =       0.06   INCHES
POROSITY                     =       0.0000 VOL/VOL
FIELD CAPACITY               =       0.0000 VOL/VOL
WILTING POINT                =       0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT   =       0.0006 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY          =       1.00   HOLES/ACRE
FML INSTALLATION DEFECTS     =      10.00   HOLES/ACRE
FML PLACEMENT QUALITY        =  4 - POOR


                          LAYER  9
                          --------

                TYPE 3 - BARRIER SOIL LINER
                 MATERIAL TEXTURE NUMBER  16
THICKNESS                    =      36.00   INCHES
POROSITY                     =       0.4270 VOL/VOL
FIELD CAPACITY               =       0.4180 VOL/VOL
WILTING POINT                =       0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT   =       0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000001000E-06 CM/SEC


           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------

NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
       SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
       GOOD STAND OF GRASS, A SURFACE SLOPE OF 19.3
       AND A SLOPE LENGTH OF  380. FEET.

  SCS RUNOFF CURVE NUMBER            =     73.70
  FRACTION OF AREA ALLOWING RUNOFF   =     90.0    PERCENT
  AREA PROJECTED ON HORIZONTAL PLANE =      1.000  ACRES
  EVAPORATIVE ZONE DEPTH             =     24.0    INCHES
  INITIAL WATER IN EVAPORATIVE ZONE  =      6.504  INCHES
  UPPER LIMIT OF EVAPORATIVE STORAGE =     11.124  INCHES
  LOWER LIMIT OF EVAPORATIVE STORAGE =      3.636  INCHES
  INITIAL SNOW WATER                 =      0.000  INCHES
  INITIAL WATER IN LAYER MATERIALS   =    369.526  INCHES
  TOTAL INITIAL WATER                =    369.526  INCHES
  TOTAL SUBSURFACE INFLOW            =      0.00   INCHES/YEAR


             EVAPOTRANSPIRATION AND WEATHER DATA
             -----------------------------------
```

```
NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
          ST. LOUIS             MISSOURI

       STATION LATITUDE                         =  39.10 DEGREES
       MAXIMUM LEAF AREA INDEX                  =   4.00
       START OF GROWING SEASON (JULIAN DATE)    =     98
       END OF GROWING SEASON (JULIAN DATE)      =    300
       EVAPORATIVE ZONE DEPTH                   =  24.0  INCHES
       AVERAGE ANNUAL WIND SPEED                =  10.40 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  71.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  74.00 %


NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR    ST. LOUIS              MISSOURI

          NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
  1.72        2.14        3.28        3.55        3.54        3.73
  3.63        2.55        2.70        2.32        2.53        2.22


NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR    ST. LOUIS              MISSOURI

       NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
-------     -------     -------     -------     -------     -------
 28.60       33.80       43.20       56.10       65.60       74.80
 78.90       77.00       69.70       57.90       44.60       34.20


NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
          COEFFICIENTS FOR    ST. LOUIS              MISSOURI
             AND STATION LATITUDE  =  39.10 DEGREES



*******************************************************************************

       AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   30
```

```
-------------------------------------------------------------------------------

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------
PRECIPITATION
-------------
  TOTALS                    1.56     2.15     3.09     3.37     3.44     4.42
                            3.38     2.66     2.75     2.18     2.16     2.06

  STD. DEVIATIONS           0.95     1.09     0.92     1.36     1.56     2.04
                            1.87     1.38     1.45     1.28     1.38     1.14

RUNOFF
------
  TOTALS                    0.166    0.454    0.287    0.013    0.002    0.021
                            0.006    0.001    0.000    0.001    0.003    0.008

  STD. DEVIATIONS           0.303    0.543    0.559    0.066    0.008    0.067
                            0.021    0.005    0.003    0.005    0.008    0.021

EVAPOTRANSPIRATION
------------------
  TOTALS                    0.508    0.632    2.126    3.273    4.651    4.550
                            3.510    2.595    2.188    1.221    0.858    0.661

  STD. DEVIATIONS           0.274    0.366    0.577    0.754    0.911    1.704
                            1.509    1.179    1.077    0.286    0.262    0.198

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                    0.4658   0.5462   1.4450   1.1499   0.6219   0.2856
                            0.0985   0.0291   0.0079   0.0084   0.2722   0.5416

  STD. DEVIATIONS           0.4949   0.7710   0.7846   0.7111   0.5203   0.2801
                            0.1388   0.0766   0.0324   0.0427   0.7985   0.7938

PERCOLATION/LEAKAGE THROUGH LAYER  5
------------------------------------
  TOTALS                    0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER  7
----------------------------------------
  TOTALS                    0.0033   0.0014   0.0007   0.0003   0.0001   0.0001
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS           0.0179   0.0074   0.0038   0.0016   0.0008   0.0003
                            0.0002   0.0001   0.0000   0.0000   0.0000   0.0000

PERCOLATION/LEAKAGE THROUGH LAYER  9
```

```
-------------------------------------
   TOTALS                  0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS         0.0001   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-----------------------------------------------------------------------------

            AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-----------------------------------------------------------------------------


 DAILY AVERAGE HEAD ON TOP OF LAYER  4
 -------------------------------------
   AVERAGES                0.0005   0.0007   0.0017   0.0014   0.0007   0.0003
                           0.0001   0.0000   0.0000   0.0000   0.0003   0.0006

   STD. DEVIATIONS         0.0006   0.0010   0.0009   0.0009   0.0006   0.0003
                           0.0002   0.0001   0.0000   0.0001   0.0010   0.0009

 DAILY AVERAGE HEAD ON TOP OF LAYER  8
 -------------------------------------
   AVERAGES                0.0111   0.0051   0.0023   0.0011   0.0005   0.0002
                           0.0001   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS         0.0605   0.0277   0.0128   0.0057   0.0026   0.0011
                           0.0005   0.0002   0.0001   0.0000   0.0000   0.0000

*****************************************************************************


*****************************************************************************

    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   30
-----------------------------------------------------------------------------

                                    INCHES            CU. FEET       PERCENT
                              -------------------  -------------   ---------
 PRECIPITATION                 33.21    (   4.731)     120562.0     100.00

 RUNOFF                         0.962   (  0.9127)      3490.91      2.896

 EVAPOTRANSPIRATION            26.773   (  2.9978)     97184.41     80.609

 LATERAL DRAINAGE COLLECTED     5.47212 (  2.10308)    19863.793   16.47600
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH    0.00002 (  0.00001)        0.076     0.00006
```

```
*****************************************************************************

             PEAK DAILY VALUES FOR YEARS    1 THROUGH   30
--------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
    PRECIPITATION                                 3.44        12487.200

    RUNOFF                                        1.923        6980.1426

    DRAINAGE COLLECTED FROM LAYER  3              0.64979      2358.75439

    PERCOLATION/LEAKAGE THROUGH LAYER  5          0.000002        0.00617

    AVERAGE HEAD ON TOP OF LAYER  4               0.024

    MAXIMUM HEAD ON TOP OF LAYER  4               0.082

    LOCATION OF MAXIMUM HEAD IN LAYER  3
           (DISTANCE FROM DRAIN)                  0.0 FEET

    DRAINAGE COLLECTED FROM LAYER  7              0.00457        16.58160

    PERCOLATION/LEAKAGE THROUGH LAYER  9          0.000017        0.06246

    AVERAGE HEAD ON TOP OF LAYER  8               0.479

    MAXIMUM HEAD ON TOP OF LAYER  8               0.935

    LOCATION OF MAXIMUM HEAD IN LAYER  7
           (DISTANCE FROM DRAIN)                 14.9 FEET

    SNOW WATER                                    2.43         8821.5488


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                     0.4148

    MINIMUM VEG. SOIL WATER (VOL/VOL)                     0.1515

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

*****************************************************************************
```

```
   LAYER  5

 AVERAGE HEAD ON TOP              0.001 (     0.000)
   OF LAYER  4

 LATERAL DRAINAGE COLLECTED       0.00587 (  0.03207)        21.324     0.01769
   FROM LAYER  7

 PERCOLATION/LEAKAGE THROUGH      0.00003 (  0.00013)         0.097     0.00008
   LAYER  9

 AVERAGE HEAD ON TOP              0.002 (     0.009)
   OF LAYER  8

 CHANGE IN WATER STORAGE          0.000    (  1.3955)         1.44      0.001

*****************************************************************************
```

```
*****************************************************************************

                FINAL WATER STORAGE AT END OF YEAR   30
 ---------------------------------------------------------------------------
                LAYER       (INCHES)      (VOL/VOL)
                -----       --------      ---------
                  1          3.2640         0.2720

                  2          9.0082         0.3003

                  3          0.0020         0.0100

                  4          0.0000         0.0000

                  5          5.1240         0.4270

                  6        336.3840         0.2920

                  7          0.3840         0.0320

                  8          0.0000         0.0000

                  9         15.3720         0.4270

               SNOW WATER    0.000

*****************************************************************************
*****************************************************************************
```

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                 DEVELOPED BY ENVIRONMENTAL LABORATORY                    **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA4EC.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA7EC.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA13EC.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA11EC.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10NC.D10
OUTPUT DATA FILE:            C:\LF33\NC47116.OUT


TIME:  09:58     DATE:   6/29/2018


******************************************************************************

     TITLE:  NORTHWESTERN AREA-70 YEAR AFTER POST CLOSURE-YEAR 47 TO 116

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                   LAYER  1
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER   8
           THICKNESS                  =      12.00    INCHES
           POROSITY                   =       0.4630 VOL/VOL
           FIELD CAPACITY             =       0.2320 VOL/VOL
           WILTING POINT              =       0.1160 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.2720 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.369999994000E-03 CM/SEC
```

```
    NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY   5.00
             FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                  LAYER  2
                                  --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  11
          THICKNESS                  =      30.00    INCHES
          POROSITY                   =       0.4640 VOL/VOL
          FIELD CAPACITY             =       0.3100 VOL/VOL
          WILTING POINT              =       0.1870 VOL/VOL
          INITIAL SOIL WATER CONTENT =       0.3003 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.639999998000E-04 CM/SEC


                                  LAYER  3
                                  --------

                       TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER   0
          THICKNESS                  =       0.20    INCHES
          POROSITY                   =       0.8500 VOL/VOL
          FIELD CAPACITY             =       0.0100 VOL/VOL
          WILTING POINT              =       0.0050 VOL/VOL
          INITIAL SOIL WATER CONTENT =       0.0100 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  1.00000000000      CM/SEC
          SLOPE                      =      19.00    PERCENT
          DRAINAGE LENGTH            =     380.0     FEET


                                  LAYER  4
                                  --------

                       TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  36
          THICKNESS                  =       0.04    INCHES
          POROSITY                   =       0.0000 VOL/VOL
          FIELD CAPACITY             =       0.0000 VOL/VOL
          WILTING POINT              =       0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT =       0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.399999993000E-12 CM/SEC
          FML PINHOLE DENSITY        =        1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS   =       15.00   HOLES/ACRE
          FML PLACEMENT QUALITY      =  4 - POOR
```

```
                                   LAYER  5
                                   --------

                          TYPE 3 - BARRIER SOIL LINER
                          MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =      12.00    INCHES
           POROSITY                   =       0.4270 VOL/VOL
           FIELD CAPACITY             =       0.4180 VOL/VOL
           WILTING POINT              =       0.3670 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.4270 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-05 CM/SEC


                                   LAYER  6
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  18
           THICKNESS                  =    1152.00    INCHES
           POROSITY                   =       0.6710 VOL/VOL
           FIELD CAPACITY             =       0.2920 VOL/VOL
           WILTING POINT              =       0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.2920 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.100000005000E-02 CM/SEC


                                   LAYER  7
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =      12.00    INCHES
           POROSITY                   =       0.3970 VOL/VOL
           FIELD CAPACITY             =       0.0320 VOL/VOL
           WILTING POINT              =       0.0130 VOL/VOL
           INITIAL SOIL WATER CONTENT =       0.0320 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.500000007000E-01 CM/SEC


                                   LAYER  8
                                   --------

                        TYPE 4 - FLEXIBLE MEMBRANE LINER
                          MATERIAL TEXTURE NUMBER  35
           THICKNESS                  =       0.06    INCHES
           POROSITY                   =       0.0000 VOL/VOL
```

```
          FIELD CAPACITY             =       0.0000 VOL/VOL
          WILTING POINT              =       0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT =       0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.199999996000E-12 CM/SEC
          FML PINHOLE DENSITY        =        1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS   =       10.00   HOLES/ACRE
          FML PLACEMENT QUALITY      =  4 - POOR


                                  LAYER  9
                                  --------

                         TYPE 3 - BARRIER SOIL LINER
                         MATERIAL TEXTURE NUMBER  16
          THICKNESS                  =      36.00    INCHES
          POROSITY                   =       0.4270 VOL/VOL
          FIELD CAPACITY             =       0.4180 VOL/VOL
          WILTING POINT              =       0.3670 VOL/VOL
          INITIAL SOIL WATER CONTENT =       0.4270 VOL/VOL
          EFFECTIVE SAT. HYD. COND.  =  0.100000001000E-06 CM/SEC


               GENERAL DESIGN AND EVAPORATIVE ZONE DATA
               ----------------------------------------

   NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
            SOIL DATA BASE USING SOIL TEXTURE # 8 WITH AN
            EXCELLENT STAND OF GRASS, A SURFACE SLOPE OF 19.3
            AND A SLOPE LENGTH OF  380. FEET.

   SCS RUNOFF CURVE NUMBER            =     71.20
   FRACTION OF AREA ALLOWING RUNOFF   =     95.0     PERCENT
   AREA PROJECTED ON HORIZONTAL PLANE =      1.000   ACRES
   EVAPORATIVE ZONE DEPTH             =     24.0     INCHES
   INITIAL WATER IN EVAPORATIVE ZONE  =      6.868   INCHES
   UPPER LIMIT OF EVAPORATIVE STORAGE =     11.124   INCHES
   LOWER LIMIT OF EVAPORATIVE STORAGE =      3.636   INCHES
   INITIAL SNOW WATER                 =      0.000   INCHES
   INITIAL WATER IN LAYER MATERIALS   =    369.539   INCHES
   TOTAL INITIAL WATER                =    369.539   INCHES
   TOTAL SUBSURFACE INFLOW            =      0.00    INCHES/YEAR


                EVAPOTRANSPIRATION AND WEATHER DATA
                -----------------------------------

   NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
```

```
          ST. LOUIS            MISSOURI

       STATION LATITUDE                            =  39.10 DEGREES
       MAXIMUM LEAF AREA INDEX                     =   5.00
       START OF GROWING SEASON (JULIAN DATE)       =     98
       END OF GROWING SEASON (JULIAN DATE)         =    300
       EVAPORATIVE ZONE DEPTH                      =  24.0  INCHES
       AVERAGE ANNUAL WIND SPEED                   =  10.40 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY       =  73.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY       =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY       =  71.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY       =  74.00 %


     NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
                 COEFFICIENTS FOR    ST. LOUIS             MISSOURI

                 NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
   1.72        2.14        3.28        3.55        3.54        3.73
   3.63        2.55        2.70        2.32        2.53        2.22


     NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
                 COEFFICIENTS FOR    ST. LOUIS             MISSOURI

             NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
   28.60       33.80       43.20       56.10       65.60       74.80
   78.90       77.00       69.70       57.90       44.60       34.20


     NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                 COEFFICIENTS FOR    ST. LOUIS             MISSOURI
                   AND STATION LATITUDE  =  39.10 DEGREES



*******************************************************************************

       AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH   70
-------------------------------------------------------------------------------

                              JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                              -------  -------  -------  -------  -------  -------
PRECIPITATION
-------------
  TOTALS                        1.81     2.12     3.31     3.55     3.59     4.08
                                3.43     2.58     2.65     2.29     2.30     2.10

  STD. DEVIATIONS               0.97     1.03     1.40     1.37     1.65     2.04
                                1.79     1.41     1.34     1.39     1.36     1.22

RUNOFF
------
  TOTALS                        0.250    0.475    0.338    0.007    0.001    0.007
                                0.005    0.001    0.000    0.000    0.006    0.052

  STD. DEVIATIONS               0.426    0.546    0.639    0.045    0.007    0.031
                                0.025    0.003    0.000    0.001    0.036    0.212

EVAPOTRANSPIRATION
------------------
  TOTALS                        0.526    0.648    2.089    3.369    4.816    4.106
                                3.518    2.583    2.310    1.204    0.824    0.658

  STD. DEVIATIONS               0.237    0.349    0.548    0.709    1.082    1.901
                                1.659    1.230    1.022    0.356    0.230    0.194

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                        0.5312   0.6762   1.7421   1.1815   0.6368   0.2785
                                0.1020   0.0330   0.0075   0.0100   0.2609   0.5633

  STD. DEVIATIONS               0.5466   0.7680   1.0652   0.7370   0.5035   0.3082
                                0.1714   0.0902   0.0353   0.0501   0.6593   0.9626

PERCOLATION/LEAKAGE THROUGH LAYER  5
------------------------------------
  TOTALS                        0.0006   0.0015   0.0051   0.0017   0.0006   0.0003
                                0.0001   0.0000   0.0000   0.0000   0.0011   0.0018

  STD. DEVIATIONS               0.0016   0.0044   0.0094   0.0038   0.0007   0.0002
                                0.0001   0.0001   0.0000   0.0000   0.0057   0.0110

PERCOLATION/LEAKAGE THROUGH LAYER  9
------------------------------------
  TOTALS                        0.0006   0.0005   0.0006   0.0006   0.0006   0.0006
                                0.0006   0.0006   0.0006   0.0006   0.0006   0.0006

  STD. DEVIATIONS               0.0003   0.0003   0.0003   0.0003   0.0003   0.0003
                                0.0003   0.0003   0.0003   0.0003   0.0003   0.0003

-------------------------------------------------------------------------------



               AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES                   0.0105   0.0377   0.1192   0.0355   0.0089   0.0034
                               0.0012   0.0004   0.0001   0.0001   0.0265   0.0409

    STD. DEVIATIONS            0.0385   0.1245   0.2399   0.0998   0.0147   0.0038
                               0.0020   0.0011   0.0004   0.0006   0.1509   0.2830

  DAILY AVERAGE HEAD ON TOP OF LAYER  8
  -------------------------------------
    AVERAGES                   0.5179   0.5196   0.5281   0.5351   0.5366   0.5361
                               0.5350   0.5336   0.5321   0.5305   0.5314   0.5337

    STD. DEVIATIONS            0.3079   0.3085   0.3123   0.3149   0.3141   0.3132
                               0.3124   0.3115   0.3107   0.3099   0.3076   0.3101

*******************************************************************************


*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   70
-------------------------------------------------------------------------------

                                     INCHES           CU. FEET     PERCENT
                               -------------------  ------------  ---------
 PRECIPITATION                  33.82   (   4.892)    122761.4     100.00

 RUNOFF                          1.142  (  0.9381)      4146.55     3.378

 EVAPOTRANSPIRATION             26.649  (  3.2848)     96737.52    78.801

 LATERAL DRAINAGE COLLECTED      6.02291 (  2.16775)    21863.158   17.80947
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH     0.01280 (  0.01540)       46.456    0.03784
   LAYER  5

 AVERAGE HEAD ON TOP             0.024 (    0.033)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH     0.00679 (  0.00367)       24.640    0.02007
   LAYER  9

 AVERAGE HEAD ON TOP             0.531 (    0.311)
   OF LAYER  8


 CHANGE IN WATER STORAGE         -0.003  (  1.4394)       -10.45     -0.009

*******************************************************************************
```

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******************************************************************************

            PEAK DAILY VALUES FOR YEARS     1 THROUGH    70
  ------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
    PRECIPITATION                                 3.57        12959.100

    RUNOFF                                        2.601        9443.1279

    DRAINAGE COLLECTED FROM LAYER  3              0.55117      2000.73535

    PERCOLATION/LEAKAGE THROUGH LAYER  5          0.028777      104.46230

    AVERAGE HEAD ON TOP OF LAYER  4              23.042

    MAXIMUM HEAD ON TOP OF LAYER  4              40.877

    LOCATION OF MAXIMUM HEAD IN LAYER  3
          (DISTANCE FROM DRAIN)                  30.8 FEET

    PERCOLATION/LEAKAGE THROUGH LAYER  9          0.000039        0.14055

    AVERAGE HEAD ON TOP OF LAYER  8               1.176

    SNOW WATER                                    3.24        11767.4912


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                        0.4101

    MINIMUM VEG. SOIL WATER (VOL/VOL)                        0.1515

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

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```

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******************************************************************************

                 FINAL WATER STORAGE AT END OF YEAR    70
  ----------------------------------------------------------------------
               LAYER         (INCHES)        (VOL/VOL)
               -----         --------        ---------
                 1             3.0552          0.2546

                 2             8.5955          0.2865

                 3             0.0020          0.0100

                 4             0.0000          0.0000

                 5             5.1240          0.4270

                 6           336.3840          0.2920

                 7             0.8047          0.0671

                 8             0.0000          0.0000

                 9            15.3720          0.4270

             SNOW WATER        0.000

******************************************************************************
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```

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                   **
**                DEVELOPED BY ENVIRONMENTAL LABORATORY                     **
**                   USAE WATERWAYS EXPERIMENT STATION                      **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA4S1.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA7S1.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA13S1.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA11S1.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10S1.D10
OUTPUT DATA FILE:            C:\LF33\S10131.OUT


TIME:  93:37     DATE:   6/29/2018


******************************************************************************

     TITLE:  SOUTHERN AREA - ACTIVE LIFE - YEARS 1 TO 31

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
              COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                            MATERIAL TEXTURE NUMBER  11
           THICKNESS                   =      12.00   INCHES
           POROSITY                    =       0.4640 VOL/VOL
           FIELD CAPACITY              =       0.3100 VOL/VOL
           WILTING POINT               =       0.1870 VOL/VOL
           INITIAL SOIL WATER CONTENT  =       0.3377 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.639999998000E-04 CM/SEC
```

```
                                  LAYER  2
                                  --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                            MATERIAL TEXTURE NUMBER  18
           THICKNESS                   =    1152.00   INCHES
           POROSITY                    =       0.6710 VOL/VOL
           FIELD CAPACITY              =       0.2920 VOL/VOL
           WILTING POINT               =       0.0770 VOL/VOL
           INITIAL SOIL WATER CONTENT  =       0.2929 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.100000005000E-02 CM/SEC


                                  LAYER  3
                                  --------

                         TYPE 2 - LATERAL DRAINAGE LAYER
                            MATERIAL TEXTURE NUMBER   0
           THICKNESS                   =      12.00   INCHES
           POROSITY                    =       0.3970 VOL/VOL
           FIELD CAPACITY              =       0.0320 VOL/VOL
           WILTING POINT               =       0.0130 VOL/VOL
           INITIAL SOIL WATER CONTENT  =       0.0739 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.500000007000E-01 CM/SEC
           SLOPE                       =       2.20   PERCENT
           DRAINAGE LENGTH             =     615.0    FEET


                                  LAYER  4
                                  --------

                         TYPE 4 - FLEXIBLE MEMBRANE LINER
                            MATERIAL TEXTURE NUMBER  35
           THICKNESS                   =       0.06   INCHES
           POROSITY                    =       0.0000 VOL/VOL
           FIELD CAPACITY              =       0.0000 VOL/VOL
           WILTING POINT               =       0.0000 VOL/VOL
           INITIAL SOIL WATER CONTENT  =       0.0000 VOL/VOL
           EFFECTIVE SAT. HYD. COND.   =  0.199999996000E-12 CM/SEC
           FML PINHOLE DENSITY         =       1.00   HOLES/ACRE
           FML INSTALLATION DEFECTS    =      10.00   HOLES/ACRE
           FML PLACEMENT QUALITY       =  4 - POOR
```

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```
                          LAYER  5
                          --------

                TYPE 3 - BARRIER SOIL LINER
                MATERIAL TEXTURE NUMBER  16
     THICKNESS                    =      36.00   INCHES
     POROSITY                     =       0.4270 VOL/VOL
     FIELD CAPACITY               =       0.4180 VOL/VOL
     WILTING POINT                =       0.3670 VOL/VOL
     INITIAL SOIL WATER CONTENT   =       0.4270 VOL/VOL
     EFFECTIVE SAT. HYD. COND.    =   0.100000001000E-06 CM/SEC


             GENERAL DESIGN AND EVAPORATIVE ZONE DATA
             ----------------------------------------

  NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
         SOIL DATA BASE USING SOIL TEXTURE #11 WITH BARE
         GROUND CONDITIONS, A SURFACE SLOPE OF 14.% AND
         A SLOPE LENGTH OF  630. FEET.

   SCS RUNOFF CURVE NUMBER            =      94.60
   FRACTION OF AREA ALLOWING RUNOFF   =      75.0    PERCENT
   AREA PROJECTED ON HORIZONTAL PLANE =       1.000  ACRES
   EVAPORATIVE ZONE DEPTH             =       6.0    INCHES
   INITIAL WATER IN EVAPORATIVE ZONE  =       1.889  INCHES
   UPPER LIMIT OF EVAPORATIVE STORAGE =       2.784  INCHES
   LOWER LIMIT OF EVAPORATIVE STORAGE =       1.122  INCHES
   INITIAL SNOW WATER                 =       0.000  INCHES
   INITIAL WATER IN LAYER MATERIALS   =     357.738  INCHES
   TOTAL INITIAL WATER                =     357.738  INCHES
   TOTAL SUBSURFACE INFLOW            =       0.00   INCHES/YEAR


              EVAPOTRANSPIRATION AND WEATHER DATA
              -----------------------------------

  NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
            ST. LOUIS              MISSOURI

      STATION LATITUDE                          =  39.10 DEGREES
      MAXIMUM LEAF AREA INDEX                   =   0.00
      START OF GROWING SEASON (JULIAN DATE)     =    98
      END OF GROWING SEASON (JULIAN DATE)       =   300
      EVAPORATIVE ZONE DEPTH                    =   6.0  INCHES
      AVERAGE ANNUAL WIND SPEED                 =  10.40 MPH
      AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  73.00 %
      AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  67.00 %
      AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  71.00 %
```

```
      AVERAGE 4TH QUARTER RELATIVE HUMIDITY     =  74.00 %


  NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
            COEFFICIENTS FOR     ST. LOUIS            MISSOURI

                NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

   JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
   -------      -------      -------      -------      -------      -------
     1.72         2.14         3.28         3.55         3.54         3.73
     3.63         2.55         2.70         2.32         2.53         2.22


  NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
            COEFFICIENTS FOR     ST. LOUIS            MISSOURI

             NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

   JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
   -------      -------      -------      -------      -------      -------
    28.60        33.80        43.20        56.10        65.60        74.80
    78.90        77.00        69.70        57.90        44.60        34.20


  NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
            COEFFICIENTS FOR     ST. LOUIS            MISSOURI
              AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

            AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   31
------------------------------------------------------------------------------
-
                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                  1.58     2.08     3.07     3.33     3.48     4.47
                           3.42     2.67     2.69     2.18     2.13     2.04

   STD. DEVIATIONS         0.94     1.14     0.91     1.35     1.55     2.02
                           1.86     1.36     1.46     1.26     1.36     1.13
```

```
 RUNOFF
 ------
   TOTALS                  0.427    0.918    0.717    0.389    0.531    0.888
                           0.667    0.342    0.403    0.251    0.305    0.212

   STD. DEVIATIONS         0.514    0.729    0.676    0.395    0.468    0.799
                           0.680    0.349    0.308    0.276    0.327    0.244

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                  0.552    0.656    2.039    2.544    2.424    3.025
                           2.198    1.936    1.842    1.430    1.242    0.859

   STD. DEVIATIONS         0.339    0.397    0.567    0.892    0.980    1.092
                           0.958    0.895    0.875    0.674    0.497    0.249

 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                  0.5517   0.3960   0.5337   0.7551   0.6470   0.5547
                           0.6116   0.5464   0.4435   0.4529   0.3970   0.5052

   STD. DEVIATIONS         0.3103   0.2780   0.2349   0.2943   0.3407   0.2586
                           0.2843   0.2566   0.2402   0.2283   0.2010   0.2946

 PERCOLATION/LEAKAGE THROUGH LAYER  5
 ------------------------------------
   TOTALS                  0.0017   0.0012   0.0017   0.0023   0.0020   0.0017
                           0.0019   0.0017   0.0014   0.0014   0.0013   0.0016

   STD. DEVIATIONS         0.0009   0.0008   0.0007   0.0008   0.0009   0.0007
                           0.0008   0.0007   0.0007   0.0007   0.0006   0.0008

------------------------------------------------------------------------------
-
              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
------------------------------------------------------------------------------
-

 DAILY AVERAGE HEAD ON TOP OF LAYER  4
 -------------------------------------
   AVERAGES                1.7558   1.3847   1.6985   2.4835   2.0592   1.8244
                           1.9465   1.7391   1.4586   1.4416   1.3057   1.6080

   STD. DEVIATIONS         0.9876   0.9751   0.7476   0.9681   1.0843   0.8506
                           0.9048   0.8168   0.7901   0.7266   0.6611   0.9376

*******************************************************************************
```

```
*******************************************************************************

       AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   31
------------------------------------------------------------------------------
-
                                      INCHES            CU. FEET      PERCENT
                                 -----------------   -------------   ---------
 PRECIPITATION                    33.16    (  4.662)    120357.9      100.00

 RUNOFF                            6.050   ( 1.7917)     21960.61     18.246

 EVAPOTRANSPIRATION               20.746   ( 2.4780)     75309.70     62.571

 LATERAL DRAINAGE COLLECTED        6.39480 ( 1.71870)    23213.115   19.28674
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH       0.01975 ( 0.00486)       71.686     0.05956
   LAYER  5

 AVERAGE HEAD ON TOP               1.725 (   0.465)
   OF LAYER  4

 CHANGE IN WATER STORAGE          -0.054   ( 1.1240)      -197.18     -0.164

*******************************************************************************
```

R1687

```
*************************************************************************

          PEAK DAILY VALUES FOR YEARS    1 THROUGH   31
------------------------------------------------------------------------
                                          (INCHES)     (CU. FT.)
                                         ----------  -------------
  PRECIPITATION                             3.44       12487.200

  RUNOFF                                    1.909       6928.9004

  DRAINAGE COLLECTED FROM LAYER  3          0.06416      232.90303

  PERCOLATION/LEAKAGE THROUGH LAYER  5      0.000178       0.64702

  AVERAGE HEAD ON TOP OF LAYER  4           6.331

  MAXIMUM HEAD ON TOP OF LAYER  4          10.846

  LOCATION OF MAXIMUM HEAD IN LAYER  3
        (DISTANCE FROM DRAIN)              87.9 FEET

  SNOW WATER                                2.43        8821.5488


  MAXIMUM VEG. SOIL WATER (VOL/VOL)                 0.4640

  MINIMUM VEG. SOIL WATER (VOL/VOL)                 0.1870

   ***  Maximum heads are computed using McEnroe's equations.  ***

        Reference:  Maximum Saturated Depth over Landfill Liner
                    by Bruce M. McEnroe, University of Kansas
                    ASCE Journal of Environmental Engineering
                    Vol. 119, No. 2, March 1993, pp. 262-270.

*************************************************************************
```

```
*************************************************************************

                FINAL WATER STORAGE AT END OF YEAR   31
------------------------------------------------------------------------
              LAYER        (INCHES)       (VOL/VOL)
              -----        --------       ---------
                1            3.1793         0.2649

                2          336.3840         0.2920

                3            0.6609         0.0551

                4            0.0000         0.0000

                5           15.3720         0.4270

            SNOW WATER       0.458

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*************************************************************************
*************************************************************************
**                                                                     **
**                                                                     **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE          **
**              HELP MODEL VERSION 3.07   (1 NOVEMBER 1997)            **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                  **
**              USAE WATERWAYS EXPERIMENT STATION                      **
**              FOR USEPA RISK REDUCTION ENGINEERING LABORATORY        **
**                                                                     **
**                                                                     **
*************************************************************************
*************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA42.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA72.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA132.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA112.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10S2.D10
OUTPUT DATA FILE:            C:\LF33\S13261.OUT


TIME:  94:13      DATE:   6/29/2018


*************************************************************************

    TITLE:  SOUTHERN AREA - 30 YEAR POST CLOSURE CARE - YEARS 32 TO 61

*************************************************************************


    NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
           WERE SPECIFIED BY THE USER.


                                 LAYER  1
                                 --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                           MATERIAL TEXTURE NUMBER   8
           THICKNESS                    =    12.00    INCHES
           POROSITY                     =     0.4630 VOL/VOL
           FIELD CAPACITY               =     0.2320 VOL/VOL
           WILTING POINT                =     0.1160 VOL/VOL
           INITIAL SOIL WATER CONTENT   =     0.2320 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.369999994000E-03 CM/SEC
```

```
   NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.20
          FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                 LAYER  2
                                 --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                           MATERIAL TEXTURE NUMBER  11
           THICKNESS                    =    30.00    INCHES
           POROSITY                     =     0.4640 VOL/VOL
           FIELD CAPACITY               =     0.3100 VOL/VOL
           WILTING POINT                =     0.1870 VOL/VOL
           INITIAL SOIL WATER CONTENT   =     0.4640 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.639999998000E-04 CM/SEC


                                 LAYER  3
                                 --------

                       TYPE 2 - LATERAL DRAINAGE LAYER
                           MATERIAL TEXTURE NUMBER  20
           THICKNESS                    =     0.20    INCHES
           POROSITY                     =     0.8500 VOL/VOL
           FIELD CAPACITY               =     0.0100 VOL/VOL
           WILTING POINT                =     0.0050 VOL/VOL
           INITIAL SOIL WATER CONTENT   =     0.0100 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  10.0000000000      CM/SEC
           SLOPE                        =    14.50    PERCENT
           DRAINAGE LENGTH              =   630.0     FEET


                                 LAYER  4
                                 --------

                      TYPE 4 - FLEXIBLE MEMBRANE LINER
                           MATERIAL TEXTURE NUMBER  36
           THICKNESS                    =     0.04    INCHES
           POROSITY                     =     0.0000 VOL/VOL
           FIELD CAPACITY               =     0.0000 VOL/VOL
           WILTING POINT                =     0.0000 VOL/VOL
           INITIAL SOIL WATER CONTENT   =     0.0000 VOL/VOL
           EFFECTIVE SAT. HYD. COND.    =  0.399999993000E-12 CM/SEC
           FML PINHOLE DENSITY          =     1.00    HOLES/ACRE
           FML INSTALLATION DEFECTS     =    15.00    HOLES/ACRE
           FML PLACEMENT QUALITY        =  4 - POOR
```

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```
                              LAYER  5
                              --------

                  TYPE 3 - BARRIER SOIL LINER
                   MATERIAL TEXTURE NUMBER  16
  THICKNESS                      =     12.00   INCHES
  POROSITY                       =      0.4270 VOL/VOL
  FIELD CAPACITY                 =      0.4180 VOL/VOL
  WILTING POINT                  =      0.3670 VOL/VOL
  INITIAL SOIL WATER CONTENT     =      0.4270 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


                              LAYER  6
                              --------

                TYPE 1 - VERTICAL PERCOLATION LAYER
                   MATERIAL TEXTURE NUMBER  18
  THICKNESS                      =   1152.00   INCHES
  POROSITY                       =      0.6710 VOL/VOL
  FIELD CAPACITY                 =      0.2920 VOL/VOL
  WILTING POINT                  =      0.0770 VOL/VOL
  INITIAL SOIL WATER CONTENT     =      0.2920 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.100000005000E-02 CM/SEC


                              LAYER  7
                              --------

                 TYPE 2 - LATERAL DRAINAGE LAYER
                   MATERIAL TEXTURE NUMBER   0
  THICKNESS                      =     12.00   INCHES
  POROSITY                       =      0.3970 VOL/VOL
  FIELD CAPACITY                 =      0.0320 VOL/VOL
  WILTING POINT                  =      0.0130 VOL/VOL
  INITIAL SOIL WATER CONTENT     =      0.0551 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.500000007000E-01 CM/SEC
  SLOPE                          =      2.20   PERCENT
  DRAINAGE LENGTH                =    615.0    FEET


                              LAYER  8
                              --------

                 TYPE 4 - FLEXIBLE MEMBRANE LINER
                   MATERIAL TEXTURE NUMBER  35
```

```
  THICKNESS                      =      0.06   INCHES
  POROSITY                       =      0.0000 VOL/VOL
  FIELD CAPACITY                 =      0.0000 VOL/VOL
  WILTING POINT                  =      0.0000 VOL/VOL
  INITIAL SOIL WATER CONTENT     =      0.0000 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.199999996000E-12 CM/SEC
  FML PINHOLE DENSITY            =      1.00   HOLES/ACRE
  FML INSTALLATION DEFECTS       =     10.00   HOLES/ACRE
  FML PLACEMENT QUALITY          =  4 - POOR


                              LAYER  9
                              --------

                  TYPE 3 - BARRIER SOIL LINER
                   MATERIAL TEXTURE NUMBER  16
  THICKNESS                      =     36.00   INCHES
  POROSITY                       =      0.4270 VOL/VOL
  FIELD CAPACITY                 =      0.4180 VOL/VOL
  WILTING POINT                  =      0.3670 VOL/VOL
  INITIAL SOIL WATER CONTENT     =      0.4270 VOL/VOL
  EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
          FAIR STAND OF GRASS, A SURFACE SLOPE OF 14.%
          AND A SLOPE LENGTH OF  630. FEET.

 SCS RUNOFF CURVE NUMBER               =     79.50
 FRACTION OF AREA ALLOWING RUNOFF      =     90.0    PERCENT
 AREA PROJECTED ON HORIZONTAL PLANE    =      1.000  ACRES
 EVAPORATIVE ZONE DEPTH                =     24.0    INCHES
 INITIAL WATER IN EVAPORATIVE ZONE     =      8.352  INCHES
 UPPER LIMIT OF EVAPORATIVE STORAGE    =     11.124  INCHES
 LOWER LIMIT OF EVAPORATIVE STORAGE    =      3.636  INCHES
 INITIAL SNOW WATER                    =      0.000  INCHES
 INITIAL WATER IN LAYER MATERIALS      =    374.247  INCHES
 TOTAL INITIAL WATER                   =    374.247  INCHES
 TOTAL SUBSURFACE INFLOW               =      0.00   INCHES/YEAR


            EVAPOTRANSPIRATION AND WEATHER DATA
            -----------------------------------
```

```
    NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
              ST. LOUIS              MISSOURI

        STATION LATITUDE                          =  39.10 DEGREES
        MAXIMUM LEAF AREA INDEX                   =   3.00
        START OF GROWING SEASON (JULIAN DATE)     =     98
        END OF GROWING SEASON (JULIAN DATE)       =    300
        EVAPORATIVE ZONE DEPTH                    =  24.0  INCHES
        AVERAGE ANNUAL WIND SPEED                 =  10.40 MPH
        AVERAGE 1ST QUARTER RELATIVE HUMIDITY     =  73.00 %
        AVERAGE 2ND QUARTER RELATIVE HUMIDITY     =  67.00 %
        AVERAGE 3RD QUARTER RELATIVE HUMIDITY     =  71.00 %
        AVERAGE 4TH QUARTER RELATIVE HUMIDITY     =  74.00 %


    NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR     ST. LOUIS              MISSOURI

              NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

 JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
 -------     -------     -------     -------     -------     -------
   1.72        2.14        3.28        3.55        3.54        3.73
   3.63        2.55        2.70        2.32        2.53        2.22


    NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR     ST. LOUIS              MISSOURI

            NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

 JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
 -------     -------     -------     -------     -------     -------
  28.60       33.80       43.20       56.10       65.60       74.80
  78.90       77.00       69.70       57.90       44.60       34.20


    NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
              COEFFICIENTS FOR     ST. LOUIS              MISSOURI
              AND STATION LATITUDE  =  39.10 DEGREES

*******************************************************************************

    AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   30
```

```
-------------------------------------------------------------------------------
-

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------
PRECIPITATION
-------------
  TOTALS                    1.56     2.15     3.09     3.37     3.44     4.42
                            3.38     2.66     2.75     2.18     2.16     2.06

  STD. DEVIATIONS           0.95     1.09     0.92     1.36     1.56     2.04
                            1.87     1.38     1.45     1.28     1.38     1.14

RUNOFF
------
  TOTALS                    0.166    0.458    0.292    0.020    0.018    0.065
                            0.026    0.005    0.005    0.004    0.014    0.013

  STD. DEVIATIONS           0.301    0.539    0.560    0.080    0.041    0.157
                            0.077    0.024    0.017    0.021    0.036    0.026

EVAPOTRANSPIRATION
------------------
  TOTALS                    0.515    0.638    2.154    3.264    4.374    4.763
                            3.510    2.592    2.135    1.282    0.917    0.686

  STD. DEVIATIONS           0.280    0.373    0.572    0.785    0.850    1.667
                            1.487    1.179    1.029    0.294    0.285    0.195

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                    0.5679   0.5417   1.4088   1.1342   0.6071   0.2783
                            0.1206   0.0321   0.0060   0.0090   0.2575   0.4858

  STD. DEVIATIONS           0.7917   0.7568   0.7509   0.6963   0.5178   0.2258
                            0.1714   0.0757   0.0193   0.0435   0.7744   0.7270

PERCOLATION/LEAKAGE THROUGH LAYER  5
------------------------------------
  TOTALS                    0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER  7
----------------------------------------
  TOTALS                    0.0053   0.0021   0.0010   0.0004   0.0002   0.0001
                            0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS           0.0292   0.0115   0.0056   0.0023   0.0010   0.0004
                            0.0002   0.0001   0.0000   0.0000   0.0000   0.0000

PERCOLATION/LEAKAGE THROUGH LAYER  9
```

```
   -----------------------------------
     TOTALS                   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                              0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

     STD. DEVIATIONS          0.0001   0.0000   0.0000   0.0000   0.0000   0.0000
                              0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

-----------------------------------------------------------------------------
-
              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-----------------------------------------------------------------------------
-

   DAILY AVERAGE HEAD ON TOP OF LAYER  4
   -------------------------------------
     AVERAGES                 0.0014   0.0015   0.0036   0.0030   0.0015   0.0007
                              0.0003   0.0001   0.0000   0.0000   0.0007   0.0012

     STD. DEVIATIONS          0.0020   0.0021   0.0019   0.0018   0.0013   0.0006
                              0.0004   0.0002   0.0001   0.0001   0.0020   0.0018

   DAILY AVERAGE HEAD ON TOP OF LAYER  8
   -------------------------------------
     AVERAGES                 0.0170   0.0074   0.0033   0.0014   0.0006   0.0003
                              0.0001   0.0000   0.0000   0.0000   0.0000   0.0000

     STD. DEVIATIONS          0.0931   0.0406   0.0179   0.0076   0.0032   0.0014
                              0.0006   0.0002   0.0001   0.0000   0.0000   0.0000

*****************************************************************************
```

```
*****************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   30
-----------------------------------------------------------------------------
-
                                   INCHES            CU. FEET      PERCENT
                             ------------------   -------------   ---------
 PRECIPITATION                 33.21    (   4.731)    120562.0     100.00

 RUNOFF                         1.086   (  0.9389)     3941.49      3.269

 EVAPOTRANSPIRATION            26.831   (  2.9580)    97394.95     80.784

 LATERAL DRAINAGE COLLECTED     5.44906 (  1.96478)   19780.072   16.40656
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH    0.00004 (  0.00001)       0.141    0.00012
```

```
*****************************************************************************

              PEAK DAILY VALUES FOR YEARS     1 THROUGH   30
----------------------------------------------------------------------
                                              (INCHES)    (CU. FT.)
                                             ----------  -------------
    PRECIPITATION                               3.44       12487.200

    RUNOFF                                      1.924       6984.6318

    DRAINAGE COLLECTED FROM LAYER  3            1.59259     5781.09424

    PERCOLATION/LEAKAGE THROUGH LAYER  5        0.000007       0.02714

    AVERAGE HEAD ON TOP OF LAYER  4             0.125

    MAXIMUM HEAD ON TOP OF LAYER  4             0.251

    LOCATION OF MAXIMUM HEAD IN LAYER  3
           (DISTANCE FROM DRAIN)                0.0 FEET

    DRAINAGE COLLECTED FROM LAYER  7            0.00762       27.65036

    PERCOLATION/LEAKAGE THROUGH LAYER  9        0.000026       0.09384

    AVERAGE HEAD ON TOP OF LAYER  8             0.752

    MAXIMUM HEAD ON TOP OF LAYER  8             1.451

    LOCATION OF MAXIMUM HEAD IN LAYER  7
           (DISTANCE FROM DRAIN)               20.9 FEET

    SNOW WATER                                  2.43        8821.5488


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.4149

    MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1515

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

*****************************************************************************
```

```
   LAYER  5

 AVERAGE HEAD ON TOP            0.001 (    0.000)
   OF LAYER  4

 LATERAL DRAINAGE COLLECTED     0.00924 (  0.05042)         33.548    0.02783
   FROM LAYER  7

 PERCOLATION/LEAKAGE THROUGH    0.00004 (  0.00019)          0.134    0.0001
   LAYER  9

 AVERAGE HEAD ON TOP            0.003 (    0.014)
   OF LAYER  8

 CHANGE IN WATER STORAGE       -0.162   (  1.4968)        -588.17    -0.488

*****************************************************************************
```

```
*****************************************************************************

                FINAL WATER STORAGE AT END OF YEAR   30
    ----------------------------------------------------------------------
                LAYER        (INCHES)        (VOL/VOL)
                -----        --------        ---------
                  1            3.2785          0.2732

                  2            8.8416          0.2947

                  3            0.0020          0.0100

                  4            0.0000          0.0000

                  5            5.1240          0.4270

                  6          336.3840          0.2920

                  7            0.3840          0.0320

                  8            0.0000          0.0000

                  9           15.3720          0.4270

              SNOW WATER       0.000

*****************************************************************************
*****************************************************************************
```

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******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                   **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                       **
**                USAE WATERWAYS EXPERIMENT STATION                         **
**          FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                 **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA43.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA73.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA133.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA113.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10S3.D10
OUTPUT DATA FILE:             C:\LF33\S162131.OUT


TIME:  94:36      DATE:   6/29/2018


******************************************************************************

      TITLE:  SOUTHERN AREA - 70 YEAR AFTER POST CLOSURE -YEARS 62 TO 131

******************************************************************************


      NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
             WERE SPECIFIED BY THE USER.


                                   LAYER  1
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   8
          THICKNESS                     =    12.00    INCHES
          POROSITY                      =     0.4630 VOL/VOL
          FIELD CAPACITY                =     0.2320 VOL/VOL
          WILTING POINT                 =     0.1160 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.2732 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.369999994000E-03 CM/SEC
```

```
      NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.90
             FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                   LAYER  2
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  11
          THICKNESS                     =    30.00    INCHES
          POROSITY                      =     0.4640, VOL/VOL
          FIELD CAPACITY                =     0.3100 VOL/VOL
          WILTING POINT                 =     0.1870 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.2947 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.639999998000E-04 CM/SEC


                                   LAYER  3
                                   --------

                       TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER   0
          THICKNESS                     =     0.20    INCHES
          POROSITY                      =     0.8500 VOL/VOL
          FIELD CAPACITY                =     0.0100 VOL/VOL
          WILTING POINT                 =     0.0050 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.0100 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =   1.00000000000      CM/SEC
          SLOPE                         =    14.50    PERCENT
          DRAINAGE LENGTH               =   630.0     FEET


                                   LAYER  4
                                   --------

                       TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  36
          THICKNESS                     =     0.04    INCHES
          POROSITY                      =     0.0000 VOL/VOL
          FIELD CAPACITY                =     0.0000 VOL/VOL
          WILTING POINT                 =     0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.399999993000E-12 CM/SEC
          FML PINHOLE DENSITY           =      1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS      =     15.00   HOLES/ACRE
          FML PLACEMENT QUALITY         =  4 - POOR
```

```
                                   LAYER  5
                                   --------

                        TYPE 3 - BARRIER SOIL LINER
                         MATERIAL TEXTURE NUMBER   0
          THICKNESS                     =    12.00    INCHES
          POROSITY                      =     0.4270 VOL/VOL
          FIELD CAPACITY                =     0.4180 VOL/VOL
          WILTING POINT                 =     0.3670 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.4270 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.999999975000E-05 CM/SEC


                                   LAYER  6
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  18
          THICKNESS                     =  1152.00    INCHES
          POROSITY                      =     0.6710 VOL/VOL
          FIELD CAPACITY                =     0.2920 VOL/VOL
          WILTING POINT                 =     0.0770 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.2920 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.100000005000E-02 CM/SEC


                                   LAYER  7
                                   --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
          THICKNESS                     =    12.00    INCHES
          POROSITY                      =     0.3970 VOL/VOL
          FIELD CAPACITY                =     0.0320 VOL/VOL
          WILTING POINT                 =     0.0130 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.0320 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.500000007000E-01 CM/SEC


                                   LAYER  8
                                   --------

                       TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  35
          THICKNESS                     =     0.06    INCHES
          POROSITY                      =     0.0000 VOL/VOL
```

```
          FIELD CAPACITY                =     0.0000 VOL/VOL
          WILTING POINT                 =     0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.199999996000E-12 CM/SEC
          FML PINHOLE DENSITY           =      1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS      =     10.00   HOLES/ACRE
          FML PLACEMENT QUALITY         =  4 - POOR


                                   LAYER  9
                                   --------

                        TYPE 3 - BARRIER SOIL LINER
                         MATERIAL TEXTURE NUMBER  16
          THICKNESS                     =    36.00    INCHES
          POROSITY                      =     0.4270 VOL/VOL
          FIELD CAPACITY                =     0.4180 VOL/VOL
          WILTING POINT                 =     0.3670 VOL/VOL
          INITIAL SOIL WATER CONTENT    =     0.4270 VOL/VOL
          EFFECTIVE SAT. HYD. COND.     =  0.100000001000E-06 CM/SEC


                 GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                 ----------------------------------------

      NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
             SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
             GOOD STAND OF GRASS, A SURFACE SLOPE OF 14.%
             AND A SLOPE LENGTH OF  630. FEET.

      SCS RUNOFF CURVE NUMBER            =     72.70
      FRACTION OF AREA ALLOWING RUNOFF   =     95.0      PERCENT
      AREA PROJECTED ON HORIZONTAL PLANE =      1.000    ACRES
      EVAPORATIVE ZONE DEPTH             =     24.0      INCHES
      INITIAL WATER IN EVAPORATIVE ZONE  =      6.815    INCHES
      UPPER LIMIT OF EVAPORATIVE STORAGE =     11.124    INCHES
      LOWER LIMIT OF EVAPORATIVE STORAGE =      3.636    INCHES
      INITIAL SNOW WATER                 =      0.000    INCHES
      INITIAL WATER IN LAYER MATERIALS   =    369.385    INCHES
      TOTAL INITIAL WATER                =    369.385    INCHES
      TOTAL SUBSURFACE INFLOW            =      0.00     INCHES/YEAR


                  EVAPOTRANSPIRATION AND WEATHER DATA
                  -----------------------------------

      NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
```

```
        ST. LOUIS             MISSOURI

     STATION LATITUDE                         =  39.10 DEGREES
     MAXIMUM LEAF AREA INDEX                  =   4.00
     START OF GROWING SEASON (JULIAN DATE)    =    98
     END OF GROWING SEASON (JULIAN DATE)      =   300
     EVAPORATIVE ZONE DEPTH                   =  24.0  INCHES
     AVERAGE ANNUAL WIND SPEED                =  10.40 MPH
     AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
     AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  67.00 %
     AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  71.00 %
     AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  74.00 %


   NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR    ST. LOUIS            MISSOURI

             NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
   1.72        2.14        3.28        3.55        3.54        3.73
   3.63        2.55        2.70        2.32        2.53        2.22


   NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR    ST. LOUIS            MISSOURI

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
  28.60       33.80       43.20       56.10       65.60       74.80
  78.90       77.00       69.70       57.90       44.60       34.20


   NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR    ST. LOUIS            MISSOURI
               AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   70
 ------------------------------------------------------------------------------

                        JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                        -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                 1.81     2.12     3.31     3.55     3.59     4.08
                          3.43     2.58     2.65     2.29     2.30     2.10

   STD. DEVIATIONS        0.97     1.03     1.40     1.37     1.65     2.04
                          1.79     1.41     1.34     1.39     1.36     1.22

 RUNOFF
 ------
   TOTALS                0.250    0.474    0.339    0.008    0.002    0.010
                         0.007    0.001    0.000    0.000    0.008    0.053

   STD. DEVIATIONS       0.426    0.546    0.638    0.046    0.011    0.040
                         0.033    0.006    0.001    0.002    0.042    0.212

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                0.530    0.652    2.101    3.341    4.771    4.136
                         3.514    2.581    2.269    1.234    0.867    0.679

   STD. DEVIATIONS       0.242    0.355    0.546    0.712    1.024    1.900
                         1.657    1.229    0.991    0.356    0.239    0.195

 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                0.5162   0.6508   1.6955   1.1740   0.6517   0.3016
                         0.1168   0.0358   0.0084   0.0110   0.2552   0.5392

   STD. DEVIATIONS       0.5448   0.7593   1.0299   0.7178   0.5379   0.3322
                         0.1757   0.0919   0.0363   0.0541   0.6434   0.9233

 PERCOLATION/LEAKAGE THROUGH LAYER  5
 ------------------------------------
   TOTALS                0.0017   0.0042   0.0191   0.0056   0.0021   0.0006
                         0.0002   0.0001   0.0000   0.0000   0.0028   0.0054

   STD. DEVIATIONS       0.0056   0.0130   0.0366   0.0151   0.0059   0.0008
                         0.0003   0.0002   0.0001   0.0001   0.0157   0.0319

 PERCOLATION/LEAKAGE THROUGH LAYER  9
 ------------------------------------
   TOTALS                0.0017   0.0015   0.0017   0.0017   0.0017   0.0017
                         0.0017   0.0017   0.0016   0.0017   0.0016   0.0017

   STD. DEVIATIONS       0.0010   0.0009   0.0010   0.0010   0.0010   0.0010
                         0.0010   0.0010   0.0010   0.0010   0.0010   0.0010

 ------------------------------------------------------------------------------


            AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
 ------------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES             0.0337   0.1082   0.4726   0.1301   0.0423   0.0090
                         0.0029   0.0009   0.0002   0.0003   0.0701   0.1321

    STD. DEVIATIONS      0.1428   0.3690   0.9422   0.4018   0.1486   0.0162
                         0.0044   0.0023   0.0009   0.0014   0.4169   0.8210

  DAILY AVERAGE HEAD ON TOP OF LAYER  8
  -------------------------------------
    AVERAGES             1.7167   1.7213   1.7494   1.7780   1.7841   1.7826
                         1.7791   1.7748   1.7703   1.7657   1.7671   1.7725

    STD. DEVIATIONS      1.1288   1.1306   1.1475   1.1635   1.1606   1.1576
                         1.1550   1.1522   1.1494   1.1466   1.1400   1.1443

*******************************************************************************


*******************************************************************************

    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   70
 ------------------------------------------------------------------------------

                                   INCHES             CU. FEET      PERCENT
                             -------------------    -------------  ---------
 PRECIPITATION                 33.82    (   4.892)     122761.4     100.00

 RUNOFF                         1.153   (  0.9386)      4184.65       3.409

 EVAPOTRANSPIRATION            26.676   (  3.2419)     96832.59      78.879

 LATERAL DRAINAGE COLLECTED     5.95611 (  2.13737)    21620.691    17.61196
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH    0.04167 (  0.04986)      151.251      0.12321
   LAYER  5

 AVERAGE HEAD ON TOP            0.084 (    0.108)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH    0.02001 (  0.01206)       72.651      0.05918
   LAYER  9

 AVERAGE HEAD ON TOP            1.763 (    1.147)
   OF LAYER  8

 CHANGE IN WATER STORAGE          0.014  (  1.4857)        50.83       0.041

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          PEAK DAILY VALUES FOR YEARS     1 THROUGH   70
------------------------------------------------------------------------
                                            (INCHES)      (CU. FT.)
                                           ----------   -------------
  PRECIPITATION                               3.57        12959.100

  RUNOFF                                      2.602        9446.6738

  DRAINAGE COLLECTED FROM LAYER  3            0.25745       934.52740

  PERCOLATION/LEAKAGE THROUGH LAYER  5        0.028587      103.77177

  AVERAGE HEAD ON TOP OF LAYER  4            22.895

  MAXIMUM HEAD ON TOP OF LAYER  4            41.326

  LOCATION OF MAXIMUM HEAD IN LAYER  3
        (DISTANCE FROM DRAIN)                49.5 FEET

  PERCOLATION/LEAKAGE THROUGH LAYER  9        0.000124        0.44838

  AVERAGE HEAD ON TOP OF LAYER  8             4.233

  SNOW WATER                                  3.24        11767.4912


  MAXIMUM VEG. SOIL WATER (VOL/VOL)                   0.4100

  MINIMUM VEG. SOIL WATER (VOL/VOL)                   0.1515

   *** Maximum heads are computed using McEnroe's equations.  ***

       Reference:  Maximum Saturated Depth over Landfill Liner
                   by Bruce M. McEnroe, University of Kansas
                   ASCE Journal of Environmental Engineering
                   Vol. 119, No. 2, March 1993, pp. 262-270.

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           FINAL WATER STORAGE AT END OF YEAR   70
----------------------------------------------------------------------
              LAYER        (INCHES)       (VOL/VOL)
              -----        --------       ---------
                1           3.0592          0.2549

                2           8.5246          0.2842

                3           0.0020          0.0100

                4           0.0000          0.0000

                5           5.1240          0.4270

                6         336.3840          0.2920

                7           1.8997          0.1583

                8           0.0000          0.0000

                9          15.3720          0.4270

            SNOW WATER      0.000

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**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                   **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                       **
**                USAE WATERWAYS EXPERIMENT STATION                         **
**         FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                  **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA4SA.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA7SA.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA13SA.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA11SA.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10SA.D10
OUTPUT DATA FILE:            C:\LF33\SA0131.OUT


TIME:  70:31     DATE:   6/29/2018


******************************************************************************

     TITLE:  SOUTHERN AREA - ACTIVE LIFE - YEARS 1 TO 31

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER WERE
            COMPUTED AS NEARLY STEADY-STATE VALUES BY THE PROGRAM.


                                  LAYER  1
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  11
          THICKNESS                    =     12.00   INCHES
          POROSITY                     =      0.4640 VOL/VOL
          FIELD CAPACITY               =      0.3100 VOL/VOL
          WILTING POINT                =      0.1870 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.3213 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.639999998000E-04 CM/SEC
```

```
          NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  4.20
                 `FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                  LAYER  2
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  18
          THICKNESS                    =   1152.00   INCHES
          POROSITY                     =      0.6710 VOL/VOL
          FIELD CAPACITY               =      0.2920 VOL/VOL
          WILTING POINT                =      0.0770 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.2932 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC


                                  LAYER  3
                                  --------

                        TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER   0
          THICKNESS                    =     12.00   INCHES
          POROSITY                     =      0.3970 VOL/VOL
          FIELD CAPACITY               =      0.0320 VOL/VOL
          WILTING POINT                =      0.0130 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.0464 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.500000007000E-01 CM/SEC
          SLOPE                        =      2.20   PERCENT
          DRAINAGE LENGTH              =    615.0    FEET


                                  LAYER  4
                                  --------

                        TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  35
          THICKNESS                    =      0.06   INCHES
          POROSITY                     =      0.0000 VOL/VOL
          FIELD CAPACITY               =      0.0000 VOL/VOL
          WILTING POINT                =      0.0000 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
          FML PINHOLE DENSITY          =      1.00   HOLES/ACRE
          FML INSTALLATION DEFECTS     =     10.00   HOLES/ACRE
          FML PLACEMENT QUALITY        =  4 - POOR
```

```
                           LAYER  5
                           --------

                  TYPE 3 - BARRIER SOIL LINER
                  MATERIAL TEXTURE NUMBER  16
   THICKNESS                     =     36.00   INCHES
   POROSITY                      =      0.4270 VOL/VOL
   FIELD CAPACITY                =      0.4180 VOL/VOL
   WILTING POINT                 =      0.3670 VOL/VOL
   INITIAL SOIL WATER CONTENT    =      0.4270 VOL/VOL
   EFFECTIVE SAT. HYD. COND.     =  0.100000001000E-06 CM/SEC


              GENERAL DESIGN AND EVAPORATIVE ZONE DATA
              ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE #11 WITH A
          FAIR STAND OF GRASS, A SURFACE SLOPE OF 14.%
          AND A SLOPE LENGTH OF  630. FEET.

 SCS RUNOFF CURVE NUMBER                =      87.00
 FRACTION OF AREA ALLOWING RUNOFF       =      75.0    PERCENT
 AREA PROJECTED ON HORIZONTAL PLANE     =       1.000  ACRES
 EVAPORATIVE ZONE DEPTH                 =      12.0    INCHES
 INITIAL WATER IN EVAPORATIVE ZONE      =       3.855  INCHES
 UPPER LIMIT OF EVAPORATIVE STORAGE     =       5.568  INCHES
 LOWER LIMIT OF EVAPORATIVE STORAGE     =       2.244  INCHES
 INITIAL SNOW WATER                     =       0.000  INCHES
 INITIAL WATER IN LAYER MATERIALS       =     357.511  INCHES
 TOTAL INITIAL WATER                    =     357.511  INCHES
 TOTAL SUBSURFACE INFLOW                =       0.00   INCHES/YEAR


               EVAPOTRANSPIRATION AND WEATHER DATA
               -----------------------------------

 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
           ST. LOUIS              MISSOURI

       STATION LATITUDE                           =  39.10 DEGREES
       MAXIMUM LEAF AREA INDEX                    =   3.00
       START OF GROWING SEASON (JULIAN DATE)      =     98
       END OF GROWING SEASON (JULIAN DATE)        =    300
       EVAPORATIVE ZONE DEPTH                     =  12.0  INCHES
       AVERAGE ANNUAL WIND SPEED                  =  10.40 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY      =  73.00 %
```

```
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY      =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY      =  71.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY      =  74.00 %


 NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
           COEFFICIENTS FOR    ST. LOUIS            MISSOURI

           NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

  JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
  -------      -------      -------      -------      -------      -------
    1.72         2.14         3.28         3.55         3.54         3.73
    3.63         2.55         2.70         2.32         2.53         2.22


 NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
           COEFFICIENTS FOR    ST. LOUIS            MISSOURI

        NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL      FEB/AUG      MAR/SEP      APR/OCT      MAY/NOV      JUN/DEC
  -------      -------      -------      -------      -------      -------
   28.60        33.80        43.20        56.10        65.60        74.80
   78.90        77.00        69.70        57.90        44.60        34.20


 NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
           COEFFICIENTS FOR    ST. LOUIS            MISSOURI
             AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

       AVERAGE MONTHLY VALUES IN INCHES FOR YEARS   1 THROUGH   31
 ------------------------------------------------------------------------------
-

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
  PRECIPITATION
  -------------
    TOTALS                 1.58     2.08     3.07     3.33     3.48     4.47
                           3.42     2.67     2.69     2.18     2.13     2.04

    STD. DEVIATIONS        0.94     1.14     0.91     1.35     1.55     2.02
```

```
                           1.86     1.36     1.46     1.26     1.36     1.13

  RUNOFF
  ------
    TOTALS                0.356    0.748    0.429    0.067    0.086    0.200
                          0.124    0.036    0.051    0.029    0.061    0.068

    STD. DEVIATIONS       0.460    0.677    0.682    0.165    0.128    0.317
                          0.222    0.091    0.078    0.054    0.099    0.121

  EVAPOTRANSPIRATION
  ------------------
    TOTALS                0.537    0.666    2.250    3.194    3.187    4.182
                          3.220    2.494    2.127    1.411    1.132    0.797

    STD. DEVIATIONS       0.304    0.416    0.557    0.934    1.073    1.483
                          1.385    1.113    1.004    0.441    0.359    0.187

  LATERAL DRAINAGE COLLECTED FROM LAYER  3
  ----------------------------------------
    TOTALS               0.6331   0.4592   0.6307   0.9439   0.7792   0.5092
                         0.4049   0.2470   0.1423   0.2006   0.2677   0.5099

    STD. DEVIATIONS      0.4678   0.3885   0.3497   0.3941   0.4688   0.3715
                         0.3477   0.2227   0.1375   0.2293   0.2997   0.4365

  PERCOLATION/LEAKAGE THROUGH LAYER  5
  ------------------------------------
    TOTALS               0.0019   0.0014   0.0019   0.0028   0.0023   0.0016
                         0.0013   0.0008   0.0005   0.0007   0.0008   0.0015

    STD. DEVIATIONS      0.0013   0.0011   0.0010   0.0011   0.0013   0.0010
                         0.0010   0.0007   0.0004   0.0007   0.0009   0.0012

 ------------------------------------------------------------------------------
-
              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
 ------------------------------------------------------------------------------
-

  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES             2.0151   1.6073   2.0074   3.1043   2.4799   1.6748
                         1.2887   0.7861   0.4679   0.6385   0.8803   1.6228

    STD. DEVIATIONS      1.4889   1.3652   1.1130   1.2962   1.4921   1.2219
                         1.1066   0.7088   0.4522   0.7299   0.9858   1.3894

*******************************************************************************
```

```
*******************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS   1 THROUGH   31
 ------------------------------------------------------------------------------
-
                                      INCHES            CU. FEET     PERCENT
                                ------------------    ------------  ---------
  PRECIPITATION                  33.16    (   4.662)    120357.9     100.00

  RUNOFF                          2.255   (  1.2480)      8185.49      6.801

  EVAPOTRANSPIRATION             25.197   (  2.8333)     91464.38     75.994

  LATERAL DRAINAGE COLLECTED      5.72761 (  2.14415)    20791.225   17.27450
    FROM LAYER  3

  PERCOLATION/LEAKAGE THROUGH     0.01748 (  0.00612)       63.448     0.05272
    LAYER  5

  AVERAGE HEAD ON TOP             1.548 (    0.581)
    OF LAYER  4

  CHANGE IN WATER STORAGE        -0.040   (  1.7014)      -146.63     -0.122

*******************************************************************************
```

R1694

```
*******************************************************************************

            PEAK DAILY VALUES FOR YEARS     1 THROUGH   31
  ------------------------------------------------------------------------
                                               (INCHES)     (CU. FT.)
                                              ----------   -------------
    PRECIPITATION                                3.44       12487.200

    RUNOFF                                       1.879       6819.4351

    DRAINAGE COLLECTED FROM LAYER  3             0.07223      262.18353

    PERCOLATION/LEAKAGE THROUGH LAYER  5         0.000199       0.72099

    AVERAGE HEAD ON TOP OF LAYER  4              7.126

    MAXIMUM HEAD ON TOP OF LAYER  4             12.065

    LOCATION OF MAXIMUM HEAD IN LAYER  3
          (DISTANCE FROM DRAIN)                 94.2 FEET

    SNOW WATER                                   2.43        8821.5488


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                      0.4640

    MINIMUM VEG. SOIL WATER (VOL/VOL)                      0.1870

     ***  Maximum heads are computed using McEnroe's equations.  ***

          Reference:  Maximum Saturated Depth over Landfill Liner
                      by Bruce M. McEnroe, University of Kansas
                      ASCE Journal of Environmental Engineering
                      Vol. 119, No. 2, March 1993, pp. 262-270.

*******************************************************************************
```

```
*******************************************************************************

              FINAL WATER STORAGE AT END OF YEAR   31
  ----------------------------------------------------------------------
              LAYER        (INCHES)        (VOL/VOL)
              -----        --------        ---------
                1            3.6431          0.3036

                2          336.3839          0.2920

                3            0.4020          0.0335

                4            0.0000          0.0000

                5           15.3720          0.4270

              SNOW WATER     0.458

*******************************************************************************
*******************************************************************************
```

```
*******************************************************************************
*******************************************************************************
**                                                                           **
**                                                                           **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE                **
**              HELP MODEL VERSION 3.07   (1 NOVEMBER 1997)                  **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                        **
**              USAE WATERWAYS EXPERIMENT STATION                            **
**          FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                  **
**                                                                           **
**                                                                           **
*******************************************************************************
*******************************************************************************


PRECIPITATION DATA FILE:      C:\LF33\DATA4EB.D4
TEMPERATURE DATA FILE:        C:\LF33\DATA7EB.D7
SOLAR RADIATION DATA FILE:    C:\LF33\DATA13EB.D13
EVAPOTRANSPIRATION DATA:      C:\LF33\DATA11EB.D11
SOIL AND DESIGN DATA FILE:    C:\LF33\DATA10SB.D10
OUTPUT DATA FILE:             C:\LF33\SB3261.OUT


TIME:  71:57      DATE:   6/29/2018


*******************************************************************************

   TITLE:  SOUTHERN AREA - 30 YEAR POST CLOSURE CARE - YEARS 32 TO 61

*******************************************************************************


   NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
          WERE SPECIFIED BY THE USER.


                                 LAYER  1
                                 --------

                   TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  8
      THICKNESS                   =     12.00    INCHES
      POROSITY                    =      0.4630 VOL/VOL
      FIELD CAPACITY              =      0.2320 VOL/VOL
      WILTING POINT               =      0.1160 VOL/VOL
      INITIAL SOIL WATER CONTENT  =      0.2320 VOL/VOL
      EFFECTIVE SAT. HYD. COND.   =  0.369999994000E-03 CM/SEC
```

```
   NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY   4.90
          FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                 LAYER  2
                                 --------

                   TYPE 1 - VERTICAL PERCOLATION LAYER
                        MATERIAL TEXTURE NUMBER  11
      THICKNESS                   =     30.00    INCHES
      POROSITY                    =      0.4640 VOL/VOL
      FIELD CAPACITY              =      0.3100 VOL/VOL
      WILTING POINT               =      0.1870 VOL/VOL
      INITIAL SOIL WATER CONTENT  =      0.4640 VOL/VOL
      EFFECTIVE SAT. HYD. COND.   =  0.639999998000E-04 CM/SEC


                                 LAYER  3
                                 --------

                    TYPE 2 - LATERAL DRAINAGE LAYER
                        MATERIAL TEXTURE NUMBER  20
      THICKNESS                   =      0.20    INCHES
      POROSITY                    =      0.8500 VOL/VOL
      FIELD CAPACITY              =      0.0100 VOL/VOL
      WILTING POINT               =      0.0050 VOL/VOL
      INITIAL SOIL WATER CONTENT  =      0.0100 VOL/VOL
      EFFECTIVE SAT. HYD. COND.   =   10.0000000000      CM/SEC
      SLOPE                       =     14.50    PERCENT
      DRAINAGE LENGTH             =    630.0     FEET


                                 LAYER  4
                                 --------

                    TYPE 4 - FLEXIBLE MEMBRANE LINER
                        MATERIAL TEXTURE NUMBER  36
      THICKNESS                   =      0.04    INCHES
      POROSITY                    =      0.0000 VOL/VOL
      FIELD CAPACITY              =      0.0000 VOL/VOL
      WILTING POINT               =      0.0000 VOL/VOL
      INITIAL SOIL WATER CONTENT  =      0.0000 VOL/VOL
      EFFECTIVE SAT. HYD. COND.   =  0.399999993000E-12 CM/SEC
      FML PINHOLE DENSITY         =      1.00    HOLES/ACRE
      FML INSTALLATION DEFECTS    =     15.00    HOLES/ACRE
      FML PLACEMENT QUALITY       =  4 - POOR
```

```
                    LAYER  5
                    --------

          TYPE 3 - BARRIER SOIL LINER
           MATERIAL TEXTURE NUMBER  16
THICKNESS                    =     12.00    INCHES
POROSITY                     =      0.4270 VOL/VOL
FIELD CAPACITY               =      0.4180 VOL/VOL
WILTING POINT                =      0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000001000E-06 CM/SEC


                    LAYER  6
                    --------

        TYPE 1 - VERTICAL PERCOLATION LAYER
           MATERIAL TEXTURE NUMBER  18
THICKNESS                    =   1152.00    INCHES
POROSITY                     =      0.6710 VOL/VOL
FIELD CAPACITY               =      0.2920 VOL/VOL
WILTING POINT                =      0.0770 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.2920 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000005000E-02 CM/SEC


                    LAYER  7
                    --------

         TYPE 2 - LATERAL DRAINAGE LAYER
           MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     12.00    INCHES
POROSITY                     =      0.3970 VOL/VOL
FIELD CAPACITY               =      0.0320 VOL/VOL
WILTING POINT                =      0.0130 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0335 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.500000007000E-01 CM/SEC
SLOPE                        =      2.20    PERCENT
DRAINAGE LENGTH              =    615.0     FEET


                   .LAYER  8
                    --------

         TYPE 4 - FLEXIBLE MEMBRANE LINER
           MATERIAL TEXTURE NUMBER  35
```

```
THICKNESS                    =      0.06    INCHES
POROSITY                     =      0.0000 VOL/VOL
FIELD CAPACITY               =      0.0000 VOL/VOL
WILTING POINT                =      0.0000 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0000 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.199999996000E-12 CM/SEC
FML PINHOLE DENSITY          =      1.00    HOLES/ACRE
FML INSTALLATION DEFECTS     =     10.00    HOLES/ACRE
FML PLACEMENT QUALITY        =  4 - POOR


                    LAYER  9
                    --------

          TYPE 3 - BARRIER SOIL LINER
           MATERIAL TEXTURE NUMBER  16
THICKNESS                    =     36.00    INCHES
POROSITY                     =      0.4270 VOL/VOL
FIELD CAPACITY               =      0.4180 VOL/VOL
WILTING POINT                =      0.3670 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.4270 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.100000001000E-06 CM/SEC


          GENERAL DESIGN AND EVAPORATIVE ZONE DATA
          ----------------------------------------

  NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
         SOIL DATA BASE USING SOIL TEXTURE # 8 WITH A
         GOOD STAND OF GRASS, A SURFACE SLOPE OF 14.%
         AND A SLOPE LENGTH OF  630. FEET.

SCS RUNOFF CURVE NUMBER            =     72.70
FRACTION OF AREA ALLOWING RUNOFF   =     90.0     PERCENT
AREA PROJECTED ON HORIZONTAL PLANE =      1.000   ACRES
EVAPORATIVE ZONE DEPTH             =     24.0     INCHES
INITIAL WATER IN EVAPORATIVE ZONE  =      8.352   INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE =     11.124   INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE =      3.636   INCHES
INITIAL SNOW WATER                 =      0.000   INCHES
INITIAL WATER IN LAYER MATERIALS   =    373.988   INCHES
TOTAL INITIAL WATER                =    373.988   INCHES
TOTAL SUBSURFACE INFLOW            =      0.00    INCHES/YEAR


             EVAPOTRANSPIRATION AND WEATHER DATA
             ----------------------------------
```

```
  NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
             ST. LOUIS                 MISSOURI

       STATION LATITUDE                             =  39.10 DEGREES
       MAXIMUM LEAF AREA INDEX                      =   4.00
       START OF GROWING SEASON (JULIAN DATE)        =     98
       END OF GROWING SEASON (JULIAN DATE)          =    300
       EVAPORATIVE ZONE DEPTH                       =  24.0  INCHES
       AVERAGE ANNUAL WIND SPEED                    =  10.40 MPH
       AVERAGE 1ST QUARTER RELATIVE HUMIDITY        =  73.00 %
       AVERAGE 2ND QUARTER RELATIVE HUMIDITY        =  67.00 %
       AVERAGE 3RD QUARTER RELATIVE HUMIDITY        =  71.00 %
       AVERAGE 4TH QUARTER RELATIVE HUMIDITY        =  74.00 %


  NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR     ST. LOUIS              MISSOURI

             NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

JAN/JUL    FEB/AUG    MAR/SEP    APR/OCT    MAY/NOV    JUN/DEC
-------    -------    -------    -------    -------    -------
  1.72       2.14       3.28       3.55       3.54       3.73
  3.63       2.55       2.70       2.32       2.53       2.22


  NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR     ST. LOUIS              MISSOURI

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

JAN/JUL    FEB/AUG    MAR/SEP    APR/OCT    MAY/NOV    JUN/DEC
-------    -------    -------    -------    -------    -------
 28.60      33.80      43.20      56.10      65.60      74.80
 78.90      77.00      69.70      57.90      44.60      34.20


  NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR     ST. LOUIS              MISSOURI
                AND STATION LATITUDE  =  39.10 DEGREES



*******************************************************************************

  AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH    30
```

```
------------------------------------------------------------------------------

                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
PRECIPITATION
-------------
  TOTALS                   1.56     2.15     3.09     3.37     3.44     4.42
                           3.38     2.66     2.75     2.18     2.16     2.06

  STD. DEVIATIONS          0.95     1.09     0.92     1.36     1.56     2.04
                           1.87     1.38     1.45     1.28     1.38     1.14
RUNOFF
------
  TOTALS                   0.166    0.453    0.287    0.012    0.001    0.017
                           0.004    0.001    0.000    0.001    0.002    0.008

  STD. DEVIATIONS          0.302    0.543    0.558    0.065    0.006    0.057
                           0.015    0.003    0.001    0.004    0.006    0.021

EVAPOTRANSPIRATION
------------------
  TOTALS                   0.508    0.633    2.126    3.256    4.670    4.546
                           3.511    2.594    2.192    1.221    0.859    0.662

  STD. DEVIATIONS          0.274    0.366    0.576    0.784    0.913    1.703
                           1.513    1.180    1.080    0.287    0.265    0.198

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                   0.5959   0.5605   1.4584   1.1494   0.6237   0.2894
                           0.0975   0.0297   0.0082   0.0079   0.2722   0.5414

  STD. DEVIATIONS          0.7971   0.7667   0.7726   0.7113   0.5104   0.2844
                           0.1388   0.0796   0.0342   0.0396   0.8014   0.7969

PERCOLATION/LEAKAGE THROUGH LAYER  5
------------------------------------
  TOTALS                   0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

LATERAL DRAINAGE COLLECTED FROM LAYER  7
----------------------------------------
  TOTALS                   0.0003   0.0001   0.0001   0.0000   0.0000   0.000[illegible]
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.000[illegible]

  STD. DEVIATIONS          0.0019   0.0007   0.0004   0.0001   0.0001   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

PERCOLATION/LEAKAGE THROUGH LAYER  9
```

```
 ------------------------------------
   TOTALS                  0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

----------------------------------------------------------------------------

              AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
----------------------------------------------------------------------------


 DAILY AVERAGE HEAD ON TOP OF LAYER  4
 -------------------------------------
   AVERAGES                0.0015   0.0016   0.0037   0.0030   0.0016   0.0008
                           0.0002   0.0001   0.0000   0.0000   0.0007   0.0014

   STD. DEVIATIONS         0.0020   0.0021   0.0020   0.0019   0.0013   0.0007
                           0.0004   0.0002   0.0001   0.0001   0.0021   0.0020

 DAILY AVERAGE HEAD ON TOP OF LAYER  8
 -------------------------------------
   AVERAGES                0.0011   0.0005   0.0002   0.0001   0.0001   0.0000
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

   STD. DEVIATIONS         0.0060   0.0026   0.0012   0.0005   0.0002   0.0001
                           0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

****************************************************************************


****************************************************************************

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   30
----------------------------------------------------------------------------

                                     INCHES            CU. FEET     PERCENT
                               ------------------   -------------  ---------
 PRECIPITATION                 33.21   (   4.731)     120562.0      100.00

 RUNOFF                         0.951  (  0.9097)       3450.71      2.862

 EVAPOTRANSPIRATION            26.776  (  3.0023)      97195.78     80.619

 LATERAL DRAINAGE COLLECTED     5.63411 (  1.99288)    20451.822   16.96374
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH    0.00004 (  0.00001)        0.145    0.00012
   LAYER  5

 AVERAGE HEAD ON TOP            0.001 (    0.000)
   OF LAYER  4

 LATERAL DRAINAGE COLLECTED     0.00063 (  0.00327)        2.304    0.00191
   FROM LAYER  7

 PERCOLATION/LEAKAGE THROUGH    0.00001 (  0.00002)        0.019     0.00002
   LAYER  9

 AVERAGE HEAD ON TOP            0.000 (    0.001)
   OF LAYER  8

 CHANGE IN WATER STORAGE       -0.148   (  1.4151)      -538.66     -0.447

****************************************************************************
```

```
****************************************************************************

               PEAK DAILY VALUES FOR YEARS     1 THROUGH   30
 --------------------------------------------------------------------------
                                                   (INCHES)     (CU. FT.)
                                                  ----------  -------------
    PRECIPITATION                                   3.44        12487.200

    RUNOFF                                          1.922        6977.6274

    DRAINAGE COLLECTED FROM LAYER  3                1.59259      5781.10449

    PERCOLATION/LEAKAGE THROUGH LAYER  5            0.000007        0.02714

    AVERAGE HEAD ON TOP OF LAYER  4                 0.125

    MAXIMUM HEAD ON TOP OF LAYER  4                 0.250

    LOCATION OF MAXIMUM HEAD IN LAYER  3
           (DISTANCE FROM DRAIN)                    0.0 FEET

    DRAINAGE COLLECTED FROM LAYER  7                0.00049         1.79574

    PERCOLATION/LEAKAGE THROUGH LAYER  9            0.000002        0.00799

    AVERAGE HEAD ON TOP OF LAYER  8                 0.049

    MAXIMUM HEAD ON TOP OF LAYER  8                 0.098

    LOCATION OF MAXIMUM HEAD IN LAYER  7
           (DISTANCE FROM DRAIN)                    0.0 FEET

    SNOW WATER                                      2.43         8821.5488


    MAXIMUM VEG. SOIL WATER (VOL/VOL)                     0.4144

    MINIMUM VEG. SOIL WATER (VOL/VOL)                     0.1515

     ***  Maximum heads are computed using McEnroe's equations.  ***

         Reference:  Maximum Saturated Depth over Landfill Liner
                     by Bruce M. McEnroe, University of Kansas
                     ASCE Journal of Environmental Engineering
                     Vol. 119, No. 2, March 1993, pp. 262-270.

****************************************************************************
```

```
****************************************************************************

                  FINAL WATER STORAGE AT END OF YEAR   30
     ----------------------------------------------------------------------
                 LAYER         (INCHES)        (VOL/VOL)
                 -----         --------        ---------
                   1             3.2479          0.2707

                   2             9.0223          0.3007

                   3             0.0020          0.0100

                   4             0.0000          0.0000

                   5             5.1240          0.4270

                   6           336.3840          0.2920

                   7             0.3840          0.0320

                   8             0.0000          0.0000

                   9            15.3720          0.4270

               SNOW WATER        0.000

****************************************************************************
****************************************************************************
```

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                   **
**              DEVELOPED BY ENVIRONMENTAL LABORATORY                       **
**                USAE WATERWAYS EXPERIMENT STATION                         **
**            FOR USEPA RISK REDUCTION ENGINEERING LABORATORY               **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************


PRECIPITATION DATA FILE:     C:\LF33\DATA4EC.D4
TEMPERATURE DATA FILE:       C:\LF33\DATA7EC.D7
SOLAR RADIATION DATA FILE:   C:\LF33\DATA13EC.D13
EVAPOTRANSPIRATION DATA:     C:\LF33\DATA11EC.D11
SOIL AND DESIGN DATA FILE:   C:\LF33\DATA10SC.D10
OUTPUT DATA FILE:            C:\LF33\SC62131.OUT


TIME:  88: 5      DATE:   6/29/2018


******************************************************************************

     TITLE:  SOUTHERN AREA - 70 YEAR AFTER POST CLOSURE -YEARS 62 TO 131

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                   LAYER  1
                                   --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   8
            THICKNESS                      =    12.00   INCHES
            POROSITY                       =     0.4630 VOL/VOL
            FIELD CAPACITY                 =     0.2320 VOL/VOL
            WILTING POINT                  =     0.1160 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.2707 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.369999994000E-03 CM/SEC
```

```
NOTE:  SATURATED HYDRAULIC CONDUCTIVITY IS MULTIPLIED BY  5.00
         FOR ROOT CHANNELS IN TOP HALF OF EVAPORATIVE ZONE.


                                   LAYER  2
                                   --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  11
            THICKNESS                      =    30.00   INCHES
            POROSITY                       =     0.4640 VOL/VOL
            FIELD CAPACITY                 =     0.3100 VOL/VOL
            WILTING POINT                  =     0.1870 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.3007 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.639999998000E-04 CM/SEC


                                   LAYER  3
                                   --------

                        TYPE 2 - LATERAL DRAINAGE LAYER
                         MATERIAL TEXTURE NUMBER   0
            THICKNESS                      =     0.20   INCHES
            POROSITY                       =     0.8500 VOL/VOL
            FIELD CAPACITY                 =     0.0100 VOL/VOL
            WILTING POINT                  =     0.0050 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.0100 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =   1.00000000000     CM/SEC
            SLOPE                          =    14.50   PERCENT
            DRAINAGE LENGTH                =   630.0    FEET


                                   LAYER  4
                                   --------

                        TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  36
            THICKNESS                      =     0.04   INCHES
            POROSITY                       =     0.0000 VOL/VOL
            FIELD CAPACITY                 =     0.0000 VOL/VOL
            WILTING POINT                  =     0.0000 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.0000 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.399999993000E-12 CM/SEC
            FML PINHOLE DENSITY            =     1.00   HOLES/ACRE
            FML INSTALLATION DEFECTS       =    15.00   HOLES/ACRE
            FML PLACEMENT QUALITY          =  4 - POOR
```

```
                                   LAYER  5
                                   --------

                          TYPE 3 - BARRIER SOIL LINER
                         MATERIAL TEXTURE NUMBER   0
            THICKNESS                      =    12.00   INCHES
            POROSITY                       =     0.4270 VOL/VOL
            FIELD CAPACITY                 =     0.4180 VOL/VOL
            WILTING POINT                  =     0.3670 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.4270 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.999999975000E-05 CM/SEC


                                   LAYER  6
                                   --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER  18
            THICKNESS                      =  1152.00   INCHES
            POROSITY                       =     0.6710 VOL/VOL
            FIELD CAPACITY                 =     0.2920 VOL/VOL
            WILTING POINT                  =     0.0770 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.2920 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.100000005000E-02 CM/SEC


                                   LAYER  7
                                   --------

                       TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
            THICKNESS                      =    12.00   INCHES
            POROSITY                       =     0.3970 VOL/VOL
            FIELD CAPACITY                 =     0.0320 VOL/VOL
            WILTING POINT                  =     0.0130 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.0320 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.500000007000E-01 CM/SEC


                                   LAYER  8
                                   --------

                        TYPE 4 - FLEXIBLE MEMBRANE LINER
                         MATERIAL TEXTURE NUMBER  35
            THICKNESS                      =     0.06   INCHES
            POROSITY                       =     0.0000 VOL/VOL
```

```
            FIELD CAPACITY                 =     0.0000 VOL/VOL
            WILTING POINT                  =     0.0000 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.0000 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.199999996000E-12 CM/SEC
            FML PINHOLE DENSITY            =     1.00   HOLES/ACRE
            FML INSTALLATION DEFECTS       =    10.00   HOLES/ACRE
            FML PLACEMENT QUALITY          =  4 - POOR


                                   LAYER  9
                                   --------

                          TYPE 3 - BARRIER SOIL LINER
                         MATERIAL TEXTURE NUMBER  16
            THICKNESS                      =    36.00   INCHES
            POROSITY                       =     0.4270 VOL/VOL
            FIELD CAPACITY                 =     0.4180 VOL/VOL
            WILTING POINT                  =     0.3670 VOL/VOL
            INITIAL SOIL WATER CONTENT     =     0.4270 VOL/VOL
            EFFECTIVE SAT. HYD. COND.      =  0.100000001000E-06 CM/SEC


                   GENERAL DESIGN AND EVAPORATIVE ZONE DATA
                   ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 8 WITH AN
          EXCELLENT STAND OF GRASS, A SURFACE SLOPE OF 14.
          AND A SLOPE LENGTH OF  630. FEET.

 SCS RUNOFF CURVE NUMBER            =     70.00
 FRACTION OF AREA ALLOWING RUNOFF   =     95.0    PERCENT
 AREA PROJECTED ON HORIZONTAL PLANE =      1.000  ACRES
 EVAPORATIVE ZONE DEPTH             =     24.0    INCHES
 INITIAL WATER IN EVAPORATIVE ZONE  =      6.857  INCHES
 UPPER LIMIT OF EVAPORATIVE STORAGE =     11.124  INCHES
 LOWER LIMIT OF EVAPORATIVE STORAGE =      3.636  INCHES
 INITIAL SNOW WATER                 =      0.000  INCHES
 INITIAL WATER IN LAYER MATERIALS   =    369.535  INCHES
 TOTAL INITIAL WATER                =    369.535  INCHES
 TOTAL SUBSURFACE INFLOW            =      0.00   INCHES/YEAR


                    EVAPOTRANSPIRATION AND WEATHER DATA
                    -----------------------------------

 NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
```

```
             ST. LOUIS             MISSOURI

         STATION LATITUDE                         =  39.10 DEGREES
         MAXIMUM LEAF AREA INDEX                  =   5.00
         START OF GROWING SEASON (JULIAN DATE)    =     98
         END OF GROWING SEASON (JULIAN DATE)      =    300
         EVAPORATIVE ZONE DEPTH                   =  24.0  INCHES
         AVERAGE ANNUAL WIND SPEED                =  10.40 MPH
         AVERAGE 1ST QUARTER RELATIVE HUMIDITY    =  73.00 %
         AVERAGE 2ND QUARTER RELATIVE HUMIDITY    =  67.00 %
         AVERAGE 3RD QUARTER RELATIVE HUMIDITY    =  71.00 %
         AVERAGE 4TH QUARTER RELATIVE HUMIDITY    =  74.00 %


      NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR     ST. LOUIS            MISSOURI

             NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
    1.72        2.14        3.28        3.55        3.54        3.73
    3.63        2.55        2.70        2.32        2.53        2.22


      NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR     ST. LOUIS            MISSOURI

          NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

  JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
  -------     -------     -------     -------     -------     -------
   28.60       33.80       43.20       56.10       65.60       74.80
   78.90       77.00       69.70       57.90       44.60       34.20


      NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
             COEFFICIENTS FOR     ST. LOUIS            MISSOURI
               AND STATION LATITUDE  =  39.10 DEGREES


*******************************************************************************

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH    70
-------------------------------------------------------------------------------


             AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------


  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES                 0.0341   0.1154   0.5010   0.1294   0.0318   0.0074
                             0.0027   0.0009   0.0002   0.0002   0.0752   0.1487

    STD. DEVIATIONS          0.1432   0.3725   0.9614   0.4242   0.1167   0.0081
                             0.0044   0.0023   0.0009   0.0012   0.4357   0.9243

  DAILY AVERAGE HEAD ON TOP OF LAYER  8
  -------------------------------------
    AVERAGES                 1.7825   1.7873   1.8176   1.8474   1.8520   1.8501
                             1.8463   1.8418   1.8371   1.8324   1.8340   1.8403

    STD. DEVIATIONS          1.1773   1.1787   1.1968   1.2139   1.2101   1.2071
                             1.2042   1.2013   1.1985   1.1956   1.1888   1.1936

*******************************************************************************


*******************************************************************************

    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   70
-------------------------------------------------------------------------------

                                      INCHES            CU. FEET      PERCENT
                                -----------------    ------------   ---------
 PRECIPITATION                   33.82     (   4.892)    122761.4     100.00

 RUNOFF                           1.135    (  0.9369)      4119.29      3.356

 EVAPOTRANSPIRATION              26.647    (  3.2857)     96729.06     78.794

 LATERAL DRAINAGE COLLECTED       6.00208 (  2.14369)    21787.555   17.74788
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH      0.04337 (  0.05248)      157.427    0.12824
   LAYER  5

 AVERAGE HEAD ON TOP              0.087 (    0.113)
   OF LAYER  4

 PERCOLATION/LEAKAGE THROUGH      0.02070 (  0.01254)       75.134    0.06120
   LAYER  9

 AVERAGE HEAD ON TOP              1.831 (    1.196)
   OF LAYER  8
```

```
                              JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                              -------  -------  -------  -------  -------  -------
 PRECIPITATION
 -------------
   TOTALS                       1.81     2.12     3.31     3.55     3.59     4.08
                                3.43     2.58     2.65     2.29     2.30     2.10

   STD. DEVIATIONS              0.97     1.03     1.40     1.37     1.65     2.04
                                1.79     1.41     1.34     1.39     1.36     1.22

 RUNOFF
 ------
   TOTALS                      0.250    0.475    0.338    0.007    0.001    0.005
                               0.004    0.000    0.000    0.000    0.005    0.052

   STD. DEVIATIONS             0.426    0.546    0.640    0.044    0.004    0.024
                               0.020    0.001    0.000    0.000    0.030    0.211

 EVAPOTRANSPIRATION
 ------------------
   TOTALS                      0.526    0.648    2.089    3.369    4.813    4.107
                               3.517    2.583    2.310    1.204    0.824    0.658

   STD. DEVIATIONS             0.237    0.349    0.548    0.708    1.083    1.902
                               1.659    1.231    1.021    0.356    0.230    0.193

 LATERAL DRAINAGE COLLECTED FROM LAYER  3
 ----------------------------------------
   TOTALS                     0.5323   0.6650   1.7236   1.1820   0.6454   0.2839
                              0.1058   0.0338   0.0083   0.0095   0.2573   0.5552

   STD. DEVIATIONS            0.5472   0.7603   1.0347   0.7253   0.5137   0.3107
                              0.1731   0.0925   0.0358   0.0474   0.6501   0.9392

 PERCOLATION/LEAKAGE THROUGH LAYER  5
 ------------------------------------
   TOTALS                     0.0017   0.0044   0.0202   0.0055   0.0017   0.0005
                              0.0002   0.0001   0.0000   0.0000   0.0029   0.0061

   STD. DEVIATIONS            0.0056   0.0131   0.0373   0.0160   0.0046   0.0005
                              0.0003   0.0002   0.0001   0.0001   0.0164   0.0359

 PERCOLATION/LEAKAGE THROUGH LAYER  9
 ------------------------------------
   TOTALS                     0.0017   0.0016   0.0017   0.0017   0.0018   0.0017
                              0.0018   0.0018   0.0017   0.0018   0.0017   0.0018

   STD. DEVIATIONS            0.0011   0.0010   0.0011   0.0010   0.0011   0.0010
                              0.0011   0.0011   0.0010   0.0011   0.0010   0.0011

-------------------------------------------------------------------------------


 CHANGE IN WATER STORAGE          0.014    (  1.4548)         50.35      0.041

*******************************************************************************
```

```
*******************************************************************************

          PEAK DAILY VALUES FOR YEARS     1 THROUGH    70
------------------------------------------------------------------------
                                           (INCHES)      (CU. FT.)
                                          ----------   -------------
  PRECIPITATION                              3.57        12959.100

  RUNOFF                                     2.601        9443.1279

  DRAINAGE COLLECTED FROM LAYER  3           0.25761       935.13361

  PERCOLATION/LEAKAGE THROUGH LAYER  5       0.031204      113.27204

  AVERAGE HEAD ON TOP OF LAYER  4           24.936

  MAXIMUM HEAD ON TOP OF LAYER  4           44.741

  LOCATION OF MAXIMUM HEAD IN LAYER  3
        (DISTANCE FROM DRAIN)               52.9 FEET

  PERCOLATION/LEAKAGE THROUGH LAYER  9       0.000129        0.46749

  AVERAGE HEAD ON TOP OF LAYER  8            4.432

  SNOW WATER                                 3.24        11767.4912


  MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.4101

  MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.1515


   ***  Maximum heads are computed using McEnroe's equations.  ***

        Reference:   Maximum Saturated Depth over Landfill Liner
                     by Bruce M. McEnroe, University of Kansas
                     ASCE Journal of Environmental Engineering
                     Vol. 119, No. 2, March 1993, pp. 262-270.

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```

```
*******************************************************************************

               FINAL WATER STORAGE AT END OF YEAR    70
------------------------------------------------------------------------
              LAYER        (INCHES)        (VOL/VOL)
              -----        --------        ---------
                1           3.0553          0.2546

                2           8.5981          0.2866

                3           0.0020          0.0100

                4           0.0000          0.0000

                5           5.1240          0.4270

                6         336.3840          0.2920

                7           1.9709          0.1642

                8           0.0000          0.0000

                9          15.3720          0.4270

            SNOW WATER      0.000

*******************************************************************************
*******************************************************************************
0
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R1700

APPENDIX I

SURROGATE ADSORPTION AND HALF LIFE VALUES

TEKLAB, INC.

#6 MEADOW HEIGHTS PROF. PARK
COLLINSVILLE, ILLINOIS 62234

ENVIRONMENTAL & CHEMICAL TESTING

TELE: 618-344-1004
FAX: 618-344-1005

August 17, 1994

REPORT #42200

Ms. Kim Pagliai
AE Exploration Corporation
2813 North Dirksen Parkway
Springfield, IL 62703

Project: Soil Testing

Sample Received: 08-10-94

ANALYSIS RESULTS

LAB ID	SAMPLE ID	TOTAL ORGANIC CARBON, mg/kg
940810-5	B94-1-St15 LF33	29900
940810-6	B94-2-St41 LF33	17300
940810-7	B94-2-St24 LF33	17600
940810-8	B94-3-S-6 LF33	2340
940810-9	B94-4-St24 LF33	1580
940810-10	B94-4-St19 LF33	12400

These tests were conducted in accordance with "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", U.S. Environmental Protection Agency, SW-846 (Revised 1990).

TEKLAB INC.

Tony A. Lynn

Tony A. Lynn
Laboratory Director

Select Language ▼

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This page contains the EPI System Summary only.
For complete control of this information -
Download the free EPI SuiteTM v4.0 program : here
To Datasheet

```
CAS Num: 007664-41-7
SMILES : N
CHEM   : Ammonia
MOL FOR: H3 N1
MOL WT : 17.03
------------------------------ EPI SUMMARY (v4.00) --------------------------
 Physical Property Inputs:
    Water Solubility (mg/L):   ------
    Vapor Pressure (mm Hg) :   ------
    Henry LC (atm-m3/mole) :   ------
    Log Kow (octanol-water):   ------
    Boiling Point (deg C)  :   ------
    Melting Point (deg C)  :   ------

 Log Octanol-Water Partition Coef (SRC):
    *** WARNING: Inorganic Compound (Outside Estimation Domain)
    Log Kow (KOWWIN v1.67 estimate) =  0.23

 Boiling Pt, Melting Pt, Vapor Pressure Estimations (MPBPWIN v1.43):
   *** WARNING: Inorganic Compound (Outside Estimate Domain) ***
   *** WARNING: Estimations NOT VALID ***
    Boiling Pt (deg C):  602.75  (Adapted Stein & Brown method)
    Melting Pt (deg C):  260.60  (Mean or Weighted MP)
    VP(mm Hg,25 deg C):  1.66E-013  (Modified Grain method)
    VP (Pa, 25 deg C) :  2.21E-011  (Modified Grain method)
    Subcooled liquid VP: 6.25E-011 mm Hg (25 deg C, Mod-Grain method)
                       : 8.33E-009 Pa (25 deg C, Mod-Grain method)

 Water Solubility Estimate from Log Kow (WSKOW v1.41):
    *** WARNING: Inorganic Compound (Outside Estimation Domain)**
    Water Solubility at 25 deg C (mg/L):  5.101e+004
       log Kow used: 0.23 (estimated)
       no-melting pt equation used

 Water Sol Estimate from Fragments:
    *** WARNING: Inorganic Compound (Outside Estimation Domain)***
    *** WARNING: Wat Sol Estimation NOT Valid ***
    Wat Sol (v1.01 est) =  30231 mg/L

 ECOSAR Class Program (ECOSAR v1.00):
    Class(es) found:
       Neutral Organics

 Henrys Law Constant (25 deg C) [HENRYWIN v3.20]:
   *** WARNING: Inorganic Compound (Outside Estimation Domain) **
   *** WARNING: Estimation NOT VALID **
   Bond Method :   3.45E-006  atm-m3/mole  (3.50E-001 Pa-m3/mole)
   Group Method:   Incomplete
 For Henry LC Comparison Purposes:
   User-Entered Henry LC:  not entered
   Henrys LC [via VP/WSol estimate using User-Entered or Estimated values]:
      HLC:  7.292E-020 atm-m3/mole  (7.389E-015 Pa-m3/mole)
      VP:   1.66E-013 mm Hg (source: MPBPVP)
```

```
     WS:   5.1E+004 mg/L (source: WSKOWWIN)

 Log Octanol-Air Partition Coefficient (25 deg C) [KOAWIN v1.10]:
   *** WARNING: Inorganic Compound (Outside Estimation Domain)**
   *** WARNING: Estimation NOT VALID ***
  Log Kow used:  0.23  (KowWin est)
  Log Kaw used:  -3.851  (HenryWin est)
      Log Koa (KOAWIN v1.10 estimate):  4.081
      Log Koa (experimental database):  None

 Probability of Rapid Biodegradation (BIOWIN v4.10):
    *** WARNING: Inorganic Compound (Outside Estimation Domain)**
    *** WARNING: Estimation NOT VALID ***
   Biowin1 (Linear Model)         :   0.7394
   Biowin2 (Non-Linear Model)     :   0.9409
 Expert Survey Biodegradation Results:
   Biowin3 (Ultimate Survey Model):   3.1615  (weeks       )
   Biowin4 (Primary Survey Model) :   3.8232  (days        )
 MITI Biodegradation Probability:
   Biowin5 (MITI Linear Model)    :   0.6522
   Biowin6 (MITI Non-Linear Model):   0.9080
 Anaerobic Biodegradation Probability:
   Biowin7 (Anaerobic Linear Model):  0.3984
 Ready Biodegradability Prediction:   YES

Hydrocarbon Biodegradation (BioHCwin v1.01):
    Structure incompatible with current estimation method!

 Sorption to aerosols (25 Dec C)[AEROWIN v1.00]:
  Vapor pressure (liquid/subcooled):  8.33E-009 Pa (6.25E-011 mm Hg)
  Log Koa (Koawin est  ): 4.081
   Kp (particle/gas partition coef. (m3/ug)):
       Mackay model            :  360
       Octanol/air (Koa) model:  2.96E-009
   Fraction sorbed to airborne particulates (phi):
       Junge-Pankow model      :  1
       Mackay model            :  1
       Octanol/air (Koa) model:  2.37E-007

 Atmospheric Oxidation (25 deg C) [AopWin v1.92]:
    *** WARNING: Inorganic Compound (Outside Estimation Domain)***
  Hydroxyl Radicals Reaction:
     OVERALL OH Rate Constant =   0.0000 E-12 cm3/molecule-sec
     Half-Life =   -------
  Ozone Reaction:
     No Ozone Reaction Estimation
  Fraction sorbed to airborne particulates (phi):
     1 (Junge-Pankow, Mackay avg)
     2.37E-007 (Koa method)
   Note: the sorbed fraction may be resistant to atmospheric oxidation

 Soil Adsorption Coefficient (KOCWIN v2.00):
   *** WARNING: Inorganic Coumpound (Outside Estimation Domain) **
   *** WARNING: Estimation NOT VALID **
      Koc    :  13.22  L/kg (MCI method)
      Log Koc:  1.121        (MCI method)
      Koc    :  1.582  L/kg (Kow method)
      Log Koc:  0.199        (Kow method)

 Aqueous Base/Acid-Catalyzed Hydrolysis (25 deg C) [HYDROWIN v2.00]:
    Rate constants can NOT be estimated for this structure!

 Bioaccumulation Estimates (BCFBAF v3.00):
   Log BCF from regression-based method = 0.500 (BCF = 3.162 L/kg wet-wt)
   Log Biotransformation Half-life (HL) = -1.5104 days (HL = 0.03088 days)
```

```
 Log BCF Arnot-Gobas method (upper trophic) = -0.003 (BCF = 0.9924)
 Log BAF Arnot-Gobas method (upper trophic) = -0.003 (BAF = 0.9924)
    log Kow used: 0.23 (estimated)

Volatilization from Water:
   Henry LC:  3.45E-006 atm-m3/mole  (estimated by Bond SAR Method)
   Half-Life from Model River:      161.5  hours   (6.727 days)
   Half-Life from Model Lake :      161.5  hours   (6.727 days)

Removal In Wastewater Treatment:
   Total removal:               2.05  percent
   Total biodegradation:        0.09  percent
   Total sludge adsorption:     1.76  percent
   Total to Air:                0.20  percent
     (using 10000 hr Bio P,A,S)

Level III Fugacity Model:
          Mass Amount    Half-Life    Emissions
           (percent)        (hr)        (kg/hr)
  Air       1.62          1e+005        1000
  Water     30.1          360           1000
  Soil      68.2          720           1000
  Sediment  0.0718        3.24e+003     0
    Persistence Time: 589 hr
```

R1706

Rowe Ammonium Hydroxide Solution (1-5% ammonia)

ROWE SCIENTIFIC

Chemwatch Hazard Alert Code: 3

Chemwatch: 4847-83
Version No: 5.1.1.1
Safety Data Sheet according to WHS and ADG requirements

Issue Date: 30/08/2016
Print Date: 31/08/2016
S.GHS.AUS.EN

SECTION 1 IDENTIFICATION OF THE SUBSTANCE / MIXTURE AND OF THE COMPANY / UNDERTAKING

Product Identifier

Product name	Rowe Ammonium Hydroxide Solution (1-5% ammonia)
Synonyms	CA4201, CA4202, CA4207, CA4552
Other means of identification	Not Available

Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses	Laboratory reagent.

Details of the supplier of the safety data sheet

Registered company name	ROWE SCIENTIFIC
Address	11 Challenge Boulevard Wangara WA 6065 Australia
Telephone	+61 8 9302 1911
Fax	+61 8 9302 1905
Website	Not Available
Email	rowewa@rowe.com.au

Emergency telephone number

Association / Organisation	Not Available
Emergency telephone numbers	+61 8 9302 1911 (24 Hrs)
Other emergency telephone numbers	Not Available

SECTION 2 HAZARDS IDENTIFICATION

Classification of the substance or mixture

HAZARDOUS CHEMICAL. NON-DANGEROUS GOODS. According to the WHS Regulations and the ADG Code.

Poisons Schedule	S5
Classification [1]	Skin Corrosion/Irritation Category 2, Serious Eye Damage Category 1
Legend:	*1. Classified by Chemwatch; 2. Classification drawn from HSIS ; 3. Classification drawn from EC Directive 1272/2008 - Annex VI*

Label elements

GHS label elements	
SIGNAL WORD	DANGER

Hazard statement(s)

Continued...

H315	Causes skin irritation.
H318	Causes serious eye damage.

Precautionary statement(s) Prevention

P280	Wear protective gloves/protective clothing/eye protection/face protection.

Precautionary statement(s) Response

P305+P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P310	Immediately call a POISON CENTER or doctor/physician.
P362	Take off contaminated clothing and wash before reuse.
P302+P352	IF ON SKIN: Wash with plenty of soap and water.
P332+P313	If skin irritation occurs: Get medical advice/attention.

Precautionary statement(s) Storage

Not Applicable

Precautionary statement(s) Disposal

Not Applicable

SECTION 3 COMPOSITION / INFORMATION ON INGREDIENTS

Substances

See section below for composition of Mixtures

Mixtures

CAS No	%[weight]	Name
1336-21-6	<5	ammonia
7732-18-5	>95	water

SECTION 4 FIRST AID MEASURES

Description of first aid measures

Eye Contact	If this product comes in contact with the eyes: ‣ Wash out immediately with fresh running water. ‣ Ensure complete irrigation of the eye by keeping eyelids apart and away from eye and moving the eyelids by occasionally lifting the upper and lower lids. ‣ Seek medical attention without delay; if pain persists or recurs seek medical attention. ‣ Removal of contact lenses after an eye injury should only be undertaken by skilled personnel.
Skin Contact	If skin contact occurs: ‣ Immediately remove all contaminated clothing, including footwear. ‣ Flush skin and hair with running water (and soap if available). ‣ Seek medical attention in event of irritation.
Inhalation	‣ If fumes or combustion products are inhaled remove from contaminated area. ‣ Lay patient down. Keep warm and rested. ‣ Prostheses such as false teeth, which may block airway, should be removed, where possible, prior to initiating first aid procedures. ‣ Apply artificial respiration if not breathing, preferably with a demand valve resuscitator, bag-valve mask device, or pocket mask as trained. Perform CPR if necessary. ‣ Transport to hospital, or doctor, without delay.
Ingestion	‣ If swallowed do NOT induce vomiting. ‣ If vomiting occurs, lean patient forward or place on left side (head-down position, if possible) to maintain open airway and prevent aspiration. ‣ Observe the patient carefully. ‣ Never give liquid to a person showing signs of being sleepy or with reduced awareness; i.e. becoming unconscious. ‣ Give water to rinse out mouth, then provide liquid slowly and as much as casualty can comfortably drink. ‣ Seek medical advice.

Indication of any immediate medical attention and special treatment needed

Treat symptomatically.

For acute or short term repeated exposures to ammonia and its solutions:

Continued...

- Mild to moderate inhalation exposures produce headache, cough, bronchospasm, nausea, vomiting, pharyngeal and retrosternal pain and conjunctivitis. Severe inhalation produces laryngospasm, signs of upper airway obstruction (stridor, hoarseness, difficulty in speaking) and, in excessively, high doses, pulmonary oedema.
- Warm humidified air may soothe bronchial irritation.
- Test all patients with conjunctival irritation for corneal abrasion (fluorescein stain, slit lamp exam)
- Dyspneic patients should receive a chest X-ray and arterial blood gases to detect pulmonary oedema.

SECTION 5 FIREFIGHTING MEASURES

Extinguishing media

- There is no restriction on the type of extinguisher which may be used.
- Use extinguishing media suitable for surrounding area.

Special hazards arising from the substrate or mixture

Fire Incompatibility	None known.

Advice for firefighters

Fire Fighting	▸ Alert Fire Brigade and tell them location and nature of hazard. ▸ Wear breathing apparatus plus protective gloves in the event of a fire. ▸ Prevent, by any means available, spillage from entering drains or water courses. ▸ Use fire fighting procedures suitable for surrounding area. ▸ DO NOT approach containers suspected to be hot. ▸ Cool fire exposed containers with water spray from a protected location. ▸ If safe to do so, remove containers from path of fire.
Fire/Explosion Hazard	▸ Non combustible. ▸ Not considered a significant fire risk, however containers may burn. Decomposition may produce toxic fumes of; nitrogen oxides (NOx)May emit poisonous fumes.

SECTION 6 ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

See section 8

Environmental precautions

See section 12

Methods and material for containment and cleaning up

Minor Spills	▸ Clean up all spills immediately. ▸ Avoid breathing vapours and contact with skin and eyes. ▸ Control personal contact with the substance, by using protective equipment. ▸ Contain and absorb spill with sand, earth, inert material or vermiculite. ▸ Wipe up. ▸ Place in a suitable, labelled container for waste disposal.
Major Spills	Moderate hazard. ▸ Clear area of personnel and move upwind. ▸ Alert Fire Brigade and tell them location and nature of hazard. ▸ Wear breathing apparatus plus protective gloves. ▸ Prevent, by any means available, spillage from entering drains or water course. ▸ Stop leak if safe to do so. ▸ Contain spill with sand, earth or vermiculite.

Personal Protective Equipment advice is contained in Section 8 of the SDS.

SECTION 7 HANDLING AND STORAGE

Precautions for safe handling

Safe handling	▸ DO NOT allow clothing wet with material to stay in contact with skin ▸ Limit all unnecessary personal contact. ▸ Wear protective clothing when risk of exposure occurs. ▸ Use in a well-ventilated area. ▸ Avoid contact with incompatible materials. ▸ When handling, DO NOT eat, drink or smoke. ▸ Keep containers securely sealed when not in use. ▸ Avoid physical damage to containers.

Continued...

Other information	‣ Store in original containers. ‣ Keep containers securely sealed. ‣ Store in a cool, dry, well-ventilated area. ‣ Store away from incompatible materials and foodstuff containers. ‣ Protect containers against physical damage and check regularly for leaks. ‣ Observe manufacturer's storage and handling recommendations contained within this SDS.

Conditions for safe storage, including any incompatibilities

Suitable container	‣ Polyethylene or polypropylene container. ‣ Packing as recommended by manufacturer. ‣ Check all containers are clearly labelled and free from leaks. ‣ Glass container is suitable for laboratory quantities
Storage incompatibility	None known

SECTION 8 EXPOSURE CONTROLS / PERSONAL PROTECTION

Control parameters

OCCUPATIONAL EXPOSURE LIMITS (OEL)

INGREDIENT DATA

Source	Ingredient	Material name	TWA	STEL	Peak	Notes
Australia Exposure Standards	ammonia	Ammonia	17 mg/m3 / 25 ppm	24 mg/m3 / 35 ppm	Not Available	Not Available

EMERGENCY LIMITS

Ingredient	Material name	TEEL-1	TEEL-2	TEEL-3
ammonia	Ammonium hydroxide	61 ppm	330 ppm	2300 ppm
ammonia	Ammonia	Not Available	Not Available	Not Available

Ingredient	Original IDLH	Revised IDLH
ammonia	500 ppm	300 ppm
water	Not Available	Not Available

Exposure controls

Appropriate engineering controls	Engineering controls are used to remove a hazard or place a barrier between the worker and the hazard. Well-designed engineering controls can be highly effective in protecting workers and will typically be independent of worker interactions to provide this high level of protection. The basic types of engineering controls are: Process controls which involve changing the way a job activity or process is done to reduce the risk. Enclosure and/or isolation of emission source which keeps a selected hazard "physically" away from the worker and ventilation that strategically "adds" and "removes" air in the work environment. Ventilation can remove or dilute an air contaminant if designed properly. The design of a ventilation system must match the particular process and chemical or contaminant in use. Employers may need to use multiple types of controls to prevent employee overexposure.
Personal protection	
Eye and face protection	‣ Safety glasses with side shields. ‣ Chemical goggles. ‣ Contact lenses may pose a special hazard; soft contact lenses may absorb and concentrate irritants. A written policy document, describing the wearing of lenses or restrictions on use, should be created for each workplace or task. This should include a review of lens absorption and adsorption for the class of chemicals in use and an account of injury experience. Medical and first-aid personnel should be trained in their removal and suitable equipment should be readily available. In the event of chemical exposure, begin eye irrigation immediately and remove contact lens as soon as practicable.
Skin protection	See Hand protection below
Hands/feet protection	‣ Wear chemical protective gloves, e.g. PVC. ‣ Wear safety footwear or safety gumboots, e.g. Rubber
Body protection	See Other protection below

Continued...

Other protection	▸ Overalls. ▸ P.V.C. apron. ▸ Barrier cream. ▸ Skin cleansing cream. ▸ Eye wash unit.
Thermal hazards	Not Available

Respiratory protection

Type K-P Filter of sufficient capacity. (AS/NZS 1716 & 1715, EN 143:2000 & 149:2001, ANSI Z88 or national equivalent)

SECTION 9 PHYSICAL AND CHEMICAL PROPERTIES

Information on basic physical and chemical properties

Appearance	Clear, colourless alkaline liquid with ammonia odour; mixes with water.

Physical state	Liquid	**Relative density (Water = 1)**	Not Available
Odour	Not Available	**Partition coefficient n-octanol / water**	Not Available
Odour threshold	Not Available	**Auto-ignition temperature (°C)**	Not Applicable
pH (as supplied)	>10	**Decomposition temperature**	Not Available
Melting point / freezing point (°C)	Not Available	**Viscosity (cSt)**	Not Available
Initial boiling point and boiling range (°C)	Not Available	**Molecular weight (g/mol)**	Not Applicable
Flash point (°C)	Not Applicable	**Taste**	Not Available
Evaporation rate	Not Available	**Explosive properties**	Not Available
Flammability	Not Applicable	**Oxidising properties**	Not Available
Upper Explosive Limit (%)	Not Applicable	**Surface Tension (dyn/cm or mN/m)**	Not Available
Lower Explosive Limit (%)	Not Applicable	**Volatile Component (%vol)**	Not Available
Vapour pressure (kPa)	Not Available	**Gas group**	Not Available
Solubility in water (g/L)	Miscible	**pH as a solution (1%)**	Not Available
Vapour density (Air = 1)	Not Available	**VOC g/L**	Not Available

SECTION 10 STABILITY AND REACTIVITY

Reactivity	See section 7
Chemical stability	▸ Unstable in the presence of incompatible materials. ▸ Product is considered stable. ▸ Hazardous polymerisation will not occur.
Possibility of hazardous reactions	See section 7
Conditions to avoid	See section 7
Incompatible materials	See section 7
Hazardous decomposition products	See section 5

SECTION 11 TOXICOLOGICAL INFORMATION

Information on toxicological effects

Inhaled	There is some evidence to suggest that the material can cause respiratory irritation in some persons. The body's response to such irritation can cause further lung damage.

Continued...

	The highly irritant properties of ammonia vapour result as the gas dissolves in mucous fluids and forms irritant, even corrosive solutions. Inhalation of the ammonia fumes causes coughing, vomiting, reddening of lips, mouth, nose, throat and conjunctiva while higher concentrations can cause temporary blindness, restlessness, tightness in the chest, pulmonary oedema (lung damage), weak pulse and cyanosis. Inhalation of high concentrations of vapour may cause breathing difficulty, tightness in chest, pulmonary oedema and lung damage. Brief exposure to high concentrations > 5000 ppm may cause death due to asphyxiation (suffocation) or fluid in the lungs. Prolonged or regular minor exposure to the vapour may cause persistent irritation of the eyes, nose and upper respiratory tract. Massive ammonia exposures may produce chronic airway hyperactivity and asthma with associated pulmonary function changes. The average nasal retention of ammonia by human subjects was found to be 83%.
Ingestion	Accidental ingestion of the material may be damaging to the health of the individual. Large doses of ammonia or injected ammonium salts may produce diarrhoea and may be sufficiently absorbed to produce increased production of urine and systemic poisoning. Symptoms include weakening of facial muscle, tremor, anxiety, reduced muscle and limb control.
Skin Contact	The material may cause skin irritation after prolonged or repeated exposure and may produce on contact skin redness, swelling, the production of vesicles, scaling and thickening of the skin. The material may accentuate any pre-existing dermatitis condition
Eye	If applied to the eyes, this material causes severe eye damage.
Chronic	Prolonged or repeated minor exposure to ammonia gas/vapour may cause long-term irritation to the eyes, nose and upper respiratory tract. Repeated exposure or prolonged contact may produce dermatitis, and conjunctivitis. Other effects may include ulcerative changes to the mouth and bronchial and gastrointestinal disturbances. Adaptation to usually irritating concentrations may result in tolerance. In animals, repeated exposures to sub-lethal levels produces adverse effects on the respiratory tract, liver, kidneys and spleen. Exposure at 675 ppm for several weeks produced eye irritation in dogs and rabbits; corneal opacity, covering between a quarter to one half of the total surface area, was evident in rabbits.

Rowe Ammonium Hydroxide Solution (1-5% ammonia)	TOXICITY	IRRITATION
	Not Available	Not Available
ammonia	TOXICITY	IRRITATION
	Inhalation (rat) LC50: 2000 ppm/4hr[2]	Eye (rabbit): 0.25 mg SEVERE
	Oral (rat) LD50: 350 mg/kg[2]	Eye (rabbit): 1 mg/30s SEVERE
water	TOXICITY	IRRITATION
	Oral (rat) LD50: >90000 mg/kg[2]	Not Available
Legend:	*1. Value obtained from Europe ECHA Registered Substances - Acute toxicity 2.* Value obtained from manufacturer's SDS. Unless otherwise specified data extracted from RTECS - Register of Toxic Effect of chemical Substances*	

AMMONIA	The material may produce severe irritation to the eye causing pronounced inflammation. Repeated or prolonged exposure to irritants may produce conjunctivitis. Asthma-like symptoms may continue for months or even years after exposure to the material ceases. This may be due to a non-allergenic condition known as reactive airways dysfunction syndrome (RADS) which can occur following exposure to high levels of highly irritating compound. Key criteria for the diagnosis of RADS include the absence of preceding respiratory disease, in a non-atopic individual, with abrupt onset of persistent asthma-like symptoms within minutes to hours of a documented exposure to the irritant. A reversible airflow pattern, on spirometry, with the presence of moderate to severe bronchial hyperreactivity on methacholine challenge testing and the lack of minimal lymphocytic inflammation, without eosinophilia, have also been included in the criteria for diagnosis of RADS. RADS (or asthma) following an irritating inhalation is an infrequent disorder with rates related to the concentration of and duration of exposure to the irritating substance. Industrial bronchitis, on the other hand, is a disorder that occurs as result of exposure due to high concentrations of irritating substance (often particulate in nature) and is completely reversible after exposure ceases. The disorder is characterised by dyspnea, cough and mucus production.
AMMONIA & WATER	No significant acute toxicological data identified in literature search.

Acute Toxicity	⊘	**Carcinogenicity**	⊘
Skin Irritation/Corrosion	✓	**Reproductivity**	⊘
Serious Eye Damage/Irritation	✓	**STOT - Single Exposure**	⊘
Respiratory or Skin sensitisation	⊘	**STOT - Repeated Exposure**	⊘
Mutagenicity	⊘	**Aspiration Hazard**	⊘

Continued...

Legend: ✗ – *Data available but does not fill the criteria for classification*
✔ – *Data required to make classification available*
⊘ – *Data Not Available to make classification*

SECTION 12 ECOLOGICAL INFORMATION

Toxicity

Ingredient	Endpoint	Test Duration (hr)	Species	Value	Source
ammonia	LC50	96	Fish	15mg/L	4
ammonia	NOEC	72	Fish	3.5mg/L	4
water	LC50	96	Fish	897.520mg/L	3
water	EC50	96	Algae or other aquatic plants	8768.874mg/L	3
water	EC50	384	Crustacea	199.179mg/L	3
Legend:	*Extracted from 1. IUCLID Toxicity Data 2. Europe ECHA Registered Substances - Ecotoxicological Information - Aquatic Toxicity 3. EPIWIN Suite V3.12 - Aquatic Toxicity Data (Estimated) 4. US EPA, Ecotox database - Aquatic Toxicity Data 5. ECETOC Aquatic Hazard Assessment Data 6. NITE (Japan) - Bioconcentration Data 7. METI (Japan) - Bioconcentration Data 8. Vendor Data*				

DO NOT discharge into sewer or waterways.

Persistence and degradability

Ingredient	Persistence: Water/Soil	Persistence: Air
ammonia	LOW	LOW
water	LOW	LOW

Bioaccumulative potential

Ingredient	Bioaccumulation
ammonia	LOW (LogKOW = 0.229)
water	LOW (LogKOW = -1.38)

Mobility in soil

Ingredient	Mobility
ammonia	LOW (KOC = 14.3)
water	LOW (KOC = 14.3)

SECTION 13 DISPOSAL CONSIDERATIONS

Waste treatment methods

Product / Packaging disposal	▸ Recycle wherever possible or consult manufacturer for recycling options. ▸ Consult State Land Waste Management Authority for disposal. ▸ Bury residue in an authorised landfill. ▸ Recycle containers if possible, or dispose of in an authorised landfill.

SECTION 14 TRANSPORT INFORMATION

Labels Required

Marine Pollutant	NO
HAZCHEM	Not Applicable

Land transport (ADG): NOT REGULATED FOR TRANSPORT OF DANGEROUS GOODS

Air transport (ICAO-IATA / DGR): NOT REGULATED FOR TRANSPORT OF DANGEROUS GOODS

Sea transport (IMDG-Code / GGVSee): NOT REGULATED FOR TRANSPORT OF DANGEROUS GOODS

Transport in bulk according to Annex II of MARPOL and the IBC code

Source	Product name	Pollution Category	Ship Type

Continued...

IMO MARPOL (Annex II) - List of Noxious Liquid Substances Carried in Bulk	Ammonia aqueous (28% or less)	Y	2

SECTION 15 REGULATORY INFORMATION

Safety, health and environmental regulations / legislation specific for the substance or mixture

AMMONIA(1336-21-6) IS FOUND ON THE FOLLOWING REGULATORY LISTS

Australia Exposure Standards

Australia Hazardous Substances Information System - Consolidated Lists

Australia Inventory of Chemical Substances (AICS)

WATER(7732-18-5) IS FOUND ON THE FOLLOWING REGULATORY LISTS

Australia Inventory of Chemical Substances (AICS)

National Inventory	Status
Australia - AICS	Y
Canada - DSL	Y
Canada - NDSL	N (ammonia; water)
China - IECSC	Y
Europe - EINEC / ELINCS / NLP	Y
Japan - ENCS	N (water)
Korea - KECI	Y
New Zealand - NZIoC	Y
Philippines - PICCS	Y
USA - TSCA	Y
Legend:	*Y = All ingredients are on the inventory* *N = Not determined or one or more ingredients are not on the inventory and are not exempt from listing(see specific ingredients in brackets)*

SECTION 16 OTHER INFORMATION

Other information

Ingredients with multiple cas numbers

Name	CAS No
ammonia	1336-21-6, 14798-03-9

Classification of the preparation and its individual components has drawn on official and authoritative sources as well as independent review by the Chemwatch Classification committee using available literature references.
A list of reference resources used to assist the committee may be found at:
www.chemwatch.net

The SDS is a Hazard Communication tool and should be used to assist in the Risk Assessment. Many factors determine whether the reported Hazards are Risks in the workplace or other settings. Risks may be determined by reference to Exposures Scenarios. Scale of use, frequency of use and current or available engineering controls must be considered.

end of SDS

A review of ammonium attenuation in soil and groundwater

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Abstract

Ammonium attenuation in subsoils and groundwater is predominantly due to cation exchange and/or nitrification (biological oxidation) processes. These processes have been little studied in UK formations and this relative lack of information can result in reduced consistency and robustness in the assessment of risks posed by ammonium contamination arising from landfills, effluent soakaways, contaminated sites and other sources. A review of ammonium fate and transport in the subsurface has been completed and guidance developed on the key processes that contribute to attenuation. The amount of relevant literature is small but sufficient to provide indicative ranges of partition coefficients and biological nitrification rates for ammonium in UK subsoils and aquifers. Ammonium attenuation was found to be highly sensitive to the clay mineralogy and pore size of the strata, the availability of oxygen and the chemical composition of the contaminated fluid. The values derived may have application in the initial (screening) phases of risk assessment where the conceptual model for the site under consideration matches that from which the presented data originate.

Keywords: environmental protection, groundwater contamination, ion exchange, risk assessment

Inorganic nitrogen in the form of ammonia (NH_3) and the ammonium ion (NH_4^+) is recognized as one of the most common groundwater contaminants arising from waste disposal activities, fertilizer use and contaminated land (Environment Agency 1996). (In this paper, NH_4^+ is used when referring to the ammonium ion, NH_3 when referring to ammonia, and NH_4-N when presenting concentration data, which are reported throughout as ammonium measured as N.) In drinking water supplies NH_4^+ can reduce disinfection efficiency, lead to nitrite formation, and cause taste and odour problems (World Health Organization 1993). In surface water, un-ionized ammonia (NH_3) can cause fish mortality at very low concentrations (National Rivers Authority 1992; Environment Agency 1998).

Ammonium is a List II substance under both the Groundwater Directive (80/68/EEC) and the Dangerous Substances Directive (76/464/EEC). As such, its entry into groundwater and surface waters must be controlled to prevent pollution. The principal environmental drivers for limiting NH_4^+ discharges to the aquatic environment are its effect on ecology (particularly fish), and potable use of water. In addition, the Water Framework Directive (2000/60/EC) requires Member States to achieve good chemical status for groundwater bodies and good ecological status in surface water bodies. Furthermore, EU Member States must reverse significant and sustained upward trends in the concentration of pollutants in groundwater. The impact of NH_4^+ within a surface water body, and the effects of polluted groundwater discharging into surface waters are important factors that need to be assessed as part of the river basin characterization process.

Ammonium is typically present in landfill leachates, wastewater discharges and other industrial liquors, such as quench waters at coking plants and gasworks sites, at very high concentrations relative to relevant standards for drinking water or environmental quality (Table 1). Under certain conditions it is also a relatively mobile contaminant. For these reasons, it is common to use NH_4^+ as a key contaminant species in risk assessments for landfills, effluent soakaways and contaminated sites (Environment Agency 2003*a*).

Attenuation of ammonium

The transport of dilute aqueous contaminants in groundwater is generally represented by the advection–dispersion equation, which assumes that the contaminants neither decay nor interact with other aqueous species or mineral phases (Domenico & Schwartz 1998). However, reactive processes will be critical in determining the transport of the majority of contaminants. For NH_4^+, the key reactive processes controlling subsurface transport are sorption as a result of cation exchange processes and biological degradation.

Although cation exchange processes have been widely studied, particularly with respect to nitrogen cycling in topsoils (Brady & Weil 2002), there has been relatively little research on the effects of cation exchange on NH_4^+ transport in subsoils and groundwater, particularly under the conditions prevailing in UK aquifers. Similarly, there are relative few field data on biological attenuation of NH_4^+, as most research has focused on

1470-9236/04 $15.00

Table 1. *Typical concentrations of sources of dissolved* NH_4^+ *to groundwater.*

Occurrence	Reference	Typical concentration (mg(NH_4-N) l^{-1})
Pumped urban groundwater (Birmingham)	Ford & Tellam 1994	<0.01– 0.93
Sewage effluent (tertiary treatment)	Horan 1990	1–5
Sewage effluent (secondary treatment)	Horan 1990	15–25
Untreated sewage	Horan 1990	20–40
Typical landfill leachate (recent wastes)	Department of the Environment 1995	800
Typical gasworks soil	CL:AIRE 2003	up to 1000 mg kg^{-1} [1]
Groundwater at cemeteries or graveyards	Environment Agency 1999*a*	up to 400
Foot and mouth epidemic mass burial leachate	Environment Agency 2003*c*	1000–7000

For comparison, the current UK Environmental Quality Standard (for ammonia) for freshwater salmonid fisheries is 0.015 mg(NH_3-N) l^{-1} and the Drinking Water Standard (for ammonium) is 0.39 mg(NH_4-N) l^{-1}.

[1] Soil concentration; no reported data on representative groundwater concentrations.

NH_4^+ fate in wastewater and topsoils (USEPA 1993; Brady & Weil 2002).

The lack of data on NH_4^+ behaviour in the subsurface limits consistency and robustness in the assessment of risks posed by NH_4^+ contamination arising from landfills, effluent soakaways, contaminated sites and other sources. Some of these data were reviewed by Erskine (2000), who considered NH_4^+ attenuation at different scales in subsoils and aquifers and suggested parameter values for application in risk assessments.

To address the requirement for field-relevant data on NH_4^+ attenuation, the Environment Agency has undertaken a review of NH_4^+ fate and transport in the subsurface and developed guidance on the key processes that contribute to NH_4^+ attenuation in subsoil and groundwater under UK conditions (Environment Agency 2003*b*). This paper summarizes the findings of that literature review.

Attenuation of ammonium by sorption

Sorption is the process by which a contaminant partitions between the solid and aqueous phases in a porous media. It includes all surface-related reactions such as adsorption, absorption, surface complexation, surface precipitation and ion exchange (Stumm 1992). The effect of sorption is to slow or retard the rate of migration of the contaminant relative to the average (advective) groundwater flow velocity.

Sorption of NH_4^+ is primarily controlled by cation exchange reactions occurring at negatively charged mineral surfaces. In aqueous solutions of low to neutral pH, cation exchange occurs primarily on clay surfaces, but at pH values above neutral sorption to iron oxyhydroxides also makes a significant contribution (Sverjensky & Sahai 1996). This is because metal oxides have a variable negative charge as a function of pH. The extent of sorption to metal oxide surfaces depends on the ambient pH, amount of oxide present and point of zero charge (PZC) of the specific oxyhydroxide mineral. Metal oxides are negatively charged at pH values above the PZC. Manganese oxides (e.g. MnO_2) with a PZC of *c.* 4–4.5 are likely to contribute more exchange capacity for NH_4^+ sorption than Fe oxides (e.g. FeOOH), with PZC around 6–7 (Parks 1965). Sorption to metal oxides may be an important contribution to the attenuation of NH_4^+ in aquifers or geological materials containing these minerals as surface coatings on particles (e.g. Triassic sandstone).

The relative strength with which cations bond to a charged mineral surface is determined by their selectivity coefficients, which are a function of both the mineral surface and solution composition (Appelo & Postma 1993). The following series of relative selectivity has been presented in order of decreasing affinity for cation exchange sites (Domenico & Schwartz 1998), although other schemes have been proposed: $Al^{3+} > Ca^{2+} > Mg^{2+} > NH_4^+ > K^+ > H^+ > Na^+$.

In many contaminant plumes, NH_4^+ is not the most abundant cation. For example, sodium is usually the dominant cation in domestic landfill leachate (Department of the Environment 1995) and competes, along with potassium, calcium and magnesium, with NH_4^+ ions for exchange sites. Cations retained electrostatically are easily exchangeable with other cations in the groundwater with a high selectivity coefficient for the sorbent.

Estimates of sorption and retardation for the same geological formation, using different test methods (and especially different solution compositions), may vary by more than two orders of magnitude (e.g. Lower Chalk, Environment Agency 2000; Lias Clay, Cave & Taylor 2002). Factors that contribute significantly to this variability are:

- non-linear sorption isotherms, which apply at higher concentrations but can be measured by appropriately designed experiments;
- composition of the aqueous phase and solid exchanger material;
- non-equilibrium behaviour, which can be measured by longer duration column experiments (although flow velocities in such tests are generally higher than expected in the field);

- non-ideal behaviour, which has been observed in laboratory and field experiments; this is thought to be predominantly due to field-scale heterogeneity in hydraulic conductivity and partition coefficients, K_d;
- method, precision and validity of experimental testing procedures (e.g. the use of single solute solutions to represent competitive sorption in multi-solute field systems).

Sorption models

Theory. The simplest sorption model relates the sorbed mass to the solute concentration by a constant of proportionality, termed the partition coefficient, K_d:

$$K_d = \frac{C^*}{C} \tag{1}$$

where K_d is the partition coefficient (l kg^{-1}), C^* is concentration of the sorbed contaminant (mg kg^{-1}) and C is aqueous concentration (mg l^{-1}). Although this formulation should strictly use activities rather than concentrations, K_d tends in practice to be based upon measured concentrations without correction for ionic strength (e.g. Environment Agency 2000).

The principal limitation of the linear sorption model is that the substrate is assumed to have infinite sorption capacity, irrespective of solute concentration. This is unrealistic for natural materials and several alternative sorption models have been proposed that account for a maximum sorption limit.

The Langmuir isotherm (Appelo & Postma 1993) assumes that there are a finite number (β) of surface sites that have identical sorption characteristics. It is commonly written as

$$C^* = \beta\frac{\alpha C}{1 + \alpha C} \tag{2}$$

where α is the partition coefficient (l kg^{-1}) and β is the maximum amount of solute that can be sorbed by the solid (mg kg^{-1}). At low concentrations the Langmuir isotherm becomes linear with $K_d = \alpha\beta$.

Neither the linear nor the Langmuir model accounts for sorption heterogeneity in the substrate, although these models are additive if there are multiple homgeneous substrates. Taken to the limit of a continuous Gaussian-like distribution of α and β to represent a heterogeneous exchanger, Langmuir isotherms may be integrated to give the Langmuir–Freundlich isotherm (Sposito 1984):

$$C^* = \beta\frac{(\alpha' C)^N}{1 + (\alpha' C)^N} \tag{3}$$

where α′ is the mean value of α in the distribution and N is a constant between zero and one that describes the degree of heterogeneity in the substrate. With $N = 1$ the distribution becomes the Langmuir isotherm. At small values of C, the Langmuir–Freundlich isotherm can be approximated by the Freundlich equation:

$$C^* = KC^N \tag{4}$$

where K is a constant of proportionality. With $N = 1$, the Freundlich isotherm becomes the linear isotherm.

Both the Langmuir and Freundlich isotherms are non-linear but tend to linearity at low concentrations or over a limited concentration range. It is particularly important to note that the ratio C^*/C decreases at higher concentrations for the Langmuir and Freundlich isotherms. Therefore, if K_d values are determined from C^*/C ratios at low concentrations, the partition coefficients may be overestimated. This will overestimate the retardation factor and breakthrough time of NH_4^+ at a receptor, and underestimate the predicted length of a pollutant plume in an aquifer.

In this paper, when a partition coefficient is derived only for a given concentration (i.e. there is no evidence for a linear isotherm), the symbol K_d^* is used to denote the ratio C^*/C. The symbol K_d is therefore reserved for a partition coefficient that describes the slope of a linear isotherm. It should be noted that many publications reviewed did not make this distinction.

Experimental observations. Both linear and non-linear isotherms have been observed in studies where sufficient data were collected to derive sorption isotherms. In general, linear isotherms are obtained where NH_4^+ concentrations were relatively low. Ceazan *et al.* (1989) obtained linear isotherms for NH_4^+ in spiked uncontaminated groundwater at concentrations up to 25 mg(NH_4-N) l^{-1}. In contrast, DeSimone *et al.* (1996) obtained linear isotherms for groundwater containing NH_4^+ at concentrations up to 2 mg(NH_4-N) l^{-1} whereas the Freundlich model best represented the sorption relationship at higher concentrations, up to 22 mg(NH_4-N) l^{-1}.

Cave & Taylor (2002) fitted a Freundlich isotherm to experimental data for which the NH_4^+ concentration was as low as 2 mg(NH_4-N) l^{-1}, although data obtained at much higher concentrations, up to 280 mg(NH_4-N) l^{-1}, were required to fully define the shape of the isotherm. Colley (1991) used both Freundlich and Langmuir isotherms to fit experimental data from three different lithologies at concentrations in landfill leachate between 35 and 185 mg(NH_4-N) l^{-1}, whereas Jackson (1989) used Langmuir isotherms only to describe sorption for four lithologies at concentrations in landfill leachate between 316 and 575 mg(NH_4-N) l^{-1}.

K_d values from column experiments are obtained by assuming that a linear isotherm applies, but there is often insufficient evidence for the validity of linear isotherms. However, Thornton *et al.* (1996) showed that, at least for the system examined (landfill leachate in

Sherwood Sandstone), a linear sorption isotherm for NH_4^+ could be used to reproduce the results of detailed cation exchange modelling using a numerical reactive transport code. The K_d values obtained for NH_4^+ by Thornton *et al.* (1996) are appropriate only for the leachate–aquifer systems studied. Moreover, the range of conditions under which complex multi-component ion-exchange reactions involving NH_4^+ can be described by a simple linear isotherm model remain poorly understood. Predictions of NH_4^+ transport under such conditions (e.g. landfill leachate plumes in geological media) should be undertaken using appropriate reactive transport codes. For example, PHREEQC or other models with comparable functionality use ion-exchange selectivity coefficients, which more correctly describe NH_4^+ exchange as a function of solution composition and exchanger properties (Appelo & Postma 1993; Tellam *et al.* 1997).

However, there is evidence that NH_4^+ sorption does not always occur by an exchange mechanism. Sorption of NH_4^+ to illite and other 2:1-type clay minerals may be an effectively irreversible process because the NH_4^+ ion fits into the intra-layer clay lattice. In soils with considerable illite content, interlayer-fixed NH_4^+ can typically account for 20–40% of the total nitrogen (Brady & Weil 2002). Discussing the data presented for Burntstump and Gorsethorpe landfills, Lewin *et al.* (1994*a*, *b*) and Harris (1988) noted that sorption of NH_4^+ is not accompanied by release of base cations as would be expected with ion exchange. Ceazan *et al.* (1989) obtained only 80% recovery of the NH_4^+ used to determine the sorption isotherm for a clay-poor sand and gravel.

Solution composition

There is abundant evidence that K_d values obtained in tests with NH_4^+ spiked artificial solutions (e.g. distilled or de-ionized water) can be significantly higher than K_d values obtained when real landfill leachate is used. The use of artificially spiked solutions therefore causes greater uptake of NH_4^+ by mineral surfaces than that which would be observed using real landfill leachate. This observation is generally ascribed to the effects of competition for exchange sites by other cations that are present in the landfill leachate but absent from a spiked solution.

This effect was clearly observed in both Chalk and Mercia Mudstone by the Environment Agency (2000). For Chalk, K_d* values for an artificial NH_4^+ solution (10 mg(NH_4-N) l^{-1}; pH 8) and leachate (4.24 mg(NH_4-N) l^{-1}; pH 6.3) were 1.43 and 0.03 ml g^{-1}, respectively. This effect was, in part, probably due to the acidic leachate dissolving calcium from the rock matrix to compete with the NH_4^+ ions. In tests using Mercia Mudstone, artificial NH_4^+ solution and leachate (but at pH 7), K_d* values of 7.78 and 5.24 ml g^{-1}, respectively, were obtained.

Similar effects were observed by Freewood *et al.* (2001) in colliery spoils and by DeSimone *et al.* (1996) in sand and gravel. Cave *et al.* (2002) noted the opposite effect with leachate in which the NH_4^+ ion was in excess; these concentrations significantly affected the ability of the rock to adsorb potassium. These results indicate that either real landfill leachate or artificial solutions with the same ionic composition as the leachate or leachate-affected groundwater should be used to estimate NH_4^+ sorption if the techniques being used to predict transport do not account for multi-species competition.

Lithology

Sorption of cations in aquifers primarily occurs at clay surfaces (and metal oxide surfaces, depending on conditions). The degree of sorption can often be explicitly related to the proportion of clay minerals in the aquifer material. Both Griffin *et al.* (1976) and Thornton *et al.* (2001) used column experiments to measure the attenuation of NH_4^+ in mineral landfill liners using landfill leachate. Griffin *et al.* (1976) tested mixtures of sand and montmorillonite, whereas Thornton *et al.* (2001) used mixtures of sand and Oxford Clay or Coal Measures Clay. In both cases the K_d values varied linearly with clay content, within the concentration range of NH_4^+ in the leachates tested.

With regard to clay mineralogy, it has generally been found that mixed-layer clays (e.g. montmorillonite–smectite, including bentonite) adsorb NH_4^+ more strongly than two-layer clays, such as illite, which in turn adsorb NH_4^+ more strongly than single-layer clays, such as kaolinite (Stumm 1992). As such, partition coefficients of NH_4^+ to aquifer materials are implicitly related to their lithology and/or mineralogy. The Environment Agency (2000) reported K_d* values for UK aquitards and the series of clay mineralogy that shows broadly decreasing NH_4^+ sorption is: smectite (Gault Clay) > illite (Mercia Mudstone) > kaolinite (Oxford Clay).

Implications for modelling of subsurface ammonium transport

In most cases competitive cation exchange will control NH_4^+ transport in a subsurface flow system. Under these conditions accurate description of NH_4^+ transport and attenuation requires the simultaneous solution of coupled non-linear equations. Although this is relatively simple for systems where transport processes are not important, such as landfill liners (Environment Agency 2002), the non-linearity of the equations prevents their use in simple transport equations. If transport is significant, numerical codes, such as PHREEQC (Pankhurst 1995) or MINTEQA2 (Allison *et al.* 1991), need to be used.

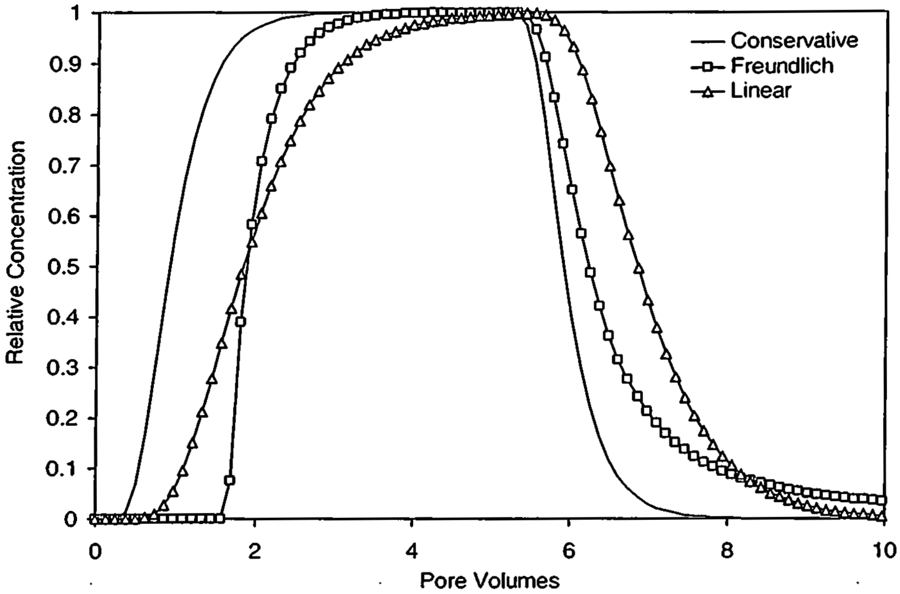

Fig. 1. Illustrative breakthrough and flushing curves for linear and Freundlich sorption models, generated using a model adapted from the column breakthrough model of Appelo & Postma (1993).

Modelling of column experiments shows that the sorption isotherm affects the shape of breakthrough curves (Appelo 1994). Because Langmuir and Freundlich isotherms adsorb relatively less at higher concentrations, they tend to have sharper initial breakthroughs and are shallower when approaching peak concentrations (Fig. 1). They also tend to have longer tails during flushing.

Indicative partition coefficients for ammonium sorption in UK lithologies

Many of the studies quoted above show that the linear sorption model is appropriate for use in predicting NH_4^+ transport in dilute solutions. It is generally considered reasonable to expect the linear isotherm to be true at low concentrations under a very wide range of conditions, even when there are many substances adsorbed and when there is some heterogeneity (Milne *et al.* 2002). Table 2 presents a compilation of reported K_d values from the reviewed literature, assuming that the linear sorption model is appropriate. They are considered relevant for screening risks associated with NH_4^+ transport and attenuation in different lithologies for dilute mixed solutions.

In Table 2, ranges are presented for probabilistic modelling purposes. Where two values for K_d are given this indicates that a uniform distribution is suggested. If three are presented, the data are of sufficient quality to justify the use of a triangular distribution. Where there is uncertainty in the lower bounding value, a value of zero has been assumed. The exception is where knowledge of the lithology suggests that there will always be some attenuation, in which case a value of 10% of the upper bound is used. Where possible, Table 2 has been based solely on values derived for mixed solutions, such as dilute landfill leachate, as these are more representative of field conditions.

The values provided are unlikely to be valid (and will not be conservative) for the assessment of transport through landfill liners or the unsaturated zone where there is migration of high-strength NH_4^+ solutions. Under these conditions the use of a linear isotherm model is likely to overestimate the amount of sorption. Modelling fate and transport in these circumstances, or where the outcome of a risk assessment is critical, is better accomplished using modelling tools that incorporate ion exchange processes and can take into account the detailed site hydrochemistry.

Microbial attenuation of ammonium

Contributory processes

Nitrogen is an essential component of cells and significant quantities of NH_4^+, nitrite, nitrate and organic nitrogen compounds may be utilized by active microorganisms. With the exception of highly fertile topsoils, microbial growth in the subsurface is constrained by the supply of oxidants, essential nutrients, substrates and other growth factors (Bitton & Gerba 1984). Consequently, biomass production is small and removal of NH_4^+ by uptake and incorporation into biomass will generally make an insignificant contribution to NH_4^+ attenuation in the subsurface.

Table 2. *Estimated partition coefficients for ammonium reported for a selection of UK lithologies.*

Lithology (and references)[1]	K_d range (ml g^{-1})[2]	Comments
Chalk (7, 10)	0–0.03	Low confidence as isotherms have not been identified
Triassic Sherwood Sandstone (1, 4, 5, 7, 8, 10, 12)	0–0.2–0.6	Reasonable confidence as there have been several independent tests, although most values are from one site only (Burntstump)
Lincolnshire Limestone (7)	0.065–0.65	Low confidence as isotherms have not been identified
Lower Greensand 'Hassock' (4, 10)	0.18–1.8	Low confidence as no isotherms have been found. Measurements have been on the 'Hassock' lithology only. A lower bound of zero should be used for Lower Greensand in general
Lower Greensand (undifferentiated) (4, 10)	0–1.8	
Red Crag (10)	0.05–0.5	Low confidence as isotherms have not been identified
Oxford Clay (7, 13)	0.135–1.35	Based on modelling of column experiments
Mercia Mudstone (7)	0.5–5	Low confidence as isotherms have not been identified
Gault Clay (7)	0.65–6.5	Low confidence as isotherms have not been identified
Lias Clay (2)	1.2–2.6	Low confidence as isotherms have not been identified. Cave & Taylor (2002) presented higher K_d* values for lower concentrations
Coal Measures Clay (13)	0.18–1.8	Based on modelling of column experiments, being derived from clay–sand mixtures. Value of 1.8 ml g^{-1} obtained for 100% clay system
Sand and gravel, clean (3, 6, 8, 11)	0–0.4–0.9	Reasonable confidence as there have been several independent tests. However, this is naturally a very heterogeneous lithology so a full site characterization should be made if the 'clayey' range of values is used
Sand and gravel, clayey (3, 6, 8, 11)	0.4–0.9	
Cohesive Boulder Clay (2) (Glacial Till)	2–4	Low confidence as isotherms have not been identified. Glacial Till is naturally a very heterogeneous lithology so a full site characterization should be made and the risk assessor must be very confident that there are no sandy sequences in the Till
Engineered clay landfill liners (9, 13)	0.1–0.5–5	Reasonable confidence as there have been a number of independent tests that yield seemingly consistent results. K_d has been shown to correlate with clay content and/or CEC so less conservatism might be permissible with suitable testing and justification. Consideration should be given to the dominant clay mineral present

References cited: (1) Butler *et al.* (2003); (2) Cave & Taylor (2002); (3) Ceazan *et al.* (1989); (4) Colley (1991); (5) Davison & Lerner (1998); (6) DeSimone *et al.* (1996); (7) Environment Agency (2000); (8) Erskine (2000); (9) Griffin *et al.* (1976); (10) Jackson (1989); (11) Kjeldsen & Christensen (1984); (12) Thornton *et al.* (2000); (13) Thornton *et al.* (2001).

[1] Values are considered to apply equally to both the unsaturated and saturated zones.

[2] Where two values for K_d are given this indicates that a uniform distribution is suggested for probabilistic modelling; where three are presented then a triangular distribution is suggested.

Ammonium can also be oxidized by certain bacteria to generate energy, a process known as nitrification. Nitrification is generally a two-stage process; each stage is performed by different microorganisms, collectively known as nitrifiers:

$$NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + 2H^+$$
$$NO_2^- + 0.5O_2 \rightarrow NO_3^-.$$

Carbon for biosynthesis in nitrifying bacteria is provided by dissolved CO_2 (as bicarbonate). Representing the chemical composition of microbial biomass as $C_5H_7NO_2$, the two stages of nitrification can be combined to give an overall reaction (Horan 1990):

$$NH_4^+ + 1.83\,O_2 + 1.98\,HCO_3^- \rightarrow 0.021\,C_5H_7NO_2 + 1.041\,H_2O + 0.98\,NO_3^- + 1.88\,H_2CO_3.$$

The process is aerobic (i.e. it requires oxygen) and oxygen consumption is *c.* 3.3 kg O_2 for each kilogram of NH_4-N degraded (i.e. 3.3 kg kg$(NH_4\text{-}N)^{-1}$). This means that nitrification requires a continuous supply of oxygen. Biomass yield from nitrification is also low, *c.* 0.13 kg kg$(NH_4\text{-}N)^{-1}$, which suggests that the growth of nitrifying bacteria will be slow.

Nitrification can also take place under anaerobic (i.e. oxygen-free) conditions with nitrate or manganese oxides acting as the oxidant, for example:

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$5NH_4^+ + 3NO_3^- \rightarrow 4N_2 + 9H_2O + 2H^+$
$2NH_4^+ + 3MnO_2 + 4H^+ \rightarrow N_2 + 6H_2O + 3Mn^{2+}$.

These reactions were originally observed in wastewater treatment processes (Mulder *et al.* 1995; Van de Graaf *et al.* 1995), but have more recently been demonstrated in soils and sediments and may play an important role in the natural nitrogen cycle (Schmidt *et al.* 2001; Thamdrup & Dalsgaard 2002). The contribution of anaerobic NH_4^+ oxidation to subsurface attenuation has not been significantly assessed to date.

The nitrite and nitrate generated by aerobic nitrification of NH_4^+ are susceptible to biological degradation (denitrification) to nitrogen (N_2) under anaerobic conditions. Further discussion of denitrification is beyond the scope of this review, except to note that this could consume nitrate that might otherwise be available for anaerobic NH_4^+ oxidation.

The significance of nitrification in subsurface ammonium attenuation

There is clear evidence that nitrification can play a significant role in the attenuation of NH_4^+ in the unsaturated zone and groundwater (Erskine 2000). Such observations have been made for NH_4^+ contamination arising from contaminated sites (e.g. Torstensson *et al.* 1998), landfills (e.g. Bjerg *et al.* 1995) and effluent discharges to land (e.g. DeSimone *et al.* 1996; Lee & Bennett 1998). Under conditions where attenuation by cation exchange is limited, for example in clay-poor aquifers, nitrification can be the main process limiting development of an NH_4^+ plume (Christensen *et al.* 2000, 2001).

Most research has evaluated nitrification under aerobic conditions. Most studies have not determined the significance of anaerobic NH_4^+ oxidation under anoxic and anaerobic conditions. This is not surprising, as anaerobic NH_4^+ oxidation has only recently been recognized, but the study of Bjerg *et al.* (1995) had already highlighted the potential importance of anaerobic NH_4^+ oxidation before it had been directly demonstrated in soils and sediments. These workers reported that nitrification was an important process controlling the attenuation of NH_4^+ in a landfill leachate plume in a Danish sand–gravel aquifer, and demonstrated a major contribution from anaerobic NH_4^+ oxidation, possibly linked to microbial manganese-reduction. In contrast, other field studies have suggested that little or no anaerobic NH_4^+ oxidation occurs (e.g. DeSimone *et al.* 1996; Ptacek 1998; Torstensson *et al.* 1998; Gooddy *et al.* 2002). Consequently, it is not yet clear whether anaerobic NH_4^+ oxidation is an important attenuation process for many plumes or whether the process becomes important only under particular conditions.

Environmental factors controlling subsurface nitrification

Nitrification is generally considered to be sensitive to environmental conditions and the presence of inhibitors, at least in wastewater treatment processes where most studies have been performed (USEPA 1993). Such inhibitory conditions may also arise in a contaminant plume and need to be taken into account when evaluating the behaviour of NH_4^+ pollution in the subsurface.

Oxygen. Aerobic nitrification in the subsurface will be limited by the supply of oxygen. This may be either the rate of oxygen (air) diffusion from the atmosphere or the infiltration of oxygenated recharge (Fetter 1999). As both nitrification and biodegradation of organic matter (either natural or contaminant compounds) consume oxygen, microbial activity in contaminated subsurface environments tends to consume oxygen more rapidly than it can be replenished and anaerobic conditions result (Christensen *et al.* 2001). In such cases, significant aerobic biological nitrification will be confined to the margins of the plume, where recharge by infiltration or mixing with uncontaminated, oxygenated groundwater by dispersion occurs. Furthermore, it should not be assumed that the unsaturated zone will contain oxygen, as monitoring at the Stangate East landfill indicated that the migration of methane could create anaerobic conditions in the subsoil beneath and around that landfill (Robinson 1989).

Anaerobic NH_4^+ oxidation is likely to occur only in the absence of oxygen, but the conditions that support this process in the subsurface are not known.

Temperature. Nitrification can be expected to occur at UK subsurface temperatures (groundwater typically around 11 °C). Rates used in assessing attenuation must be derived for ambient aquifer conditions.

Acidity. Nitrification is relatively sensitive to pH, in part because of the generation of ammonia (NH_3) under alkaline conditions and nitrous acid (HNO_2) under acidic conditions (USEPA 1993). Both substances inhibit nitrifying bacteria. The nitrification reaction itself generates acidity via the production of H^+ (see reaction above).

It is reasonable to infer that pH 6.5–8 is the optimum pH range for nitrification, but rates are likely to be significantly decreased below pH 6.0 or above pH 8.5 (USEPA 1993). However, Allison & Prosser (1993) have measured nitrification in natural environments at pH values as low as 3.7.

Soils are generally well-buffered systems but significant pH changes can be induced by alkaline or acidic contaminants present at contaminated sites. For landfill leachates containing a high proportion of putrescible organic matter, highly acidic leachate (e.g. pH 5–6) can

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arise during the early period of leachate generation in domestic waste landfills (Department of the Environment 1995). Although not explicitly considering nitrification, a review by Mather (1989) provides pertinent information on microbial activity in the unsaturated zone of the Chalk and sandstone aquifers underlying landfills. Chalk and other calcareous formations appear to be sufficiently buffered to prevent detrimental pH changes, as are strata that contain a high proportion of clay minerals (as a result of ion exchange, although this capacity will ultimately become exhausted). However, in formations containing little clay and only a few per cent carbonate minerals (e.g. much of the Permo-Triassic sandstone) the pH may drop below 6.0 during the early period of landfill leachate generation. This can cause a significant decline in microbial activity (e.g. Thornton *et al.* 1996; Tellam *et al.* 1997). Older landfill leachates tend to have a neutral pH value and microbial inhibition as a result of pH changes is generally transient, although it may persist for a number of years (Department of the Environment 1995; Environment Agency 1999*b*).

Ammonium concentration. Except for the production of ammonia (NH_3) or nitrous acid at pH values outside the optimum range, nitrification in the subsurface does not appear to be sensitive to the NH_4^+ concentration. For topsoil, Malhi & McGill (1982) considered 400–800 mg(NH_4-N) kg^{-1} to be a reasonable upper concentration to ensure optimum nitrification under neutral conditions.

Water content. Nitrification does not take place in desiccated soils but is otherwise a viable process across the range of soil water contents normally found in the unsaturated zone in the UK (Malhi & McGill 1982; Flowers & O'Callaghan 1983). Rates of aerobic nitrification in unsaturated zone soils will tend to decrease at high water contents as a result of reduced oxygen availability.

Presence of other contaminants. Nitrification in wastewater treatment is often relatively sensitive to inhibition by organic and inorganic components (e.g. USEPA 1993), such as heavy metals and many organic contaminants that may also arise from industrially contaminated sites or landfills. However, there has been little research on their effects on nitrification in the subsurface.

Deni & Penninckx (1999) reported the effects of hydrocarbon contamination on the rate of nitrification in loamy sand topsoils obtained from an agricultural source and an oil refinery site. The addition to the soil of diesel fuel hydrocarbons at a concentration of 4000 mg kg^{-1} had no detrimental effect on nitrification in the agricultural soil but inhibited nitrification in the refinery soil by *c.* 50%. It was demonstrated that this inhibition was not due to toxic effects but rather to competition for mineral nutrients by hydrocarbon-degrading bacteria stimulated by the addition of diesel.

Broholm & Arvin (2000) found no nitrification in laboratory microcosms constructed with samples from a coking waste-contaminated site on the Triassic Sherwood Sandstone aquifer, even after biodegradation had removed a significant proportion of the dissolved organic contaminants. Those workers noted that the lack of nitrification may have been due to the absence of aerobic nitrifying bacteria in the strongly anaerobic samples collected.

Salinity. Nitrifying bacteria appear to be relatively sensitive to changes in salinity. Many reports indicating nitrification inhibition at high concentrations of inorganic NH_4^+ have found that this was due to osmotic shock caused by the added salts (e.g. Malhi & McGill 1982; Flowers & O'Callaghan 1983).

Rapid changes in salinity can therefore affect nitrification rate. However, adaptation to elevated salinity occurs relatively readily (USEPA 1993) and dissolved salts in landfill leachates (Department of the Environment 1995) are not expected to have a significant detrimental long-term effect on nitrification.

The significance of hydraulic flow paths

The majority of microbial biomass in the subsurface is attached to solid surfaces. Consequently, most microbiological metabolism in subsoils and aquifers occurs at the mineral surface–water interface (Fredrickson & Fletcher 2001). The nature of hydraulic flow in the subsurface will therefore play a significant role in determining the rate and ultimate capacity of nitrification and other biological attenuation processes.

Intergranular flow provides a high surface area to volume ratio for microbial growth and the pore space is the location of greatest biomass and metabolic activity (see data for the Chalk and sandstone of Blakey & Towler (1988) and the Environment Agency (1999*b*)). The exception to this is when the pore spaces are too small to permit the entry of microorganisms. For example, Rees (1981) noted the absence of microbial activity in the pore spaces of unfissured Lower Chalk beneath a landfill in Oxfordshire. Whitelaw & Rees (1980) confirmed the presence of nitrifying bacteria in the unsaturated zone, to a depth of at least 50 m, of the Middle and Upper Chalk underlying agricultural land but proposed that microbial activity was confined to fissures. Both studies concluded that penetration of microbial cells (typical diameter 1 μm) was precluded by the small pore sizes of the Chalk matrix (median diameter 0.22 μm for the Lower Chalk and 0.5–0.7 μm for the Middle and Upper Chalk; Rees 1981). Based on these studies it appears unlikely that a large microbial population can develop in the pore space of the Chalk matrix. Consequently, there could be a much lower capacity for nitrification in poorly fissured Chalk aquifers. In general, the pore sizes of the matrix of other UK aquifers are larger (British Geological Survey & Environment Agency 1997, 2000) and therefore are likely to have the capacity to support an active microbial population for nitrification (Environment Agency 2001).

Conversely, where large fractures represent the predominant flow pathway in a formation, there will be a small surface area for microbial growth relative to the fracture volume, and a comparatively short hydraulic residence time within the fractures. Consequently, the rate of biodegradation activity in a fracture flow system will be low compared with an otherwise similar intergranular system (Mather 1989). The reduced biodegradation potential of organic contaminants in aquifers during fracture flow is well known (e.g. Wealthall *et al.* 2001) and the aquifer capacity for nitrification may similarly be significantly less in such systems. Selection of a model that adequately simulates conceptual model assumptions (relating to both hydrogeological and microbiological processes), including both flow and degradation within fracture and matrix environments, is essential. The common approach of simulating flow and attenuation in fractured aquifers by assuming a low effective porosity value within a porous medium model is unlikely to be sufficiently robust to accurately represent pollutant behaviour in fractured aquifers.

Measured rates of nitrification in subsurface environments

There is relatively little information on subsurface nitrification rates, except for topsoils. DeSimone *et al.* (1996) reported a long-term mass balance evaluation for contaminants arising from a rural sewage treatment plant soakaway in Massachusetts, USA. Ammonium was almost completely removed during transport through the unsaturated subsoil zone (sandy soil) with nitrification being the predominant attenuation mechanism. The estimated rate of nitrification was *c.* 0.017 kg(NH_4-N) day^{-1}, corresponding to a half-life of *c.* 13 days at the discharge NH_4^+ concentration of 27 mg(NH_4-N) l^{-1}. However, such rates are likely to occur only where high biological growth rates can be supported by other nutrients in the contaminant mixture. The assumption adopted by DeSimone *et al.* (1996) and many others is that NH_4^+ degradation is a first-order process, which requires estimation of a single parameter equivalent to a half-life.

The much slower rates of nitrification that can be expected under typical aquifer conditions were illustrated by Erskine (2000), who discussed nitrification rates obtained from field data for two landfill leachate plumes. At the Llwn Isaf landfill in North Wales, aerobic nitrification in the shallow sand–gravel aquifer was calculated to result in an NH_4^+ half-life of *c.* 6 years. Data for the Sherwood Sandstone aquifer underlying the Burntstump landfill in Nottinghamshire (Lewin *et al.* 1994a) suggested a half-life close to 3.5 years, although more recent work at the same site by Butler *et al.* (2003) suggested a half-life of 2.2 years.

Where a high concentration of NH_4^+ exists, the rate of nitrification in deeper subsoils and aquifers may be inadequate for it to be distinguished from abiotic processes, except at the margins of a plume. A similar situation may result from the presence of high concentrations of biodegradable organic contaminants. For example, in a mixed organics–ammonium plume in the Triassic Sherwood Sandstone, Torstensson *et al.* (1998) were unable to determine the rates of nitrification, although geochemical evidence clearly indicated that it took place. This may have been due to the relatively high concentrations of dissolved NH_4^+, or to the preferential biodegradation of the organic contaminants (Broholm & Arvin 2000), or both.

Nitrification kinetics

The kinetics of nitrification in wastewater biotreatment processes have been intensively studied and modelled, commonly using Monod kinetics (USEPA 1993). Readers are directed to Kovárová-Kovar & Egli (1998) for a fuller description of the principles of Monod and related kinetic expressions. In contrast, nitrification kinetics in subsoil and groundwater have received little attention.

Selection of an appropriate kinetic model (Bekins *et al.* 1998; Suarez & Rifai 1999) for subsurface nitrification will be complicated by a number of factors. Where NH_4^+ concentrations show significant spatial variation (e.g. within a groundwater plume), different kinetic models may be appropriate in different regions of the plume. First-order kinetics, which have been widely applied for modelling biodegradation of organic contaminants, are applicable for biological processes only when the substrate concentration is significantly below the reaction half-saturation constant (K_s). Such conditions may well apply towards the margins of a plume, as K_s values for nitrifying bacteria are generally 0.2–5.0 mg(NH_4-N) l^{-1} (USEPA 1993). However, a zero- or second-order model may be more appropriate at other NH_4^+ concentrations or where site data support its use. Monod and other kinetic expressions that incorporate microbial growth may be inappropriate in subsoil and groundwater where limiting conditions mean that net biomass growth of nitrifiers may be insignificant. Furthermore, a necessary input to these models is a number of biological parameters, few of which have been determined for nitrifying organisms growing under subsurface conditions. As a further complication, the greatest proportion of subsurface nitrification activity is likely to result from biomass present on mineral surfaces (Fredrickson & Fletcher 2001), which may require special kinetic models.

In a study of biodegradation kinetics for groundwater contaminant fate and transport modelling, Davison & Lerner (1998) found that degradation rates were often relatively insensitive to the biological parameters applied in the Monod model. They concluded that it may be acceptable to assume that the degradation reaction is instantaneous relative to groundwater velocity. Based on a dataset from a column study, Davison & Lerner (1998) argued that the instantaneous reaction assumption could apply to aerobic nitrification, but noted considerable uncertainty as to when this assumption may be valid.

The selection and application of an appropriate kinetic model for nitrification is complicated and suffers from a lack of relevant parameter data. When the effect of biodegradation modelling plays a critical role in determining the impact of NH_4^+ contamination, the justification for the kinetic model applied ought to be carefully made on the basis of appropriate site-specific data, but for screening purposes a simpler approach may be used.

Of equal importance is the method used to simulate biodegradation of contaminants sorbed to aquifer minerals. Many contaminant fate and transport methods assume that degradation of contaminants can occur in both sorbed and aqueous phases. However, sorption may affect the bioavailability of contaminants (Bosma *et al.* 1997) and it may therefore be necessary to model biodegradation using different rate constants for the dissolved and sorbed contaminant fractions (Zheng & Bennett 1995). In the extreme case, degradation may be inhibited by sorption and although sorption may reduce the apparent velocity of a contaminant plume in an aquifer, it will not reduce the concentration eventually observed at the receptor.

Indicative rates of nitrification under UK subsurface conditions

There are very few data on measured rates of nitrification in unsaturated subsoils and aquifers. It is evident from the literature that nitrification can play a significant role in controlling the concentrations of NH_4^+ in infiltrating water and contaminated groundwater. Aerobic nitrification is particularly important at plume margins, where the influx of oxygenated groundwater via dispersion is sufficient to support this process. However, the literature is contradictory on whether anaerobic NH_4^+ oxidation is a significant process in the subsurface, especially at high contaminant concentrations.

It is apparent from the literature that nitrification can occur in most formations, except where intergranular flow takes place through pore spaces too small to allow the access of microorganisms (an average pore diameter of <1 μm; Rees 1981). The dataset is insufficient to allow conclusions to be made on parameterization of kinetic models for nitrification in the subsurface. Estimated ranges for the first-order degradation half-life of NH_4^+ in UK subsoils and aquifers have been derived from the published literature (Table 3) but caution must be used in their application, as they are based on a very limited dataset and extrapolation from broader studies. With the present state of knowledge, it is not possible to provide more reliable guidance, and further research on subsurface nitrification under both aerobic and anaerobic conditions is essential. Although the rates of nitrification are slow, the long contaminant travel times that apply in many cases mean that indigenous nitrifiers may have the opportunity to achieve significant mass removal of NH_4^+ (Robinson 1992).

Conclusions

Significant attenuation of NH_4^+ contamination in subsoils and groundwater is predominantly due to cation exchange and/or nitrification (biological oxidation) processes. A literature review (Environment Agency 2003*b*), of which this paper is a summary, has provided a moderate amount of data on NH_4^+ sorption for a number of UK geological strata and engineered landfill liners. The degree of NH_4^+ attenuation is strongly dependent on the clay mineralogy of the strata and the chemical composition of the contaminated fluid. However, sufficient evidence was available to provide a range of partition coefficients for NH_4^+ in UK lithologies. The literature indicates that nitrification can be a significant mechanism for NH_4^+ attenuation in unsaturated subsoils under both aerobic and anaerobic conditions. However, in aquifers nitrification may be limited by the relatively low aqueous solubility of dissolved oxygen (maximum $10\,mg\,l^{-1}$ at standard temperature and pressure) and physical mixing by dispersion of the anaerobic NH_4^+ plume with aerobic groundwater.

Based on the limited literature available, estimates of the typical degradation rate and attenuation capacity under both aerobic and anaerobic conditions have been derived (Tables 2 and 3). These values may be helpful in the initial (screening) phases of risk assessment for landfills, sewage effluent disposal to land, and potentially contaminated sites. However, the ranges provided are indicative and site-specific data will always be preferred and will be necessary for more detailed risk assessments or when the conceptual model for the site under consideration does not match that from which the presented data originate. In such cases, it is recommended that more sophisticated reactive transport modelling should be undertaken using codes that

Table 3. *Estimated half-lives for NH_4^+ biodegradation (nitrification) in different subsurface lithologies under aerobic and anaerobic conditions.*

Lithology[1]	NH_4^+ half-life under aerobic conditions (years)[2]	NH_4^+ half-life under anaerobic conditions (years)[3]	Comments
Sands and gravels	1–6	∞	Based on range of literature-derived values (<1–6 years) in unsaturated subsoil and aquifers
Unfissured Chalk and other strata with mean pore size of <1 µm	∞	∞	No degradation; pore size excludes entry of bacteria
Strata with mean pore size of >1 µm or showing a significant degree of fissure flow[4]	5–10	∞	No kinetic data exist but attenuation has been demonstrated to take place. Suggested range (5–10 years) is considered reasonably conservative
Landfill liners	∞	∞	No data, but pore size may exclude entry of bacteria. Assume no degradation to ensure liner design suitably conservative

Estimated half-lives are taken from literature and extrapolated to representative systems, which must be consistent with the conceptual model to which the data are applied during risk assessments.

[1] Values are considered to apply equally to both the unsaturated and saturated zones.

[2] Where a range is given a uniform distribution is recommended for probabilistic modelling.

[3] It is assumed that no anaerobic NH_4^+ oxidation takes place unless site-specific data indicate otherwise.

[4] Where mean pore sizes in the matrix of dual porosity media are less than 1 µm (e.g. fissured Chalk) care should be taken that only the fraction of contaminant flowing in the fractures is degraded by the model used.

describe the fundamental ion-exchange reactions controlling NH_4^+ transport in natural porous media. This approach will provide a more accurate and robust prediction of NH_4^+ fate in the subsurface than that which can be achieved at present using partition coefficients.

The literature review has shown that there are few data on NH_4^+ sorption by cation exchange in UK subsoils and aquifer solids, and there is even less information on nitrification. Further evaluation and quantification of these processes *in situ* under UK conditions would be of significant benefit.

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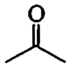
12.1.2 KETONES

12.1.2.1 Acetone



Common Name: Acetone
Synonym: 2-propanone, dimethylketone, DMK
Chemical Name: acetone, 2-propanone
CAS Registry No: 67-64-1
Molecular Formula: C_3H_6O, CH_3COCH_3
Molecular Weight: 58.079
Melting Point (°C):
 –94.7 (Lide 2003)
Boiling Point (°C):
 56.05 (Lide 2003)
Density (g/cm³ at 20°C):
 0.7899 (Weast 1982–83)
 0.7908 (Dean 1985)
Molar Volume (cm³/mol):
 73.5 (20°C, calculated-density)
 74.0 (calculated-Le Bas method at normal boiling point)
Enthalpy of Fusion ΔH_{fus} (kJ/mol):
 5.690 (Riddick et al. 1986)
Entropy of Fusion ΔS_{fus} (J/mol K):
Fugacity Ratio at 25°C (assuming ΔS_{fus} = 56 J/mol K), F: 1.0

Water Solubility (g/m³ or mg/L at 25°C or as indicated):
 miscible (20°C, Palit 1947)
 miscible (Dean 1985; Yaws et al. 1990)
 miscible (Riddick et al. 1986; Howard 1990)
 217700, 453000 (pseudo-solubilities, Staples 2000)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
 29610* (interpolated-regression of tabulated data, temp range –59.4 to 56.5°C, Stull 1947)
 $\log (P/\text{mmHg}) = 7.19038 - 1233.4/(230 + t/°\text{C})$ (Antoine eq., Dreisbach & Martin 1949)
 30490 (Perry 1950)
 51854* (37.68°C, temp range 37.68–56.02°C, Brown & Smith 1957)
 30800 (Buttery et al. 1969)
 30810 (Hoy 1970)
 29923* (24.330°C, temp range –12.949 to 55.285°C, Boublik & Aim 1972; quoted, Boublik et al. 1984)
 $\log (P/\text{mmHg}) = [-0.2185 \times 10577.7/(T/K)] + 9.143231$; temp range –20 to 96°C (Antoine eq., Weast 1972–73)
 30780, 30800 (calculated-Antoine eq., Boublik et al. 1973)
 $\log (P/\text{mmHg}) = 7.15853 - 1231.232/(231.766 + t/°\text{C})$; temp range 37.6–56.02°C (Antoine eq. from reported exptl. data of Brown & Smith 1957, Boublik et al. 1973)
 $\log (P/\text{mmHg}) = 7.11714 - 1210.595/(229.664 + t/°\text{C})$; temp range –12.95 to 55.3°C (Antoine eq. from reported exptl. data, Boublik et al. 1973)
 30810* (ebulliometry, fitted to Antoine eq., measured range 259–350.9 K, Ambrose et al. 1974)
 $\log (P/\text{kPa}) = 6.25632 - 1217.904/(T/K - 42.692)$; temp range 311.7–350.9 K, or for pressure range 53–202 kPa (Antoine eq., ebulliometry, Ambrose et al. 1975a)
 $\log (P/\text{kPa}) = 6.25478 - 1216.689/(T/K - 42.875)$; temp range 259.17–350.9 K, or for pressure below 225 kPa (Antoine eq., ebulliometry, Ambrose et al. 1974)
 30870, 31520 (quoted exptl., calculated-Antoine eq., Boublik et al. 1984)

log (P/kPa) = 6.24039 – 1209.746/(229.574 + t/°C); temp range –12.95 to 55.3°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)
log (P/kPa) = 6.26017 – 1214.208/(230.002 + t/°C); temp range –13.98 to 77.72°C (Antoine eq. from reported exptl. data of Ambrose et al. 1974, Boublik et al. 1984)
log (P/kPa) = 6.28185 – 1230.342/(231.665 + t/°C); temp range 37.6–56.02°C (Antoine eq. from reported exptl. data of Brown & Smith 1957, Boublik et al. 1984)
30780 (calculated-Antoine eq., Dean 1985)
log (P/mmHg) = 7.11714 – 1210.595/(229.664 + t/°C), temp range: liquid (Antoine eq., Dean 1985, 1992)
24227, 30806 (20, 25°C, Riddick et al. 1986)
log (P/kPa) = 6.25478 – 1216.589/(230.275 + t/°C), temp range not specified (Antoine eq., Riddick et al. 1986)
30730 (interpolated-Antoine eq.-V, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.24204 – 1210.6/(–43.49 + T/K); temp range 261–329 K (Antoine eq.-I, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.75622 – 1566.69/(0.269 + T/K); temp range 329–488 K (Antoine eq.-II, Stephenson & Malanowski 1987)
log (P_L/kPa) = 3.6452 – 469.5/(–108.21 + T/K); temp range 178–243 K (Antoine eq.-III, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.19735 – 1190.382/(–45.373 + T/K); temp range 203–269 K (Antoine eq.-IV, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.26483 – 1221.852/(–42.388 + T/K); temp range 257–334 K (Antoine eq.-V, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.24554 – 1211.515/(–43.471 + T/K); temp range 323–379 K (Antoine eq.-VI, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.69966 – 1542.465/(0.447 + T/K); temp range 374–464 K (Antoine eq.-VII, Stephenson & Malanowski 1987)
log (P/mmHg) = $28.5884 - 2.469 \times 10^3/(T/K) - 7.351 \cdot \log (T/K) + 2.8025 \times 10^{-10} \cdot (T/K) + 2.7361 \times 10^{-6} \cdot (T/K)^2$; temp range 178–508 K (vapor pressure eq., Yaws 1994)

Henry's Law Constant (Pa m^3/mol at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
3.34 (partial pressure, Butler & Ramchandani 1935)
3.96 (shake flask, partial vapor pressure-GC, Burnett 1963)
3.25 (28°C, concn. ratio-GC, Nelson & Hoff 1968)
3.97 (shake flask, partial vapor pressure-GC, Buttery et al. 1969)
4.02, 3.93, 2.91 (exptl., calculated-group contribution, calculated-bond contribution, Hine & Mookerjee 1975)
4.05 (headspace-GC, Vitenberg et al. 1975)
4.10 (calculated-activity coeff and vapor pressure, γ·P, Rathbun & Tai 1982)
0.908, 3.93 (0, 25°C, headspace-GC, Snider & Dawson 1985)
3.38 (review, Gaffney et al. 1987)
2.928* (gas-stripping-HPLC-UV, measured range 10–45°C, Zhou & Mopper 1990)
ln [K_H'/(M/atm)] = –5.00 + 1977/(T/K); temp range 10–45°C (gas stripping-HPLC measurements, freshwater, Zhou & Mopper 1990)
ln [K_H'/(M/atm)] = –3.60 + 1518/(T/K); temp range 25–45°C (gas stripping-HPLC measurements, seawater (salinity 35 ± 1l), Zhou & Mopper 1990)
3.07* (gas stripping-GC, measured range –14.9 to 44.9°C, Betterton 1991)
4.33 (computed, Yaws et al. 1991)
0.722, 1.26, 2.045, 5.31, 7.514 (0.51, 9.0, 16.11, 31, 38.51°C, headspace-GC, de-ionized water, Benkelberg et al. 1995)
3.735* (headspace-GC, rain water, measured range –30 to 39.51°C, Benkelberg et al. 1995)
0.762, 2.19, 6.64, 10.30 (0, 14.51, 30, 39.51°C, headspace-GC, artificial seawater, Benkelberg et al. 1995)
ln (k_H/atm) = (18.4 ± 0.3) – (5386 ± 100)/(T/K), temp range 10–40°C (headspace-GC measurements, Benkelberg et al. 1995)
2.56 (20°C, selected from literature experimentally measured data, Staudinger & Roberts 1996)
9.92 (EPICS-GC, Ayuttaya et al. 2001)
2.58 (20°C, selected from literature experimentally measured data, Staudinger & Roberts 2001)
log K_{AW} = 3.742 – 1965/(T/K) (van't Hoff eq. derived from literature data, Staudinger & Roberts 2001)

Octanol/Water Partition Coefficient, log K_{OW}:

−0.24	(shake flask-CR, Collander 1951)
−0.24	(shake flask at pH 7, Unger et al. 1978)
−0.48	(shake flask-GC, Tanii et al. 1986)
−0.24	(recommended, Sangster 1989, 1993)
−0.31	(CPC centrifugal partition chromatography, Gluck & Martin 1990)
−0.37	(calculated-UNIFAC activity coeff., Dallos et al. 1993)
−0.24	(recommended, Hansch et al. 1995)

Octanol/Air Partition Coefficient, log K_{OA}:

2.31	(head-space GC, Abraham et al. 2001)

Bioconcentration Factor, log BCF:

−0.187	(calculated, Staples 2000)

Sorption Partition Coefficient, log K_{OC}:

−0.586	(calculated-K_{OW}, Kollig 1993)
−0.523	(quoted calculated value, Staples 2000)

Environmental Fate Rate Constants, k, or Half-Lives, $t_{½}$:

Volatilization: using Henry's law constant, $t_{½}$ = 20 h was estimated for a model river 1 m deep flowing at 1 m/s with a wind velocity of 3 m/s (Lyman et al. 1982; quoted, Howard 1990).

Photolysis: rate constant k = 1.4×10^{-5} s^{-1} in the atmosphere (Carlier et al. 1986); calculated lifetime τ ~ 60 d in air (Atkinson 2000)

Oxidation: rate constant k, for gas-phase second order rate constants, k_{OH} for reaction with OH radical, k_{NO3} with NO_3 radical and k_{O3} with O_3 or as indicated, *data at other temperatures and/or Arrhenius expression see reference:

photooxidation $t_{½}$ = 11.3–453 yr, based on measured data for the reaction with hydroxyl radical in aqueous solution (Dorfman & Adams 1973; selected, Howard et al. 1991)

photooxidation $t_{½}$ > 9.9 d for the gas-phase reaction with hydroxyl radical in air, based on the rate of disappearance of hydrocarbon due to reaction with hydroxyl radical (Darnall et al. 1976)

$k_{OH} = (0.23 \pm 0.03) \times 10^{-12}$ cm^3 $molecule^{-1}$ s^{-1} at 300 K (flash photolysis-resonance fluorescence, Zetzsch 1982; quoted, Atkinson 1985)

$k_{OH} = (0.62 \pm 0.09) \times 10^{-12}$ cm^3 $molecule^{-1}$ s^{-1} at 298 K (relative rate technique to *n*-hexane, Chiorboli et al. 1983; quoted, Atkinson 1985)

k = 0.032 ± 0.006) M^{-1} s^{-1} for the reaction with ozone in water using 1 mM propyl alcohol as scavenger at pH 2 and 20–23°C (Hoigné & Bader 1983)

k_{OH}(calc) = 2.2×10^{-13} cm^3 $molecule^{-1}$ s^{-1}, k_{OH}(obs.) = 2.3×10^{-13} cm^3 $molecule^{-1}$ s^{-1} at room temp. (SAR structure-activity relationship, Atkinson 1985)

photooxidation $t_{½}$ = 279–2790 h, based on measured data for the vapor-phase reaction with hydroxyl radical in air (Atkinson 1985; selected, Howard et al. 1991)

$k_{OH} = 2.16 \times 10^{-13}$ cm^3 $molecule^{-1}$ s^{-1} at 296 K and k = 1.80×10^{-13} cm^3 $molecule^{-1}$ s^{-1} for the aqueous-phase reaction with hydroxyl radical in solution (Wallington & Kurylo 1987)

$k_{OH} = 2.16 \times 10^{-13}$ cm^3 $molecule^{-1}$ s^{-1}; k(soln) = 1.8×10^{-13} cm^3 $molecule^{-1}$ s^{-1} for reaction with OH radical in aqueous solution (Wallington et al. 1988)

$k_{OH}{}^{*} = 2.26 \times 10^{-11}$ cm^3 $molecule^{-1}$ s^{-1} at 298 K (recommended, Atkinson 1989)

k_{OH}(calc) = 0.18×10^{-12} cm^3 $molecule^{-1}$ s^{-1} (molecular orbital calculations, Klamt 1996)

Hydrolysis:

Biodegradation: biodegradation rate constants, k = 0.016–0.020 h^{-1} in 30 mg/L activated sludge after a time lag of 20–25 h (Urano & Kato 1986b);

$t_{½}$(aq. aerobic) = 24–168 h, based on unacclimated aqueous screening test data (Bridie et al. 1979; Dore et al. 1975; selected, Howard et al. 1991);

$t_{½}$(aq. anaerobic) = 96–672 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991);

k(exptl) = 0.0440 h^{-1} compared to predicted rate constants by group contribution method: k = 0.0433 h^{-1} (nonlinear) and k = 0.043 h^{-1} (linear) (Tabak & Govind 1993).

Biotransformation:

Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants:

Half-Lives in the Environment:

Air: $t_{1/2}$ > 9.9 d for the gas-phase reaction with hydroxyl radical in air, based on the rate of disappearance of hydrocarbon due to reaction with hydroxyl radical (Darnall et al. 1976);

photooxidation $t_{1/2}$ = 279–2790 h, based on measured data for the vapor-phase reaction with hydroxyl radical in air (Howard et al. 1991);

calculated lifetimes τ = 53 d and τ > 11 yr for reactions with OH radical, NO_3 radical, respectively (Atkinson 2000);

photooxidation and photolysis $t_{1/2}$ = 36 h (Staples 2000).

Surface water: photooxidation $t_{1/2}$ = 11.3–453 yr, based on measured data for the reaction with hydroxyl radicals in aqueous solution (Dorfman & Adams 1973; quoted, Howard et al. 1991);

$t_{1/2}$ = 24–168 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991);

aerobic biodegradation $t_{1/2}$ = 96–168 h (Staples 2000).

Ground water: $t_{1/2}$ = 48–336 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Sediment: anaerobic biodegradation $t_{1/2}$ = 384 h or 16 d (Staples 2000).

Soil: $t_{1/2}$ = 24–168 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991);

aerobic biodegradation $t_{1/2}$ = 96–168 h (Staples 2000).

Biota:

TABLE 12.1.2.1.1

Reported vapor pressures of acetone at various temperatures and the coefficients for the vapor pressure equations

$\log P = A - B/(T/K)$ (1)

$\log P = A - B/(C + t/°C)$ (2)

$\log P = A - B/(C + T/K)$ (3)

$\log P = A - B/(T/K) - C \cdot \log(T/K)$ (4)

$\ln P = A - B/(T/K)$ (1a)

$\ln P = A - B/(C + t/°C)$ (2a)

1.

Stull 1947		**Brown & Smith 1957**		**Boublik & Aim 1972**			
summary of literature data		**Austr. J. Chem. 10, 423-**		**ref. in Boublik et al. 1984***			
t/°C	**P/Pa**	**t/°C**	**P/Pa**	**t/°C**	**P/Pa**	**t/°C**	**P/Pa**
−59.4	133.3	37.68	51854	−12.949	4524	36.649	49704
−40.5	666.6	41.58	60127	−5.424	6967	42.094	61295
−31.1	1333	44.96	68271	−0.103	9306	48.344	77125
−20.8	2666	45.0	68367	4.882	12046	55.285	98572
−9.40	5333	47.01	73603	8.666	14549	bp/°C	56.102
−2.0	7999	49.31	79969	13.019	17921	Antoine eq.	
7.7	13332	51.91	87727	16.831	21314	eq. 2	P/kPa
22.7	26664	56.02	101199	20.939	25780	A	6.24039
39.5	53329			24.330	29923	B	1209.746
56.5	101325			28.351	35493	C	229.574
				32.138	41470		
mp/°C	−94.6						

*ref. Collection Czech. Chem. Commun 37, 3513 (1972)

TABLE 12.1.2.1.1 *(Continued)*

2.

Ambrose et al. 1974			
comparative ebulliometry			
t/°C	P/Pa	t/°C	P/Pa
		cont'd	
−13.975	4257	55.876	100666
−11.019	5076	56.646	103344
−8.106	6005	60.963	119433
−4.982	7186	64.859	135602
−1.388	8691	69.512	157101
0.288	9497	73.943	180024
1.972	10376	77.724	201571
2.007	10391	25.0	30806
5.493	12417		
5.511	12432	eq. 3	P/kPa
9.077	14840	A	6.25478
9.093	14851	B	1216.689
12.473	17480	C	−42.875
16.928	21525		
20.717	25544		
25.045	30867	Ambrose et al 1975a	
29.275	36912		
33.720	44267	bp/°C	56.067
28.601	53675		
42.834	63079	eq. 3	P/kPa
47.320	74449	A	6.25632
52.170	88536	B	1217.904
		C	−42.692
		equation for vapor pressures below 200 kPa	
		ΔH_V/(kJ mol^{-1}) =	
		at 25°C	31.3
		at bp	29.6

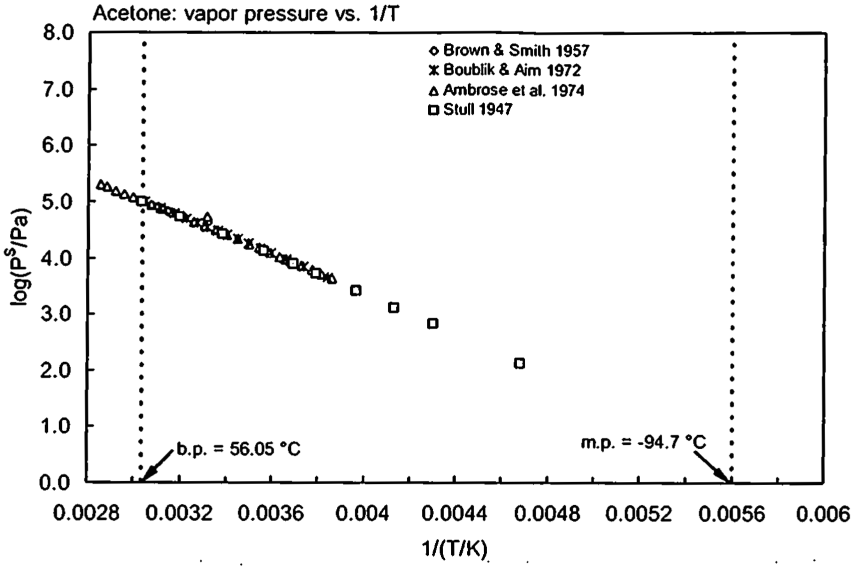


FIGURE 12.1.2.1.1 Logarithm of vapor pressure versus reciprocal temperature for acetone.

TABLE 12.1.2.1.2
Reported Henry's law constants of acetone at various temperatures and temperature dependence equations

$\ln K_{AW} = A - B/(T/K)$ (1) $\log K_{AW} = A - B/(T/K)$ (1a)
$\ln (1/K_{AW}) = A - B/(T/K)$ (2) $\log (1/K_{AW}) = A - B/(T/K)$ (2a)
$\ln (k_H/atm) = A - B/(T/K)$ (3)
$\ln [H/(Pa\ m^3/mol)] = A - B/(T/K)$ (4) $\ln [H/(atm{\cdot}m^3/mol)] = A - B/(T/K)$ (4a)
$K_{AW} = A - B{\cdot}(T/K) + C{\cdot}(T/K)^2$ (5)

1.

Snider & Dawson 1985		Zhou & Mopper 1990				Betterton 1991	
gas stripping-GC/FID		gas stripping-HPLC/UV		gas stripping-HPLC/UV		gas stripping-GC/FID	
t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)
			fresh water		sea water		
0	0.908	10	1.421	10	1.735	14.9	2.303
25	3.935	17	-	17	2.356	25	3.070
		25	2.846	25	3.311	25	3.269
		30	3.658	30	4.037	25	3.897
enthalpy of transfer		35	4.585	35	4.825	25	3.753
ΔH =	37.24 kJ/mol	40	-	40	5.537	25	3.958
		45	6.178	45	6.846	35.1	7.794
						44.9	11.92
		eq. 1a	K_H'/(M/atm)	eq. 1a	k_H'/(M/atm)		
		A	−5.00	A	−3.60		
		B	−1977	B	−1518		

TABLE 12.1.2.1.2 *(Continued)*

2.

Benkelberg et al. 1995

equilibrium vapor phase concentration-headspace GC

t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)
	deionized water		rain water
0.51	0.7222	–28.0	0.742
9.0	1.260	25.0	3.735
16.61	2.0445	39.51	8.328
31.0	5.313		
38.51	7.514		artificial sea water
		0	0.757
for deionized and rain water:		14.51	2.189
eq. 3	k_H/atm	30.0	6.639
A	18.4 ± 0.3	39.51	10.305
B	5286 ± 100		

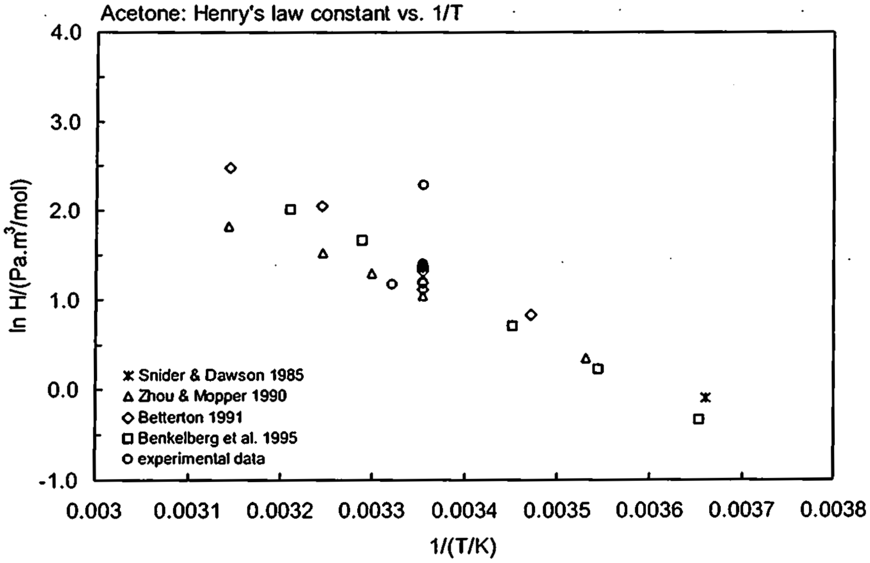
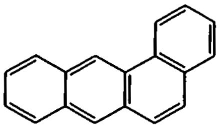


FIGURE 12.1.2.1.2 Logarithm of Henry's law constant versus reciprocal temperature for acetone.

4.1.1.39 Benz[a]anthracene



Common Name: Benz[*a*]anthracene
Synonym: 1,2-benzanthracene, 2,3-benzophenanthrene, naphthanthracene, BaA, B(*a*) a, tetraphene
Chemical Name: 1,2-benzanthracene
CAS Registry No: 56-55-3
Molecular Formula: $C_{18}H_{12}$
Molecular Weight: 228.288
Melting Point (°C):
160.5 (Lide 2003)
Boiling Point (°C):
438 (Lide 2003)
Density (g/cm^3 at 20°C):
1.2544 (Mailhot & Peters 1988)
Molar Volume (cm^3/mol):
211.8 (Ruelle & Kesselring 1997; Passivirta et al. 1999)
248.3 (calculated-Le Bas method at normal boiling point)
Enthalpy of Fusion, ΔH_{fus} (kJ/mol):
21.38 (Ruelle & Kesselring 1997; Chickos et al. 1999)
Entropy of Fusion, ΔS_{fus} (J/mol K):
49.23, 44.1 (exptl., calculated-group additivity method, Chickos et al. 1999)
49.2 (Passivirta et al. 1999)
Fugacity Ratio at 25°C (assuming ΔS_{fus} = 56 J/mol K), F: 0.0468 (mp at 160.5°C)
0.040 (calculated, assuming ΔS_{fus} = 56 J/mol K, Mackay et al. 1980)
0.0661 (calculated, ΔS_{fus} = 49.2 J/mol K, Passivirta et al. 1999)

Water Solubility (g/m^3 or mg/L at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
0.011 (27°C, shake flask-nephelometry, Davis & Parker 1942)
0.010 (shake flask-UV, Klevens 1950)
0.014 (shake flask-fluorescence, Mackay & Shiu 1977)
0.0094, 0.0122 (25, 29°C, generator column-HPLC/UV, May et al. 1978b)
$S/(\mu g/kg) = 1.74 + 0.1897\cdot(t/°C) + 0.0031\cdot(t/°C)^2 + 0.0003\cdot(t/°C)^3$, temp range 5–30°C (generator column-HPLC/UV, May et al. 1978b, May 1980)
0.044 (shake flask-nephelometry, Hollifield 1979)
0.00837* (generator column-HPLC, measured range 6.9–29.7°C, May 1980)
0.0086* (generator column-HPLC, measured range 6.9–29.7°C, May et al. 1983)
0.00935* (generator column-fluo., measured range 10–30°C, Velapoldi et al. 1983)
0.011 (average lit. value, Pearlman et al. 1984)
0.0168 (generator column-HPLC/fluorescence, Walters & Luthy 1984)
0.00854 (generator column-HPLC/UV, measured range 3.7–25.0°C, Whitehouse 1984)
0.011 (recommended, IUPAC Solubility Data Series, Shaw 1989)
0.0146 (shake flask-HPLC, Haines & Sandler 1995)
0.0130 (generator column-HPLC/fluorescence, De Maagd et al. 1998)
$\log [S_L/(mol/L)] = -0.326 - 1119/(T/K)$ (supercooled liquid, Passivirta et al. 1999)
$\ln x = -3.060466 - 5354.51/(T/K)$, temp range 5–50°C (regression eq. of literature data, Shiu & Ma 2000)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
2.93×10^{-6} (20°C, Hoyer & Peperle 1958)
$\log (P/mmHg) = 13.68 - 6250/(T/K)$; temp range 60–120°C (Knudsen effusion method, Hoyer & Peperle 1958)

2.17×10^{-5} (solid, extrapolated from Antoine eq., Kelley & Rice 1964; quoted, Bidleman 1984)
log (P/mmHg) = 11.528 – 5461/(T/K); temp range: 104–127°C (effusion method, Kelley & Rice 1964)
3.87×10^{-7} (effusion method, Wakayama & Inokuchi 1967)
1.47×10^{-5} (solid, effusion method, extrapolated-Antoine eq., Murray et al. 1974)
log (P/mmHg) = 10.045 – 5929/(T/K); temp range: 330–390 K (effusion method, Murray et al. 1974)
6.67×10^{-7} (20°C, effusion, Pupp et al. 1974)
7.30×10^{-6}* (effusion method, De Kruif 1980)
2.71×10^{-5}* (gas saturation-HPLC/fluo./UV, Sonnefeld et al. 1983)
log (P/Pa) = 9.684 – 4246.51/(T/K); temp range 10–50°C (solid, Antoine eq., Sonnefeld et al. 1983)
0.00107, 0.0003 (P_{GC} by GC-RT correlation, different GC columns, Bidleman 1984)
0.000543 (supercooled liquid P_L, converted from literature P_S with ΔS_{fus} Bidleman 1984)
2.49×10^{-4} (Yamasaki et al. 1984)
4.10×10^{-6} (selected, Howard et al. 1986)
1.51×10^{-5}, 2.17×10^{-5} (extrapolated-Antoine eq., Stephenson & Malanowski 1987)
log (P_S/kPa) = 12.0507 – 5925/(T/K); temp range 330–390 K (solid, Antoine eq.-I, Stephenson & Malanowski 1987)
log (P_S/kPa) = 10.653 – 5461/(T/K); temp range 377–400 K (solid, Antoine eq-II., Stephenson & Malanowski 1987)
5.43×10^{-4} (supercooled P_L, converted from literature P_S, Hinckley et al. 1990)
0.00107, 3.23×10^{-4} (P_{GC} by GC-RT correlation with different reference standards, Hinckley et al. 1990)
log P_L/Pa = 12.63 – 4742/(T/K) (GC-RT correlation, Hinckley et al. 1990)
2.51×10^{-4} (supercooled liquid P_L, calculated from Yamasaki et al. 1984, Finizio et al. 1997)
$(4.11–281) \times 10^{-7}$; 2.76×10^{-5} (P_S, quoted exptl., effusion; gas saturation, Delle Site 1997)
3.39×10^{-5}; 5.29×10^{-5}, 1.48×10^{-5}, 2.57×10^{-5} (P_S, quoted lit., calculated; GC-RT correlation, Delle Site 1997)
5.47×10^{-4}; 3.59×10^{-5} (quoted supercooled liquid P_L from Hinckley et al. 1990; converted to solid P_S with fugacity ratio F, Passivirta et al. 1999)
log (P_S/Pa) = 11.91 – 4858/(T/K) (solid, Passivirta et al. 1999)
log (P_L/Pa) = 9.34 – 3760/(T/K) (supercooled liquid, Passivirta et al. 1999)
log (P/Pa) = 9.683 – 4246.51/(T/K); temp range 5–50°C (regression eq. from literature data, Shiu & Ma 2000)

Henry's Law Constant (Pa m³/mol at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):

0.813	(gas stripping-GC, Southworth 1979)
0.102	(headspace solid-phase microextraction (SPME)-GC, Zhang & Pawliszyn 1993)
1.22*	(gas stripping-GC; measured range 4.1–31°C, Bamford et al. 1999)

ln K_{AW} = –7986.53/(T/K) + 19.124, ΔH = 66.4 kJ mol⁻¹, measured range 4.1–31°C (gas stripping-GC, Bamford et al. 1999)
log (H/(Pa m³/mol)) = 9.67 – 2641/(T/K) (Passivirta et al. 1999)

Octanol/Water Partition Coefficient, log K_{OW} at 25°C and the reported temperature dependence equations:

5.61	(Radding et al. 1976)
5.66	(Leo 1986; quoted, Schüürmann & Klein 1988)
5.79	(HPLC-RT correlation, Wang et al. 1986)
5.91	(recommended, Sangster 1989, 1993)
5.84	(TLC retention time correlation, De Voogt et al. 1990)
5.79	(recommended, Hansch et al. 1995))

5.54 ± 0.19, 5.50 ± 0.64 (HPLC-k′ correlation: ODS column; Diol column, Helweg et al. 1997)

5.91	(range 5.74–6.04) (shake flask/slow stirring-HPLC/fluorescence, De Maagd et al. 1998)
5.75	(shake flask-SPME solid-phase micro-extraction, Paschke et al. 1999)

5.33; 4.98 (calibrated GC-RT correlation; GC-RT correlation, Lei et al. 2000)
log K_{OW} = 1.238 + 1216.89/(T/K); temp range 5–55°C (temperature dependence HPLC-k′ correlation, Lei et al. 2000)

Octanol/Air Partition Coefficient, log K_{OA}:

9.50	(calculated-K_{OW}/K_{AW}, Wania & Mackay 1996)
9.54	(calculated, Finizio et al. 1997)

Bioconcentration Factor, log BCF:

4.56 (Smith et al. 1978; Steen & Karickhoff 1981)

4.0 (*Daphnia pulex*, Southworth et al. 1978)

4.0 (fathead minnow, Veith et al. 1979)

4.56, 5.0 (bacteria, Baughman & Paris 1981)

4.39 (activated sludge, Freitag et al. 1984)

4.0 (*Daphnia pulex*, correlated as per Mackay & Hughes 1984, Howell & Connell 1986)

4.39, 3.50, 2.54 (activated sludge, algae, fish, Freitag et al. 1985)

4.01 (*Daphnia magna*, Newsted & Giesy 1987)

4.303, 4266 (calculated-molecular connectivity indices, calculated-K_{OW}, Lu et al. 1999)

Sorption Partition Coefficient, log K_{OC}:

4.52 (22°C, suspended particulates, Herbes et al. 1980)

6.30 (sediments average, Kayal & Connell 1990)

7.30 (Baltic Sea particulate field samples, concn distribution-GC/MS, Broman et al. 1991)

5.62 (humic acid, HPLC-k′ correlation; Nielsen et al. 1997)

5.77 (5.73–5.80), 5.47 (5.44–5.50) (sediments: Lake Oostvaardersplassen, Lake Ketelmeer, shake flask-HPLC/UV, de Maagd et al. 1998)

5.20 (soil, calculated-universal solvation model; Winget et al. 2000)

5.63–7.53; 4.50–6.70 (range, calculated from sequential desorption of 11 urban soils; lit. range, Krauss & Wilcke 2001)

5.11; 6.33, 5.84, 6.18 (20°C, batch equilibrium, A2 alluvial grassland soil; calculated values of expt 1,2,3-solvophobic approach, Krauss & Wilcke 2001)

Environmental Fate Rate Constants, k or Half-Lives, $t_{1/2}$:

Volatilization: aquatic fate rate $k = 8 \times 10^{3}$ h^{-1} with $t_{1/2} \sim 90$ h (Callahan et al. 1979);

half-lives predicted by one compartment model: $t_{1/2} > 1000$ h in stream, eutrophic pond or lake and oligotrophic lake (Smith et al. 1978);

calculated $t_{1/2} = 500$ h for a river of 1-m deep with water velocity of 0.5 m/s and wind velocity of 1 m/s (Southworth 1979; quoted, Herbes et al. 1980; Hallett & Brecher 1984).

Photolysis: aquatic fate rate $k \sim 6 \times 10^{-5}$ s^{-1} with $t_{1/2} = 10–50$ h (Callahan et al. 1979)

$t_{1/2} = 20$ h in stream, $t_{1/2} = 50$ h in eutrophic pond or lake and $t_{1/2} = 10$ h in oligotrophic lake, predicated by one compartment model (Smith et al. 1978)

direct photochemical transformation $t_{1/2}$(calc) = 0.59 h, computed near-surface water, latitude 40°N, midday, midsummer and photolysis $t_{1/2} = 3.7$ d and 9.2 d in 5-m deep inland water body without and with sediment-water partitioning, respectively, to top cm of bottom sediment over full summer day, 40°N (Zepp & Schlotzhauer 1979)

$t_{1/2} = 0.58$ h in aquatics (quoted of EPA Report 600/7-78-074, Haque et al. 1980)

$t_{1/2} = 0.2$ d for early day in March (Mill et al. 1981);

$k = 1.93$ h^{-1} (Zepp 1980; quoted, Mill & Mabey 1985)

$k = 13.4 \times 10^{-5}$ s^{-1} in early March with $t_{1/2} = 5$ h in pure water at 366 nm, in sunlight at 23–28°C and $k = 2.28 \times 10^{-5}$ s^{-1} at 313 nm with 1% acetonitrile in filter-sterilized natural water (Mill et al. 1981);

$k = 1.39$ h^{-1} for summer midday at 40°N latitude (quoted, Mabey et al. 1982)

$t_{1/2} = 1–3$ h, atmospheric and aqueous photolysis half-life, based on measured photolysis rate constant for midday March sunlight on a cloudy day (Smith et al. 1978; quoted, Harris 1982; Howard et al. 1991) and adjusted for approximate summer and winter sunlight intensity (Lyman et al. 1982; quoted, Howard et al. 1991)

half-lives on different atmospheric particulate substrates (approx. 25 µg/g on substrate): $t_{1/2} = 4.0$ h on silica gel, $t_{1/2} = 2.0$ h on alumina and $t_{1/2} = 38$ h on fly ash (Behymer & Hites 1985)

first order daytime decay $k = 0.0125$ min^{-1} for soot particles loading of 1000–2000 ng/mg and $k = 0.0250$ min^{-1} for soot particles loading of 30–350 ng/mg (Kamens et al. 1988)

photodegradation $k = 0.0251$ min^{-1} with $t_{1/2} = 0.46$ h in ethanol-water (2:3, v/v) solution for initial concentration of 12.5 ppm by high pressure mercury lamp or sunlight (Wang et al. 1991)

pseudo-first-order direct photolysis k(exptl) = 0.0251 min^{-1} with the calculated $t_{1/2} = 0.46$ h and the predicted $k = 0.0245$ min^{-1} calculated by QSPR method in aqueous solution when irradiated with a 500 W medium pressure mercury lamp (Chen et al. 1996) direct photolysis $t_{½}$(obs) = 0.94 h, $t_{½}$(calc) = 0.89 h predicted by QSPR method in atmospheric aerosol (Chen et al. 2001)

Photodegradation $k = 5.0 \times 10^{-4}$ s^{-1} in surface water during the summertime at mid-latitude (Fasnacht & Blough 2002)

Oxidation: half-lives predicted by one compartment model: $t_{½}$ = 38 h in stream, eutrophic pond or lake and oligotrophic lake based on peroxy radical concentration of 10^{-9} M (Smith et al. 1978)

aquatic fate rate $k = 5 \times 10^{3}$ M^{-1} s^{-1} with $t_{½}$ = 38 h (Callahan et al. 1979);

$t_{½}$ = 6400 h for photosensitized oxygenation with singlet oxygen at near-surface natural water, 40°N, midday, midsummer (Zepp & Schlotzhauer 1979)

$k = 5 \times 10^{8}$ M^{-1} h^{-1} for singlet oxygen and 2×10^{4} M^{-1} h^{-1} for peroxy radical (Mabey et al. 1982)

$k = 3.3 \times 10^{-4}$ h^{-1} with $t_{½}$ = 0.6 h under natural sunlight conditions; k(aq.) = 5.0×10^{3} M^{-1} h^{-1} with $t_{½}$ = 1.6 d for free-radical oxidation in air-saturated water (NRCC 1983)

photooxidation $t_{½}$ = 0.801–8.01 h, based on estimated rate constant for reaction with hydroxyl radical in air (Howard et al. 1991);

photooxidation $t_{½}$ = 77–3850 h in water, based on measured rate constant for reaction with hydroxyl radical in water (Howard et al. 1991)

Hydrolysis: not hydrolyzable (Mabey et al. 1982); no hydrolyzable groups (Howard et al. 1991).

Biodegradation: not observed during enrichment procedures (Smith et al. 1978)

no significant degradation in 7 d for an average of three static-flask screening test (Tabak et al. 1981)

$k = 3.3 \times 10^{-3}$ h^{-1} with $t_{½}$ = 208 h for mixed bacterial populations in stream sediment (NRCC 1983)

$k = 1.0 \times 10^{-4}$ h^{-1} with $t_{½}$ = 288 d; $k = 4.0 \times 10^{-6}$ h^{-1} with $t_{½}$ = 20 yr for mixed bacterial populations in oil-contaminated and pristine stream sediments (NRCC 1983)

k = 0.0026 d^{-1} with $t_{½}$ = 261 d for Kidman sandy loam and k = 0.0043 d^{-1} with $t_{½}$ = 162 d for McLarin sandy loam all at –0.33 bar soil moisture (Park et al. 1990)

$t_{½}$(aq.aerobic) = 2448–16320 h, based on aerobic soil dieaway test data at 10–30°C (Howard et al. 1991)

$t_{½}$(aq. anaerobic) = 9792–65280 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Biotransformation: rate constant estimated to be 1×10^{-10} mL $cell^{-1}$ h^{-1} for bacteria (Mabey et al. 1982).

Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants:

$k_1 = 669$ h^{-1}; $k_2 = 0.144$ h^{-1} (*Daphnia pulex*, Southworth et al. 1978)

log $k_1 = 2.83$ h^{-1}; log $k_2 = -0.84$ h^{-1} (*Daphnia pulex*, correlated as per Mackay & Hughes 1984, Hawker & Connell 1986)

$k_1 = 138.6$ mL g^{-1} h^{-1}; $k_2 = 0.0022$ h^{-1} (4°C, *P. hoyi*, Landrum 1988)

$k_1 = 0.72–1.4$ mg g^{-1} h^{-1}; $k_2 = 0.0096$ h^{-1} (freshwater oligochaete from sediment, Van Hoof et al. 2001)

Half-Lives in the Environment:

Air: $t_{½}$ = 1–3 h, based on estimated photolysis half-life in air (Howard et al. 1991);

$t_{½}$ = 4.20 h under simulated sunlight, $t_{½}$ = 1.35 h in simulated sunlight + ozone (0.2 ppm), $t_{½}$ = 2.88 h in dark reaction ozone (0.2 ppm), under simulated atmospheric conditions (Katz et al. 1979)

$t_{½}$ = 0.4 h for adsorption on soot particles in an outdoor Teflon chamber with an estimated rate constant k = 0.0265 min^{-1} at 1 cal cm^{-2} min^{-1}, 10 g/m^3 H_2O and 20°C (Kamens et al. 1988).

Surface water: photolysis $t_{½}$ = 0.59 h near surface water, $t_{½}$ = 3.7 d and 9.2 d in 5-m deep water body without and with sediment-water partitioning in full summer day, 40°N; photosensitized oxygenation $t_{½}$ = 2.6 h at near surface water, 40°N, midday, midsummer (Zepp & Schlotzhauer 1979)

$t_{½}$ = 0.20 d under summer sunlight (Mill & Mabey 1985);

$t_{½}$ = 1–3 h, based on estimated photolysis half-life in water, Howard et al. 1991);

photolysis $t_{½}$ = 0.46 h (reported in units of minutes) in aqueous solution when irradiated with a 500 W medium pressure mercury lamp (Chen et al. 1996).

Groundwater: $t_{½}$ = 4896–32640 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Sediment: The uptake clearance from sediment was k = (0.005 ± 0.001)g of dry sediment·g^{-1} of organism·h^{-1}, and the elimination rate constants k = (0.0014 ± 0006)h^{-1} for amphipod, *P. hoyi* in Lake Michigan sediments at 4°C (Landrum 1989);

desorption $t_{½}$ = 11.1 d from sediment under conditions mimicking marine disposal (Zhang et al. 2000).

Soil: $t_{½}$ = 4–6250 d (Sims & Overcash 1983; quoted, Bulman et al. 1987);

$t_{½}$ = 240 d for 5 mg/kg treatment and 130 d for 50 mg/kg treatment (Bulman et al. 1987);
biodegradation k = 0.0026 d^{-1} with $t_{½}$ = 261 d for Kidman sandy loam soil, and k = 0.0043 d^{-1} with $t_{½}$ = 162 d for McLaurin sandy loam soil (Park et al. 1990);
$t_{½}$ ~ 2448–16320 h, based on aerobic die-away test data at 10–30°C (Howard et al. 1991);
$t_{½}$ > 50 d (Ryan et al. 1988).

Biota: depuration $t_{½}$ = 9 d by oysters (Lee et al. 1978);
elimination $t_{½}$ = 4.3–17.8 d from mussel *Mytilus edulis*; $t_{½}$ = 7–15.4 d from Oyster, $t_{½}$ = 8.0 d from clam *Mercenario mercenaria* (quoted, Meador et al. 1995).

TABLE 4.1.1.39.1

Reported aqueous solubilities of benz[a]anthracene at various temperatures and reported temperature dependence equation

$S/(\mu g/kg) = a \cdot t^3 + b \cdot t^2 + c \cdot t + d$ (1)

$\ln x = A + B/(T/K) + C \cdot \ln (T/K)$ (2)

May 1980		May et al. 1978b		May et al. 1983		Velapoldi et al. 1983	
generator column-HPLC		generator column-HPLC		generator column-HPLC		generator column-fluo.	
t/°C	$S/g \cdot m^{-3}$	t/°C	$S/g \cdot m^{-3}$	t/°C	$S/g \cdot m^{-3}$	t/°C	$S/g \cdot m^{-3}$
6.9	0.00299	25	0.0094	6.9	0.00299	10	0.00342
10.7	0.00378	29	0.0.0122	10.7	0.00378	15	0.00475
14.3	0.00479			11.0	0.00361	20	0.00669
19.3	0.00633			14.7	0.00558	25	0.00935
23.1	0.00837	temp dependence eq. 1		18.1	0.00634	30	0.01297
29.7	0.0127	S	µg/kg	19.3	0.00801		
		a	0.0003	23.6	0.00838		
temp dependence eq. 1		b	–0.0031	25.0	0.00862	eq. 2	mole fraction
S	µg/kg	c	0.1897	29.5	0.0124	A	–83.75982
a	0.0003	d	1.74	29.7	0.0127	B	41884.5
b	–0.0031					C	161.175
c	0.1897	$\Delta H_{sol}/(kJ\ mol^{-1})$ = 44.81					
d	1.74	measured between 5–30°C				$\Delta H_{sol}/(kJ\ mol^{-1})$ = 49.0	
							at 25°C
$\Delta H_{sol}/(kJ\ mol^{-1})$ = 44.81							
measured between 5–30°C							

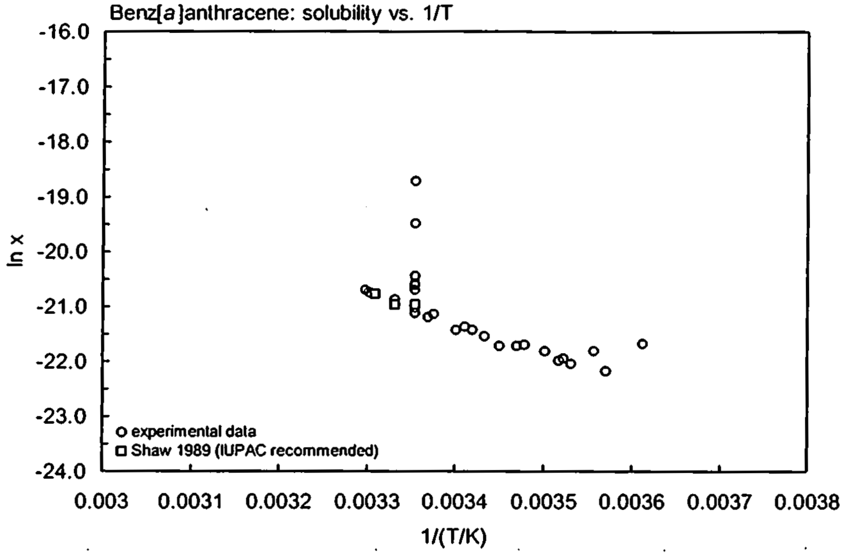


FIGURE 4.1.1.39.1 Logarithm of mole fraction solubility (ln *x*) versus reciprocal temperature for benz[*a*]anthracene.

TABLE 4.1.1.39.2
Reported vapor pressures of benz[a]anthracene at various temperatures and the coefficients for the vapor pressure equations

$\log P = A - B/(T/K)$	(1)	$\ln P = A - B/(T/K)$	(1a)
$\log P = A - B/(C + t/°C)$	(2)	$\ln P = A - B/(C + t/°C)$	(2a)
$\log P = A - B/(C + T/K)$	(3)		
$\log P = A - B/(T/K) - C\cdot\log(T/K)$	(4)		

Kelley & Rice 1964		Murray et al. 1972		de Kruif 1980		Sonnefeld et al. 1983	
effusion-electrobalance		Knudsen effusion		torsion-, effusion method		generator column-HPLC	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
data represented by		data presented by graph and		98.07	0.1	13.81	8.05×10^{-5}
		eq. 2	P/atm	105.21	0.2	13.81	6.06×10^{-5}
eq. 1	P/mmHg	A	10.045	109.51	0.3	13.81	1.13×10^{-5}
A	11.528	B	5925	112.62	0.4	25.1	2.66×10^{-5}
B	5461	temp range 330–390 K		115.06	0.5	25.1	2.56×10^{-5}
measured range 104–127°C				117.09	0.6	25.1	2.81×10^{-5}
$\Delta H_{subl}/(kJ\ mol^{-1}) = 104.56$				118.82	0.7	40.12	1.39×10^{-4}
		$\Delta H_{subl}/(kJ\ mol^{-1}) = 113.5$		120.32	0.8	40.12	1.41×10^{-4}
mp/°C	160–161.5			121.66	0.9	40.12	1.36×10^{-4}
				122.87	1.0	40.75	1.31×10^{-4}
				25.0	7.3×10^{-6}	40.85	1.17×10^{-4}
					extrapolated	40.85	1.27×10^{-4}
						40.85	1.21×10^{-4}
Hoyer & Peperle 1958				$\Delta H_{sub}/(kJ\ mol^{-1}) = 113$		49.56	3.87×10^{-4}
effusion method						49.56	3.85×10^{-4}
t/°C	**P/Pa**					49.56	3.88×10^{-4}
						34.93	2.69×10^{-4}
data presented by equation.						25.0	2.80×10^{-5}

(*Continued*)

TABLE 4.1.1.39.2 (*Continued*)

Kelley & Rice 1964		Murray et al. 1972		de Kruif 1980		Sonnefeld et al. 1983	
effusion-electrobalance		Knudsen effusion		torsion-, effusion method		generator column-HPLC	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
eq. 1	P/mmHg					eq. 1	P/Pa
A	13.68					A	9.684
B	6250					B	4246.51
for temp range 60–120°C						$\Delta H_{subl}/(kJ\ mol^{-1}) = 51.83$	
						for temp range 10–50°C	

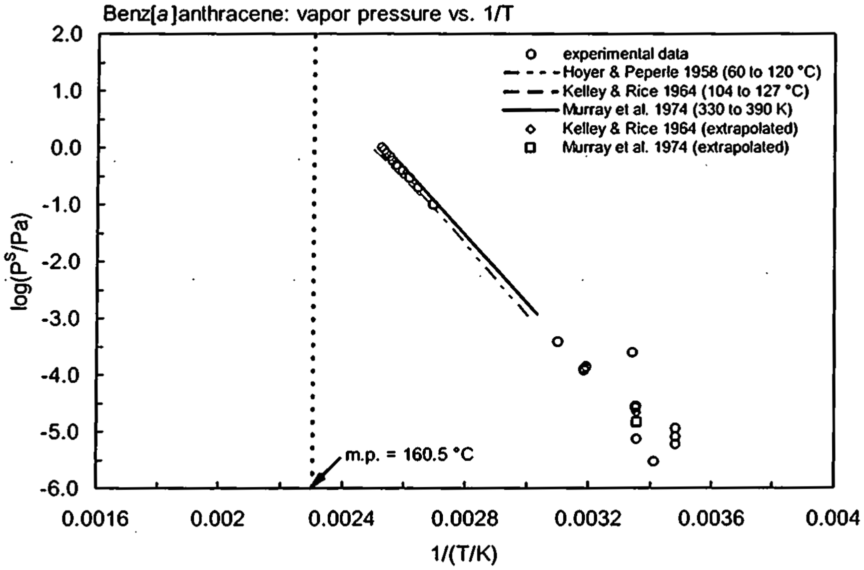


FIGURE 4.1.1.39.2 Logarithm of vapor pressure versus reciprocal temperature for benz[a]anthracene.

TABLE 4.1.1.39.3
Reported Henry's law constants of benz[a]anthracene at various temperatures and temperature dependence equations

$\ln K_{AW} = A - B/(T/K)$ (1) $\log K_{AW} = A - B/(T/K)$ (1a)
$\ln (1/K_{AW}) = A - B/(T/K)$ (2) $\log (1/K_{AW}) = A - B/(T/K)$ (2a)
$\ln (k_H/atm) = A - B/(T/K)$ (3)
$\ln [H/(Pa\ m^3/mol)] = A - B/(T/K)$ (4) $\ln [H/(atm{\cdot}m^3/mol)] = A - B/(T/K)$ (4a)
$K_{AW} = A - B{\cdot}(T/K) + C{\cdot}(T/K)^2$ (5)

Bamford et al. 1999		
gas stripping-GC/MS		
t/°C	H/(Pa m³/mol)	H/(Pa m³/mol)
		average
4.1	0.10, 0.22	0.15
11.0	0.24, 0.41	0.31
18.0	0.50, 0.79	0.63
25.0	0.91, 1.64	1.22
31.0	1.43, 3.13	2.11

$\ln K_{AW} = A - B/(T/K)$

TABLE 4.1.1.39.3 (*Continued*)

	Bamford et al. 1999	
	gas stripping-GC/MS	
t/°C	H/(Pa m³/mol)	H/(Pa m³/mol)
A	19.124	
B	7986.5	
enthalpy, entropy change:		
$\Delta H/(kJ{\cdot}mol^{-1}) = 66.4 \pm 6.9$		
$\Delta S/(J{\cdot}K^{-1}\ mol^{-1}) = 159$		
	at 25°C	

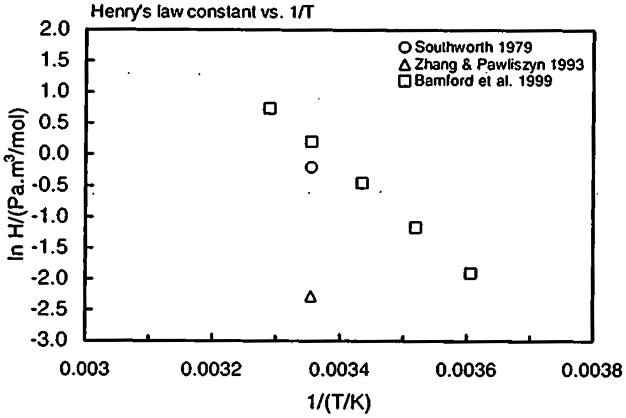
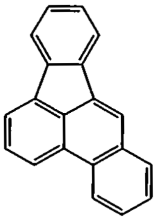


FIGURE 4.1.1.39.3 Logarithm of Henry's law constant versus reciprocal temperature for benz[*a*]anthracene.

4.1.1.40 Benzo[*b*]fluoranthene



Common Name: Benzo[*b*]fluoranthene
Synonym: 2,3-benzofluoranthene, 3,4-benzofluoranthene, benz[*e*]acephenanthrylene, B[*b*]F
Chemical Name: 2,3-benzofluoranthene
CAS Registry No: 205-99-2
Molecular Formula: $C_{20}H_{12}$
Molecular Weight: 252.309
Melting Point (°C):
168 (Bjørseth 1983; Pearlman et al. 1984; Lide 2003)
Boiling Point (°C):
481 (Bjørseth 1983)
Density (g/cm^3 at 20°C):
Molar Volume (cm^3/mol):
222.8 (Ruelle & Kesselring 1997; Passivirta et al. 1999)
268.9 (calculated-Le Bas method at normal boiling point)
Enthalpy of Fusion, ΔH_{fus} (kJ/mol):
Entropy of Fusion, ΔS_{fus} (J/mol K):
56.5 (Passivirta et al. 1999)
Fugacity Ratio at 25°C (assuming ΔS_{fus} = 56 J/mol K), F: 0.0395 (mp at 168°C)

Water Solubility (g/m^3 or mg/L at 25°C or as indicated and reported temperature dependence equations):
0.0015 (generator column-HPLC/fluorescence, Wise et al. 1981)
0.0015 (average lit. value, Pearlman et al. 1984)
0.00109 (generator column-HPLC/fluo., De Maagd et al. 1998)
$\log [S_L/(mol/L)] = -0.351 - 1303/(T/K)$ (supercooled liquid, Passivirta et al. 1999)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations):
6.67×10^{-5} (20°C, estimated, Callahan et al. 1979)
2.12×10^{-5} (Yamasaki et al. 1984)
5.0×10^{-8}; 1.30×10^{-6} (quoted solid P_S from Mackay et al. 1992; converted to supercooled liquid P_L with fugacity ratio F, Passivirta et al. 1999)
$\log (P_S/Pa) = 12.43 - 5880/(T/K)$ (solid, Passivirta et al. 1999)
$\log (P_L/Pa) = 9.48 - 4578/(T/K)$ (supercooled liquid, Passivirta et al. 1999)
7.55×10^{-6} (supercooled liquid P_L, calibrated GC-RT correlation, Lei et al. 2002)
$\log (P_L/Pa) = -4682/(T/K) + 10.58$, $\Delta H_{vap.} = -89.7\ kJ \cdot mol^{-1}$ (GC-RT correlation, Lei et al. 2002)

Henry's Law Constant (Pa m^3/mol at 25°C or as indicated and reported temperature dependence equations.):
0.051 (20°C, gas stripping-HPLC/fluorescence, measured range 10–55°C, ten Hulscher et al. 1992)
$\log [H/(Pa\ m^3/mol)] = 9.83 - 3274/(T/K)$ (Passivirta et al. 1999)
0.0485 (20°C, selected from reported experimentally measured values, Staudinger & Roberts 1996, 2001)
$\log K_{AW} = 2.955 - 2245/(T/K)$, (van't Hoff eq. derived from literature data, Staudinger & Roberts 2001)

Octanol/Water Partition Coefficient, $\log K_{OW}$:
5.78 (HPLC-RT correlation, Wang et al. 1986)
5.78 (recommended, Sangster 1989, 1993)

Octanol/Air Partition Coefficient, log K_{OA}:

Bioconcentration Factor, log BCF:

5.15 (microorganisms-water, Mabey et al. 1982)
4.00 (*Daphnia magna*, Newsted & Giesy 1987)
0.959, 0.230 (*Polychaete sp, Capitella capitata*, Bayona et al. 1991)

Sorption Partition Coefficient, log K_{OC} at 25°C or as indicated:

6.182; 6.00, 6.18 (sediment: concn ratio C_{sed}/C_W; concn-based coeff., areal-based coeff. of flux studies of sediment/water boundary layer, Helmstetter & Alden 1994)
5.45 (log K_{DOC} - Aldrich humic acid, RP-HPLC, Ozretich et al. 1995)
6.57 (10°C), 6.55, 6.61 (20°C), 6.26 (35°C), 6.44, 6.45 (45°C) (log K_{DOC}, dissolved organic material from lake, gas-purge technique-HPLC/fluorescence, Lüers & ten Hulscher 1996)
6.20 (20°C, log K_{DOC}, particulate organic material from lake, Lüers & ten Hulscher 1996)
6.15–8.02; 5.70–7.50 (range, calculated from sequential desorption of 11 urban soils; lit. range, Krauss & Wilcke 2001, for benzo[*b* + *j* + *k*]fluoranthenes)
5.91; 6.50, 6.26, 6.68 (20°C, batch equilibrium, A2 alluvial grassland soil; calculated values of expt 1,2,3-solvophobic approach, Krauss & Wilcke 2001, for benzo[*b* + *j* + *k*]fluoranthenes)

Environmental Fate Rate Constants, k or Half-Lives, $t_{½}$:

Volatilization:

Photolysis: atmospheric and aqueous $t_{½}$ = 8.7–720 h, based on measured rate of photolysis in heptane irradiated with light > 290 nm (Howard et al. 1991);

first order daytime decay rate constants: k = 0.0065 min^{-1} for 1000–2000 ng/mg soot particles loading and k = 0.0090 min^{-1} with 30–350 ng/mg loading (Kamens et al. 1988);

$t_{½}$(obs.) = 4.31 h, $t_{½}$(calc) = 1.49 h predicted by QSPR in atmospheric aerosol (Chen et al. 2001)

Photodegradation k = 3×10^{-5} s^{-1} in surface water during the summertime at mid-latitude (Fasnacht & Blough 2002).

Oxidation: rate constant k = 4×10^7 M^{-1} h^{-1} for singlet oxygen and k = 5×10^3 M^{-1} h^{-1} for peroxy radical (Mabey et al. 1982);

photooxidation $t_{½}$ = 1.43–14.3 h, based on estimated rate constant for reaction with hydroxyl radical in air (Howard et al. 1991).

Hydrolysis: not hydrolyzable (Mabey et al. 1982; no hydrolyzable groups (Howard et al. 1991).

Biodegradation:

aerobic $t_{½}$ = 8640–14640 h, based on aerobic soil die-away test data (Coover & Sims 1987; quoted, Howard et al. 1991);

k = 0.0024 d^{-1} with $t_{½}$ = 294 d for Kidman sandy loam and k = 0.0033 d^{-1} with $t_{½}$ = 211 d for McLarin sandy loam all at –0.33 bar soil moisture (Park et al. 1990);

$t_{½}$(aq. anaerobic) = 34560–58560 h, based on estimated unacclimated aqueous aerobic degradation half-life (Howard et al. 1991).

Biotransformation: estimated to be 3×10^{-12} mL $cell^{-1}$ h^{-1} for bacteria (Mabey et al. 1982).

Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants:

k_1 = 0.11–0.38 mg g^{-1} h^{-1}; k_2 = 0.0029 h^{-1} (freshwater oligochaete from sediment, Van Hoof et al. 2001)

Sorption-Desorption Rate constants: desorption rate constant k = 0.016 d^{-1} with $t_{½}$ = 42.4 d from sediment under conditions mimicking marine disposal (Zhang et al. 2000).

Half-Lives in the Environment:

Air: $t_{½}$ = 1.43–14.3 h, based on estimated photooxidation half-life in air (Howard et al. 1991)

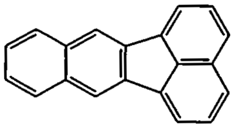
half-lives under simulated atmospheric conditions: simulated sunlight – $t_{½}$ = 8.70 h, simulated sunlight + ozone (0.2 ppm) $t_{½}$ = 4.20 h, dark reaction ozone (0.2 ppm) $t_{½}$ = 52.70 h (Katz et al. 1979; quoted, Bjørseth & Olufsen 1983);

$t_{½}$ = 1.3 h for adsorption on soot particles in an outdoor Teflon chamber with an estimated rate constant k = 0.0091 min^{-1} at 1 cal cm^{-2} min^{-1}, 10 g/m^3 H_2O and 20°C (Kamens et al. 1988).

Surface water: $t_{½}$ = 8.7–720 h, based on estimated aqueous photolysis half-life (Lane & Katz 1977; Muel & Saguem 1985; quoted, Howard et al. 1991).

Groundwater: $t_{1/2}$ = 17280–29280 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).
Sediment: desorption $t_{1/2}$ = 42.4 d from sediment under conditions mimicking marine disposal (Zhang et al. 2000).
Soil: biodegradation rate constant k = 0.0024 d^{-1} with $t_{1/2}$ = 294 d for Kidman sandy loam soil, and k = 0.0033 d^{-1} with $t_{1/2}$ = 211 d for McLaurin sandy loam soil (Park et al. 1990);
$t_{1/2}$ = 8640–14640 h, based on aerobic die-away test data (Coover & Sims 1987; quoted, Howard et al. 1991);
$t_{1/2}$ = 42 wk, 9.0 yr (quoted, Luddington soil, Wild et al. 1991).
Biota: elimination $t_{1/2}$ = 5.7–16.9 d from mussel *Mytilus edulis*; $t_{1/2}$ = 7.7 d from Oyster (isomer unspecified), $t_{1/2}$ = 3.9 d from clam *Mercenario mercenaria* (isomer unspecified) (quoted, Meador et al. 1995).

4.1.1.42 Benzo[*k*]fluoranthene



Common Name: Benzo[*k*]fluoranthene
Synonym: 8,9-benzofluoranthene, 11,12-benzofluoranthene, B[*k*]F
Chemical Name: 8,9-benzofluoranthene
CAS Registry No: 207-08-9
Molecular Formula: $C_{20}H_{12}$
Molecular Weight: 252.309
Melting Point (°C):
217 (Weast 1977; Bjørseth 1983; Stephenson & Malanowski 1987; Lide 2003)
Boiling Point (°C):
480 (Stephenson & Malanowski 1987; Lide 2003)
Density (g/cm^3 at 20°C):
Molar Volume (cm^3/mol):
222.8 (Ruelle & Kesselring 1997; Passivirta et al. 1999)
268.9 (calculated-Le Bas method at normal boiling point)
Enthalpy of Fusion, ΔH_{fus} (kJ/mol):
Entropy of Fusion, ΔS_{fus} (J/mol K):
56.6 (Passivirta et al. 1999)
Fugacity Ratio at 25°C (assuming ΔS_{fus} = 56 J/mol K), F: 0.0131 (mp at 217°C)
0.0126 (calculated, Passivirta et al. 1999)

Water Solubility (g/m^3 or mg/L at 25°C and reported temperature dependence equations):
0.0008 (generator column-HPLC/UV, Wise et al. 1981)
0.00081 (average lit. value, Pearlman et al. 1984)
0.00109 (generator column-HPLC/fluorescence, De Maagd et al. 1998)
$\log [S_L/(\text{mol/L})] = -0.351 - 1448/(T/K)$ (supercooled liquid, Passivirta et al. 1999)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations):
1.28×10^{-8} (20°C, Radding et al. 1976)
6.70×10^{-5} (20°C, Mabey et al. 1982)
2.07×10^{-5} (Yamasaki et al. 1984)
5.20×10^{-8}, 4.93×10^{-6} (20°C, lit. mean solid P_S, supercooled liquid value P_L, Bidleman & Foreman 1987)
1.29×10^{-7} (extrapolated, Antoine eq., Stephenson & Malanowski 1987)
$\log (P_S/\text{kPa}) = 12.8907 - 6792/(T/K)$; temp range 363–430 K (Antoine eq., Stephenson & Malanowski 1987)
2.09×10^{-5} (supercooled liquid P_L, calculated from Yamasaki et al. 1984, Finizio et al. 1997)
5.20×10^{-8}; 4.14×10^{-6} (quoted solid P_S from Mackay et al. 1992; converted to supercooled liquid P_L with fugacity ratio F, Passivirta et al. 1999)
$\log (P_S/\text{Pa}) = 12.43 - 5874/(T/K)$ (solid, Passivirta et al. 1999)
$\log (P_L/\text{Pa}) = 9.48 - 4427/(T/K)$ (supercooled liquid, Passivirta et al. 1999)
8.96×10^{-6} (supercooled liquid P_L, calibrated GC-RT correlation, Lei et al. 2002)
$\log (P_L/\text{Pa}) = -4623/(T/K) + 10.46$; $\Delta H_{vap.} = -88.5$ kJ·mol^{-1} (GC-RT correlation, Lei et al. 2002)

Henry's Law Constant (Pa m^3/mol at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
0.111 (15°C, calculated, Baker & Eisenreich 1990)
0.043* (20°C, gas stripping-HPLC/fluorescence, measured range 10–55°C, ten Hulscher et al. 1992)
$\log (H/(\text{Pa m}^3/\text{mol})) = 9.83 - 2979/(T/K)$ (Passivirta et al. 1999)
0.0422 (20°C, selected from reported experimentally measured values, Staudinger & Roberts 1996, 2001)
$\log K_{AW} = 3.498 - 2421/(T/K)$ (van't Hoff eq. derived from literature data, Staudinger & Roberts 2001)

Octanol/Water Partition Coefficient, log K_{OW}:

6.84	(calculated-fragment const., Callahan et al. 1979)
6.06	(calculated-f const., Mabey et al. 1982)
6.44	(calculated-MCI χ as per Rekker & De Kort 1979)
6.40	(Bayona et al. 1991)
6.50	(calculated-S and mp, Capel et al. 1991)
7.20	(calculated-K_{OC}, Broman et al. 1991)
6.00	(selected, Mackay et al. 1992; quoted, Finizio et al. 1997)
6.30	(computed-expert system SPARC, Kollig 1995)
6.50–6.85; 6.73	(quoted lit. range; lit. mean, Meador et al. 1995)
6.11	(range 5.86–6.28) (shake flask/slow stirring-HPLC/fluo., De Maagd et al. 1998)
5.94; 6.16	(quoted lit.; calculated, Passivirta et al. 1999)

Octanol/Air Partition Coefficient, log K_{OA}:

11.19	(calculated, Finizio et al. 1997)

Bioconcentration Factor, log BCF:

5.15	(microorganisms-water, calculated from K_{OW}, Mabey et al. 1982)
4.12	(*Daphnia magna*, Newsted & Giesy 1987)

Sorption Partition Coefficient, log K_{OC} at 25°C or as indicated:

5.99 (sediments average, Kayal & Connell 1990)

7.00 (Baltic Sea particulate field samples, concn distribution-GC/MS, Broman et al. 1991)

6.80 (10°C), 6.74, 6.89 (20°C), 6.46 (35°C), 6.44, 6.45 (45°C) (log K_{DOC} - dissolved organic material from lake, gas-purge technique- HPLC/fluorescence, Lüers & ten Hulscher 1996)

6.30 (20°C, log K_{POC} - particulate organic material from lake, Lüers & ten Hulscher 1996)

6.04 (5.93–6.12), 5.47 (5.39–5.54) (sediments: Lake Oostvaardersplassen, Lake Ketelmeer, shake flask-HPLC/UV, de Maagd et al. 1998)

6.15–8.02; 5.70–7.50 (range, calculated from sequential desorption of 11 urban soils; lit. range, Krauss & Wilcke 2001, for benzo[*b* + *j* + *k*]fluoranthenes)

5.91; 6.50, 6.26, 6.68 (20°C, batch equilibrium, A2 alluvial grassland soil; calculated values of expt 1, 2, 3-solvophobic approach, Krauss & Wilcke 2001, for benzo[*b* + *j* + *k*]fluoranthenes)

Environmental Fate Rate Constants, k or Half-Lives, $t_{1/2}$:

Volatilization:

Photolysis: atmospheric and aqueous photolysis $t_{1/2}$ = 3.8–499 h, based on measured rate of photolysis in heptane under November sunlight and adjusted by ratio of sunlight photolysis half-lives in water versus heptane (Howard et al. 1991);

first-order daytime decay constants: $k = 0.0047\ \text{min}^{-1}$ for soot particles loading of 1000–2000 ng/mg and $k = 0.0013\ \text{min}^{-1}$ with 30–350 ng/mg loading (Kamens et al. 1988);

direct photolysis $t_{1/2}$(obs) = 0.88 h, $t_{1/2}$(calc) = 0.80 h predicted by QSPR in atmospheric aerosol (Chen et al. 2001)

Photodegradation $k = 3 \times 10^{-5}\ \text{s}^{-1}$ in surface water during the summertime at mid-latitude (Fasnacht & Blough 2002)

Oxidation: rate constant $k = 4 \times 10^{7}\ \text{M}^{-1}\ \text{h}^{-1}$ for singlet oxygen and $k = 5 \times 10^{3}\ \text{M}^{-1}\ \text{h}^{-1}$ for peroxy radical (Mabey et al. 1982);

photooxidation $t_{1/2}$ = 1.1–11 h, based on estimated rate constant for reaction with hydroxyl radical in air (Howard et al. 1991).

Hydrolysis: not hydrolyzable (Mabey et al. 1982);

no hydrolyzable groups (Howard et al. 1991).

Biodegradation:

aerobic $t_{1/2}$ = 21840–51360 h, based on aerobic soil die-away test data (Howard et al. 1991);

$t_{1/2}$(aq. anaerobic) = 87360–205440 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Biotransformation: estimated to be 3×10^{-12} mL $cell^{-1}$ h^{-1} for bacteria (Mabey et al. 1982).
Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants:

Half-Lives in the Environment:

Air: $t_{½}$ = 1.1–11 h, based on estimated photooxidation half-life in air (Howard et al. 1991);
$t_{½}$ = 14.10 h in simulated sunlight: $t_{½}$ = 3.90 h in simulated sunlight + ozone (0.2 ppm), $t_{½}$ = 34.90 h in dark reaction ozone (0.2 ppm) u) under simulated atmospheric conditions (Katz et al. 1979);
$t_{½}$ = 0.8 h for adsorption on soot particles in an outdoor Teflon chamber with an estimated rate constant k = 0.0138 min^{-1} at 1 cal cm^{-2} min^{-1} and 10 g/m^3 H_2O at 20°C (Kamens et al. 1988).
Surface water: $t_{½}$ = 3.8–499 h, based on photolysis half-life in water (Howard et al. 1991).
Groundwater: $t_{½}$ = 42680–102720 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).
Sediment: desorption $t_{½}$ = 23.2 d from sediment under conditions mimicking marine disposal (Zhang et al. 2000).
Soil: $t_{½}$ = 21840–51360 h, based on aerobic soil die-away test data Howard et al. 1991);
$t_{½}$ > 50 d (Ryan et al. 1988);
mean $t_{½}$ = 8.7 yr for Luddington soil (Wild et al. 1991).
Biota: elimination $t_{½}$ = 11.9 d from mussel *Mytilus edulis*; $t_{½}$ = 7.7 d from Oyster (isomer unspecified), $t_{½}$ = 3.9 d from clam *Mercenario mercenaria* (isomer unspecified) (quoted, Meador et al. 1995).

TABLE 4.1.1.42.1
Reported Henry's law constants of benzo[k]fluoranthene at various temperatures and temperature dependence equations

$\ln K_{AW} = A - B/(T/K)$ (1) $\log K_{AW} = A - B/(T/K)$ (1a)
$\ln (1/K_{AW}) = A - B/(T/K)$ (2) $\log (1/K_{AW}) = A - B/(T/K)$ (2a)
$\ln (k_H/atm) = A - B/(T/K)$ (3)
$\ln [H/(Pa\ m^3/mol)] = A - B/(T/K)$ (4) $\ln [H/(atm{\cdot}m^3/mol)] = A - B/(T/K)$ (4a)
$K_{AW} = A - B{\cdot}(T/K) + C{\cdot}(T/K)^2$ (5)

ten Hulscher et al. 1992

gas stripping-HPLC/fluorescence

t/°C	H/(Pa m³/mol)
10.0	0.022
20.0	0.043
35.0	0.107
40.1	0.138
45.0	0.198
55.0	0.403

$\ln K_{AW} = -\Delta H_{vol}/RT + \Delta S_{vol}/R$
R = 8.314Pa m^3 mol^{-1} K^{-1}
ΔS_{vol} 16.41
ΔH_{vol} 5893.7
enthalpy of volatilization:
$\Delta H_{vol}/(kJ{\cdot}mol^{-1}) = 49 \pm 1.9$
entropy of volatilization, ΔS
$T\Delta S_{vol}/(kJ{\cdot}mol^{-1}) = 40 \pm 4$
at 20°C

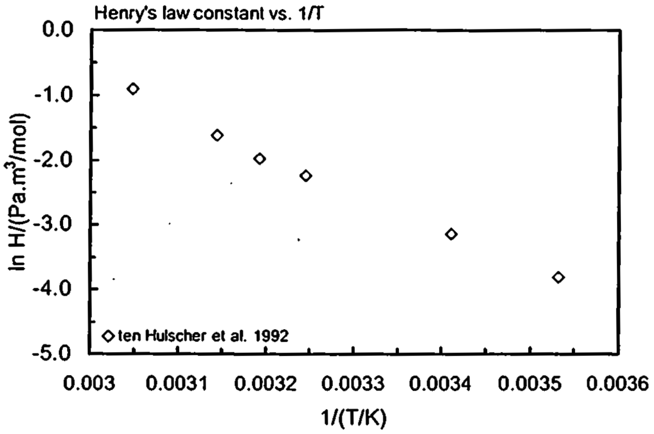
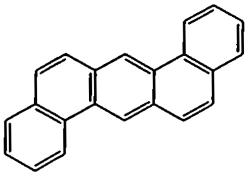


FIGURE 4.1.1.42.1 Logarithm of Henry's law constant versus reciprocal temperature for benzo[*k*]fluoranthrene.

4.1.1.52 Dibenz[*a,h*]anthracene



Common Name: Dibenz[*a,h*]anthracene
Synonym: DB[a,h]A, 1,2,5,6-dibenzanthracene, 1,2:5,6-dibenzanthracene
Chemical Name: 1,2:5,6-dibenzanthracene
CAS Registry No: 53-70-3
Molecular Formula: $C_{22}H_{14}$
Molecular Weight: 278.346
Melting Point (°C):
269.5 (Lide 2003)
Boiling Point (°C):
524 (Weast 1977)
Density (g/cm^3 at 20°C):
Molar Volume (cm^3/mol):
252.6 (Ruelle & Kesselring 1997; Passivirta et al. 1999)
299.9 (calculated-Le Bas method at normal boiling point)
Enthalpy of Fusion, ΔH_{fus} (kJ/mol):
31.165 (Ruelle & Kesselring 1997)
31.16 (exptl., Chickos et al. 1999)
Entropy of Fusion, ΔS_{fus} (J/mol K):
58.26, 44.0 (exptl., calculated-group additivity method, Chickos et al. 1999)
57.3 (Passivirta et al. 1999)
Fugacity Ratio at 25°C (assuming ΔS_{fus} = 56 J/mol K), F: 0.00399 (mp at 269.5°C)
0.00389 (calculated, Passivirta et al. 1999)

Water Solubility (g/m^3 or mg/L at 25°C or as indicated and the reported temperature dependence equations):
0.0005 (27°C, shake flask-nephelometry, Davis et al. 1942)
0.0006 (shake flask-UV, Klevens 1950)
0.0025 (shake flask-LSC, Means et al. 1980b)
0.00056 (lit. mean, Pearlman et al. 1984)
$\log [S_L/(\text{mol/L})] = -1.409 - 1631/(T/K)$ (supercooled liquid, Passivirta et al. 1999)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
1.33×10^{-8} (20°C, estimated, Callahan et al. 1979)
3.70×10^{-10}* (effusion method, De Kruif 1980)
$\log (P/Pa) = 16.049 - 7395.4/(T/K)$; temp range: 163–189°C (torsion-effusion, de Kruif 1980)
$\log (P/Pa) = 15.876 - 7312/(T/K)$; temp range: 163–189°C (weighing-effusion, de Kruif 1980)
$\log (P/Pa) = 15.962 - 7730/(T/K)$; temp range: 163–189°C (mean, de Kruif 1980)
4.25×10^{-10} (extrapolated-Antoine eq., Stephenson & Malanowski 1987)
$\log (P_S/kPa) = 12.515 - 7420/(T/K)$; temp range 403–513 K (Antoine eq., Stephenson & Malanowski 1987)
3.70×10^{-10}; 9.31×10^{-8} (quoted solid P_S from Mackay et al. 1992; converted to supercooled liquid P_L with fugacity ratio F, Passivirta et al. 1999)
$\log (P_S/Pa) = 12.82 - 5824/(T/K)$ (solid, Passivirta et al. 1999)
$\log (P_L/Pa) = 9.82 - 5002/(T/K)$ (supercooled liquid, Passivirta et al. 1999)
2.51×10^{-7} (supercooled liquid P_L, calibrated GC-RT correlation, Lei et al. 2002)
$\log (P_L/Pa) = -5193/(T/K) + 10.82$; $\Delta H_{vap.} = -99.4$ kJ·mol^{-1} (GC-RT correlation, Lei et al. 2002)

Henry's Law Constant (Pa m^3/mol at 25°C and reported temperature dependence equations):

0.0074 (calculated-P/C, Mabey et al. 1982)
0.0076 (calculated-P/C, Eastcott et al. 1988)
$\log [H/(\mathrm{Pa\ m^3/mol})] = 11.23 - 3371/(T/K)$, (Passivirta et al. 1999)

Octanol/Water Partition Coefficient, log K_{OW}:

6.50 (shake flask-LSC, Means et al. 1980b)
6.88 (HPLC-RT/MS, Burkhard et al. 1985)
5.80 (Hansch & Leo 1985)
6.75 ± 0.40 (recommended, Sangster 1989, 1993)
7.11 (TLC retention time correlation, De Voogt et al. 1990)
6.60 (shake flask-UV, pH 7.4, Alcorn et al. 1993)
6.50 (recommended, Hansch et al. 1995)
6.54 ± 0.19, 6.60 ± 0.78 (HPLC-k′ correlation: ODS column; Diol column, Helweg et al. 1997)

Octanol/Air Partition Coefficient, log K_{OA}:

Bioconcentration Factor, log BCF:

5.84 (microorganisms-water, calculated from K_{OW}, Mabey et al. 1982)
4.63 (activated sludge, Freitag et al. 1984)
3.38, 4.63, 1.0 (algae, activated sludge, fish, Freitag et al. 1985)
4.00 (*Daphnia magna*, Newsted & Giesy 1987)

Sorption Partition Coefficient, log K_{OC}:

6.31 (average of 14 soil/sediment samples, equilibrium sorption isotherms by shake flask-LSC, Means et al. 1980b)
6.22, 6.18 (calculated-regression of k_p versus substrate properties, calculated-K_{OW}, Means et al. 1980b)
6.22; 6.11, 5.30, 5.62 (quoted; calculated-K_{OW}, calculated-S and mp, calculated-S, Karickhoff 1981)
6.52 (calculated-K_{OW}, Mabey et al. 1982)
5.20 (calculated, Pavlou 1987)
6.31; 6.44; 3.75–5.77 (soil, quoted exptl.; calculated-MCI $^1\chi$, calculated-K_{OW} range, Sabljic 1987a,b)
5.77 (soil, calculated-K_{OW} based on model of Karickhoff et al. 1979, Sabljic 1987b)
5.66 (soil, calculated-K_{OW} based on model of Means et al. 1982, Sabljic 1987b)
4.60 (soil, calculated-K_{OW} based on model of Chiou et al. 1983, Sabljic 1987b)
4.61 (soil, calculated-K_{OW} based on model of Kenaga 1980, Sabljic 1987b)
3.75 (soil, calculated-K_{OW} based on model of Briggs 1981, Sabljic 1987b)
6.22 (calculated-MCI $^1\chi$, Sabljic et al. 1995)
6.44 (humic acid, HPLC-k′ correlation, Nielsen et al. 1997)
6.00; 6.30 (soil, calculated-universal solvation model; quoted exptl., Winget et al. 2000)
6.76–8.42; 5.80–8.50 (range, calculated from sequential desorption of 11 urban soils; lit. range, Krauss & Wilcke 2001)
6.03; 7.0, 6.76, 7.32 (20°C, batch equilibrium, A2 alluvial grassland soil; calculated values of expt 1,2,3-solvophobic approach, Krauss & Wilcke 2001)

Environmental Fate Rate Constants, k or Half-Lives, $t_{1/2}$:

Volatilization:

Photolysis: atmospheric and aqueous photolysis $t_{1/2}$ = 782 h, based on measured rate of photolysis in heptane under November sunlight (Muel & Saguim 1985; quoted, Howard et al. 1991) and $t_{1/2}$ = 6 h after adjusting the ratio of sunlight photolysis in water versus heptane (Smith et al. 1978; Muel & Saguem 1985; quoted, Howard et al. 1991);

pseudo-first-order direct photolysis rate constant k(exptl) = 0.014 min^{-1} with the calculated $t_{1/2}$ = 0.83 h and the predicted k = 0.0216 min^{-1} calculated by QSPR method in aqueous solution when irradiated with a 500 W medium pressure mercury lamp (Chen et al. 1996);

direct photolysis $t_{1/2}$(obs.) = 0.31 h, $t_{1/2}$ = 0.38 h predicted by QSPR method in atmospheric aerosol (Chen et al. 2001).

Oxidation: rate constant k = 5×10^8 M^{-1} h^{-1} for singlet oxygen and k = 1.5×10^4 M^{-1} h^{-1} for peroxy radical (Mabey et al. 1982);

photooxidation $t_{½}$ = 0.428–4.28 h, based on estimated rate constant for reaction with hydroxyl radical in air (Atkinson 1987; quoted, Howard et al. 1991).

Hydrolysis: not hydrolyzable (Mabey et al. 1982); no hydrolyzable groups (Howard et al. 1991).

Biodegradation: aerobic $t_{½}$ = 8664–22560 h, based on aerobic soil die-away test data (Coover & Sims 1987; Sims 1990; quoted, Howard et al. 1991);

k = 0.0019 d^{-1} with $t_{½}$ = 361 d for Kidman sandy loam and k = 0.0017 d^{-1} with $t_{½}$ = 420 d for McLarin sandy loam all at –0.33 bar soil moisture (Park et al. 1990).

Biotransformation: estimated to be 3×10^{-12} mL $cell^{-1}$ h^{-1} for bacteria (Mabey et al. 1982).

Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants:

Half-Lives in the Environment:

Air: half-lives under simulated atmospheric conditions: $t_{½}$ = 9.6 h in simulated sunlight, $t_{½}$ = 4.8 h in simulated sunlight + ozone (0.2 ppm), $t_{½}$ = 2.71 h in dark reaction ozone (0.2 ppm) (Katz et al. 1979; quoted, Bjørseth & Olufsen 1983);

$t_{½}$ = 0.428–4.28 h, based on estimated photooxidation half-life in air (Atkinson 1987; quoted, Howard et al. 1991).

Surface water: $t_{½}$ = 6–782 h, based on sunlight photolysis half-life in water (Smith et al. 1978; Muel & Saguem 1985; quoted, Howard et al. 1991);

photolysis $t_{½}$ = 0.83 h in aqueous solution when irradiated with a 500 W medium-pressure mercury lamp (Chen et al. 1996).

Groundwater: $t_{½}$ = 17328–45120 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Sediment:

Soil: biodegradation rate constant k = 0.0019 d^{-1} with $t_{½}$ = 361 d for Kidman sandy loam soil and k = 0.117 d^{-1} with $t_{½}$ = 420 d for McLaurin sandy loam soil (Park et al. 1990);

$t_{½}$ ~ 8664–22560 h, based on aerobic soil dieaway test data (Coover & Sims 1987; Sims 1990; quoted, Howard et al. 1991);

mean $t_{½}$ = 20.607 wk (quoted, Wild et al. 1991).

Biota:

TABLE 4.1.1.52.1
Reported vapor pressures of dibenz[a,h]anthracene at various temperatures and the coefficients for the vapor pressure equations

$\log P = A - B/(T/K)$ (1) $\ln P = A - B/(T/K)$ (1a)
$\log P = A - B/(C + t/°C)$ (2) $\ln P = A - B/(C + t/°C)$ (2a)
$\log P = A - B/(C + T/K)$ (3)
$\log P = A - B/(T/K) - C \cdot \log (T/K)$ (4)

de Kruif 1980	
torsion-, weighing effusion	
t/°C	P/Pa
160.38	0.1
168.21	0.2
172.93	0.3
176.33	0.4
179.01	0.5
181.22	0.6
183.11	0.7
184.76	0.8

TABLE 4.1.1.52.1 (*Continued*)

de Kruif 1980	
torsion-, weighing effusion	
t/°C	P/Pa
186.22	0.9
187.54	1.0
25.0	3.7×10^{-10} extrapolated
$\Delta H_{subl}/(kJ\ mol^{-1}) = 140.0$	

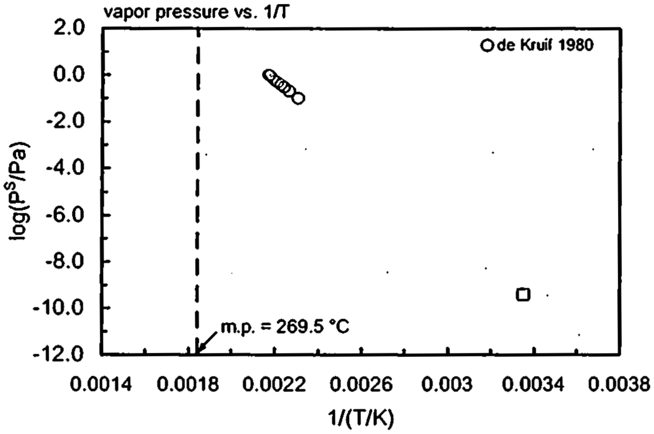
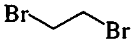


FIGURE 4.1.1.52.1 Logarithm of vapor pressure versus reciprocal temperature for dibenz[*a,h*]anthracene.

5.1.2.5 1,2-Dibromoethane



Common Name: 1,2-Dibromoethane
Synonym: ethylene bromide, ethylene dibromide, *sym*-dibromoethane, EDB
Chemical Name: 1,2-dibromoethane
CAS Registry No: 106-93-4
Molecular Formula: $C_2H_4Br_2$, CH_2BrCH_2Br
Molecular Weight: 187.861
Melting Point (°C):
  9.84 (Lide 2003)
Boiling Point (°C):
  131.6 (Lide 2003)
Density (g/cm^3 at 20°C):
  2.1792, 2.1688 (20°C, 25°C, Dreisbach 1959; Horvath 1982)
  2.1791, 2.1687 (20°C, 25°C, Riddick et al. 1986)
Molar Volume (cm^3/mol):
  86.25 (20°C, calculated-density, Stephenson & Malanowski 1987)
  98.4 (calculated-Le Bas method at normal boiling point)
Enthalpy of Vaporization, ΔH_V (kJ/mol):
  41.73, 36.35 (25°C, at bp, Riddick et al. 1986)
Enthalpy of Fusion, ΔH_{fus} (kJ/mol):
  10.03 (calculated, Dreisbach 1959)
  10.945 (quoted, Riddick et al. 1986)
Entropy of Fusion, ΔS_{fus} (J/mol K):
Fugacity Ratio at 25°C, F: 1.0

Water Solubility (g/m^3 or mg/L at 25°C or as indicated. Additional data at other temperatures designated * are compiled at the end of this section):
  3920, 4310 (15°C, 30°C, shake flask-interferometer, Gross & Saylor 1931)
  4040* (measured range 0–50°C, van Arkel & Vles 1936)
  4017 (Seidell 1940; quoted, Deno & Berkheimer 1960; Hine & Mookerjee 1975)
  8600 (shake flask-volumetric method, Booth & Everson 1948)
  4200 (measured by Dow Chemical, Dreisbach 1959)
  3510* (20°C, shake flask-GC, measured range 3–34°C, Chiou & Freed 1977)
  2910 (shake flask-GC, Jones et al. 1977/78)
  3520 (shake flask-GC, Chiou et al. 1979)
  4320, 4321 (20°C, 25°C, shake flask-GC, Mackay et al. 1980)
  4152* (summary of literature data, Horvath 1982)
  4310 (30°C, Verschueren 1983)
  4290 (30°C, selected, Riddick et al. 1986)
  3120 (shake flask-reverse phase polarography, Tokoro et al. 1988)
  4120*, 4310 (19.5°C, 30.7°C, shake flask-GC/TC, measured range 10.0–90.6°C, Stephenson 1992)
  4192 (20°C, limiting activity coeff. by equilibrium air stripping-GC, Hovorka & Dohnal 1997)
  3910* (tentative value, temp range 0–75°C. IUPAC-NIST Solubility Data Series, Hovath & Getzen 1999a)
  $S/(\text{wt}\%) = 3.8651 - 2.7921 \times 10^{-2} \cdot (T/K) + 5.45647 \times 10^{-5} \cdot (T/K)^2$, temp range 273–348 K (eq. derived from literature solubility data, Horvath & Getzen 1999a)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations):
  1333 (18.2°C, summary of literature data, temp range –27 to 131.1°C, Stull 1947)
  1560 (calculated-Antoine eq., Dreisbach 1959)
  $\log (P/\text{mmHg}) = 7.06245 - 1469.7/(220.0 + t/°C)$; temp range 43–215°C (Antoine eq. for liquid state, Dreisbach 1959)

log (P/mmHg) = [–0.2185 × 9229.4/(T/K)] + 7.93581; temp range –27 to 304°C (Antoine eq., Weast 1972–73)
1466, 2266 (20°C, 30°C, Verschueren 1983)
1626 (interpolated-Antoine eq., Boublik et al. 1984)
log (P/kPa) = 5.62666 – 1156.346/(2187.446 + t/°C); temp range 52.56–131.41°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)
log (P/mmHg) = 6.72148 – 1280.82/(201.75 + t/°C); temp range 52–131°C (Antoine eq., Dean 1985, 1992)
1540 (lit. average, Riddick et al. 1986)
log (P/kPa) = 4.32297 – 1560.3/(230.0 + t/°C); temp range not specified (Antoine eq., Riddick et al. 1986)
log (P_S/kPa) = 10.03 – 2863/(T/K); temp range 228–248 K (Antoine eq.-I, Stephenson & Malanowski 1987)
log (P_S/kPa) = 9.009 – 2606.5/(T/K); temp range 251–281 K (Antoine eq.-II, Stephenson & Malanowski 1987)
log (P_L/kPa) = 7.501– 2181.1/(T/K); temp range 283–317 K (liquid, Antoine eq.-III, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.18375 – 1469.7/(–53.15 + T/K); temp range 316–488 K (Antoine eq.-IV, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.16941 – 3200/(117.25 + T/K); temp range 404–578 K (Antoine eq.-V, Stephenson & Malanowski 1987)
log (P/mmHg) = 16.8759 – 2.4267 × 10^3/(T/K) –3.0891·log (T/K) – 6.0088 × 10^{-10}·(T/K) + 3.5901 × 10^{-7}·$(T/K)^2$; temp range 283–650 K (vapor pressure eq., Yaws 1994)

Henry's Law Constant (Pa m^3/mol at 25°C):
71.49 (calculated as 1/K_{AW}, C_W/C_A, reported as exptl., Hine & Mookerjee 1975)
15.64, 110.7 (calculated-group contribution method, calculated-bond contribution, Hine & Mookerjee 1975)
65.86* (EPICS-GC, measured range 10–30°C, Ashworth et al. 1988)
ln [H/(atm m^3 mol^{-1})] = 5.703 – 3876/(T/K); temp range 10–30°C (EPICS-GC, Ashworth et al. 1988)
71.49, 133.12 (quoted, calculated-QSAR, Nirmalakhandan & Speece 1988)
83.07 (20–25°C and low ionic strength, quoted, Pankow & Rosen 1988; Pankow 1990)
70.77 (computed value, Yaws et al. 1991)
52.6 (20°C, equilibrium air stripping-GC, Hovorka & Dohnal 1997)
52.02 (20°C, exponential saturator EXPSAT technique, Dohnal & Hovorka 1999)
54.84 (20°C, selected from reported experimental determined values, Staudinger & Roberts 2001)
log K_{AW} = 3.661 – 1556/(T/K) (summary of literature data, Staudinger & Roberts 2001)

Octanol/Water Partition Coefficient, log K_{OW}:
1.96 (shake flask, Log P Database, Hansch & Leo 1987)
1.96 (recommended, Sangster 19943)
1.96 (recommended, Hansch et al. 1995)

Bioconcentration Factor, log BCF:
0.778 (calculated-S as per Kenaga & Goring 1978, Kenaga 1980)
0.301 (calculated-K_{OC} as per Kenaga & Goring 1978, Kenaga 1980)

Sorption Partition Coefficient, log K_{OC}:
1.556 (soil, equilibrium sorption isotherm, Chiou et al. 1979)
1.643 (soil, quoted, Kenaga 1980; Kenaga & Goring 1980)
1.699 (soil, calculated as per Kenaga & Goring 1978, Kenaga 1980)
1.643 (soil, selected, Jury et al. 1990)
1.64 (soil, organic carbon OC ≥ 0.5%, average, Delle Site 2001)

Environmental Fate Rate Constants, k and Half-Lives, $t_{1/2}$:
Volatilization: estimated volatilization $t_{1/2}$ ~ 6.1 h from water (Thomas 1982)
Photolysis:
Oxidation: rate constant k, for gas-phase second order rate constants, k_{OH} for reaction with OH radical, k_{NO3} with NO_3 radical and k_{O3} with O_3 or as indicated, *data at other temperatures see reference:
k_{OH} = 2.5 × 10^{-13} cm^3 $molecule^{-1}$ s^{-1} at 296 K (discharge flow system, Howard & Evenson 1976)

k_{OH}(calc) = 2.9×10^{-13} cm^3 molecule^{-1} s^{-1}, k_{OH}(obs.) = 2.5×10^{-13} cm^3 molecule^{-1} s^{-1} at room temp. (SAR [structure-activity relationship], Atkinson 1985)

k_{OH} = 2.5×10^{-13} cm^3 molecule^{-1} s^{-1} with a loss rate of 0.01 d^{-1}, k_{O3} < 10^{-23} cm^3 molecule^{-1} s^{-1} with a loss rate of < 6×10^{-7} d^{-1} at room temp. (Atkinson 1985)

k_{O3}(aq.) ≤ 0.014 M^{-1} s^{-1} for direct reaction with ozone in water at pH 2 and 22°C, with a half-life of 28 d at pH 7 (Yao & Haag 1991).

Hydrolysis: EDB hydrolyzes to ethylene glycol and bromoethanol in water at pH 7 and 25°C with $t_{1/2}$ = 5–10 d (Leinster et al. 1978; quoted, Verschueren 1983);

k = 9.9×10^{-6} h^{-1} at pH 7 and 25°C with a calculated $t_{1/2}$ = 8.0 yr (Jungclaus & Cohen 1986; quoted, Ellington 1989);

rate constant k = $(8.9 \pm 0.1) \times 10^{-9}$ s^{-1} in water at 25°C and pH 7.5 with an estimated half-life of 2.5 yr (Vogel & Reinhard 1986);

$t_{1/2}$ = 2.2 yr, based on measured neutral hydrolysis rate constant at pH 7 and 25°C (Weintraub et al. 1986; quoted, Howard et al. 1991).

Biodegradation: aerobic $t_{1/2}$(aq.) = 672–4320 h, based on unacclimated aqueous aerobic biodegradation screening test data (Bouwer & McCarty 1983; quoted, Howard et al. 1991);

anaerobic $t_{1/2}$(aq.) = 48–360 h, based on anaerobic stream and pond water sediment die-away test data (Jafvert & Wolfe 1987; quoted, Howard et al. 1991).

Biotransformation:

Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants or Half-Lives:

Half-Lives in the Environment:

Air: disappearance $t_{1/2}$ = 2.4–24 h for the reaction with OH radical in air (USEPA 1974; quoted, Darnall et al. 1976); photooxidation $t_{1/2}$ = 257–2567 h, based on estimated rate constant for the reaction with hydroxyl radical in air (Atkinson 1987; quoted, Howard et al. 1991).

Surface water: $t_{1/2}$ = 672–4320 h, based on unacclimated aqueous aerobic biodegradation (Howard et al. 1991);

k(exptl) ≤ 0.014 M^{-1} s^{-1} for direct reaction with ozone in water at pH 2 and 22°C, with $t_{1/2}$ ≥ 28 d at pH 7 (Yao & Haag 1991).

Ground water: $t_{1/2}$ = 470–2880 h, based on data from anaerobic ground water ecosystem study (Wilson et al. 1986; quoted, Howard et al. 1991) and data from an aerobic ground water ecosystem study (Swindoll et al. 1987; quoted, Howard et al. 1991).

Sediment: calculated $t_{1/2}$ = 1500 d at 25°C and pH 7, based on studies in pure water and in barely saturated subsurface sediment at 25–60°C (Haag & Mill 1988).

Soil: estimated $t_{1/2}$ ~ 3650 d of volatilization loss from soil (Jury et al. 1990);

disappearance $t_{1/2}$ < 2.0 d, estimated from the volatilization loss of mixtures (Anderson et al. 1991);

$t_{1/2}$ = 672–4320 h, based on unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Biota:

TABLE 5.1.2.5.1
Reported aqueous solubilities of 1,2-dibromoethane at various temperatures

$$S/(\text{wt}\%) = 0.36583 + 1.4836 \times 10^{-3} \cdot (t/°C) + 3.48175 \times 10^{-6} \cdot (t/°C)^2 + 6.47685 \times 10^{-7} \cdot (t/°C)^3 \quad (1)$$

$$S/(\text{wt}\%) = 3.8651 - 2.7921 \times 10^{-2} \cdot (T/K) + 5.45647 \times 10^{-5} \cdot (T/K)^2, \quad (2)$$

1.

Gross & Saylor 1931		van Arkel & Vles 1936		Chiou & Freed 1977		Horvath 1982	
shake flask-interferometer				shake flask-GC		summary of literature data	
t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}
15	3920	0	3340	3	2960	5	3658
30	4310	20	4020	20	3510	10	3817
		35	4490	34	4150	20	4012
		50	5290			25	4152

(Continued)

TABLE 5.1.2.5.1 (*Continued*)

Gross & Saylor 1931		van Arkel & Vles 1936		Chiou & Freed 1977		Horvath 1982	
shake flask-interferometer				shake flask-GC		summary of literature data	
t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}
						30	4310
						40	4722
						50	5297
						60	6073
						70	7089
						80	8384
						eq.1	S/wt%

2.

Stephenson 1992		Horvath & Getzen 1999a			
shake flask-GC		tentative, IUPAC-NIST			
t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}
				continued	
10.1	3950	0	3090	55	5780
19.5	4120	5	3200	60	6190
30.7	4310	10	3340	65	6630
39.6	4440	15	3500	70	7090
50	4930	20	3690	75	7580
59.9	4890	25	3910		
70.2	5420	30	4150	eq. 2	S/wt%
80.3	5720	35	4420		
90.6	6580	40	4720		
		45	5050		
		50	5400		

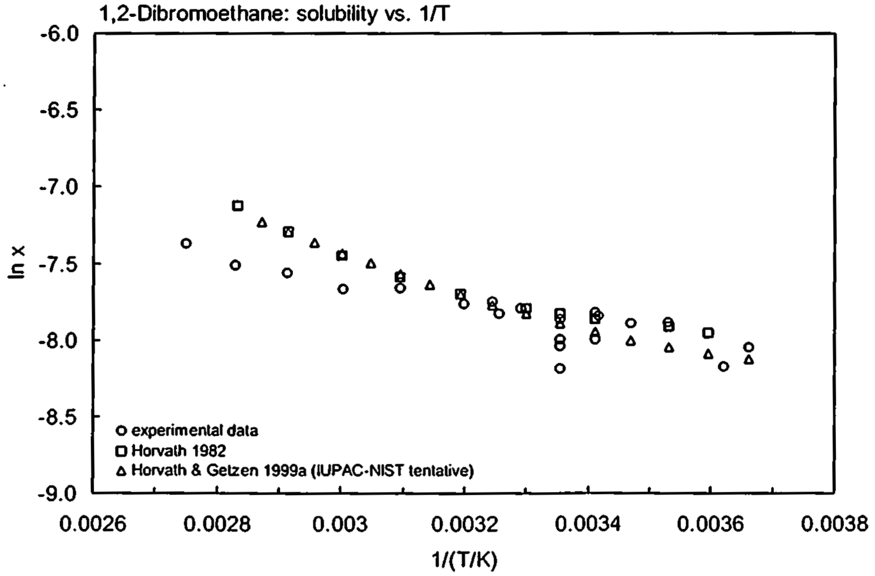


FIGURE 5.1.2.5.1 Logarithm of mole fraction solubility (ln *x*) versus reciprocal temperature for 1,2-dibromomethane.

R1757

TABLE 5.1.2.5.2
Reported Henry's law constants of 1,2-dibromoethane at various temperatures

Ashworth et al. 1988	
EPICS-GC	
t/°C	H/(Pa m³/mol)
10	30.4
15	48.6
20	61.8
25	65.9
30	81.1
ln [H/(atm·m3/mol)] = A – B/(T/K)	
A	5.703
B	3876

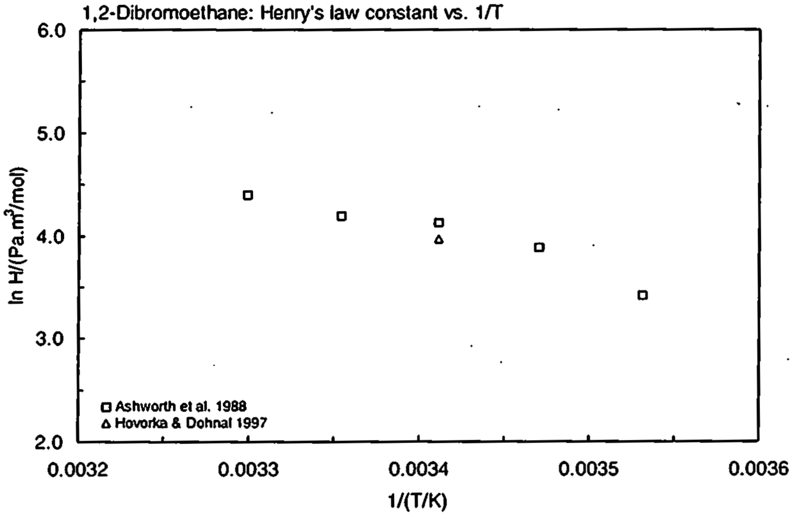
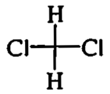


FIGURE 5.1.2.5.2 Logarithm of Henry's law constant versus reciprocal temperature for 1,2-dibromomethane.

5.1.1.2 Dichloromethane


$$\mathrm{Cl-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-Cl}$$

Common Name: Dichloromethane
Synonym: methylene chloride, methylene dichloride, methane dichloride, methylene bichloride
Chemical Name: dichloromethane
CAS Registry No: 75-09-2
Molecular Formula: CH_2Cl_2
Molecular Weight: 84.933

Melting Point (°C):

–95.2	(Lide 2003)

Boiling Point (°C):

40	(Lide 2003)

Density (g/cm³ at 20°C):

1.3255, 1.3163	(20°C, 25°C, Dreisbach 1959; 1961)
1.3266	(Horvath 1982; Weast 1982–83)
1.3256, 1.131678	(20°C, 25°C, Riddick et al. 1986)

Molar Volume (cm³/mol):

64.0	(calculated-density, Wang et al. 1992)
71.4	(calculated-Le Bas method at normal boiling point)

Enthalpy of Vaporization, ΔH_V (kJ/mol):

28.56, 28.98	(25°C, bp, Riddick et al. 1986)

Enthalpy of Fusion, ΔH_{fus} (kJ/mol):

1.435	(calculated, Dreisbach 1959; 1961)
1.472	(quoted, Riddick et al. 1986)

Entropy of Fusion, ΔS_{fus} (J/mol K):
Fugacity Ratio at 25°C, F: 1.0 (Suntio et al. 1988)

Water Solubility (g/m³ or mg/L at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are complied at the end of this section):

20000*	(20°C, volumetric method, Rex 1906)
19910	(Seidell 1940)
13200	(25°C, data presented between 0–50°C in graph, McGovern 1943)
34480	(shake flask-residue volume method, Booth & Everson 1948)
13200	(20°C, McConnell et al. 1975; Pearson & McConnell 1975)
20000*	(Archer & Sterns 1977; Andelman 1978; measured range 0–30°C, quoted, Horvath 1982)
22700, 19400	(1.5, 20°C, literature average, Dilling 1977)
13700	(shake flask-titration/turbidity, Coca et al. 1980)
13030*	(summary of literature data, Horvath 1982)
13000	(selected, Thomas 1982; Riddick et al. 1986; Howard 1990)
16700	(Verschueren 1983; selected, Valsaraj 1988)
19020	(calculated-UNIFAC activity coeff., Banerjee 1985)
17200*	(26.8°C, shake flask-GC/TC, measured range 0–35.7°C, Stephenson 1992)
19260, 19830, 19500, 19500	(20, 30, 35, 40°C, infinite dilution activity coeff. γ^∞-GC, Tse et al. 1992)
18080, 19995, 20880, 21850	(20, 30, 35, 40°C, infinite dilution activity coeff. γ^∞-UNIFAC, Tse et al. 1992)
20080, 18800, 18880	(10, 20, 30°C, activity coeff. γ^∞-differential pressure transducer, Wright et al. 1992)
18650	(gas stripping-GC, Li et al. 1993)
20340	(20°C, limiting activity coeff. by equilibrium air stripping-GC, Hovorka & Dohnal 1997)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):

46510, 68170	(20°C, 30°C, Rex 1906)
57120	(interpolated from graph, temp range –40 to 110°C, McGovern 1943)

57480* (Antoine eq. regression, temp range –70 to 40.7°C, Stull 1947)

58100 (calculated-Antoine eq., Dreisbach 1959; 1961)

log (P/mmHg) = 7.07138 – 1134.6/(231.0 + t/°C); temp range –28 to 121°C (Antoine eq. for liquid state, Dreisbach 1955)

49704* (21.199°C, temp range –9.03 to 39.429°C, Boublik 1960; quoted, Boublik et al. 1984)

70530* (29.993°C, temp range 29.993–39.993°C, Mueller & Ignatoswski 1960)

log (P/mmHg) = 7.0803 – 1138.91/(231.45 + t/°C); temp range –28 to 73°C (Antoine eq. for liquid state, Dreisbach 1961)

57390 (calculated-Antoine eq., temp range –70 to 40.7°C, Weast 1972–73)

log (P/mmHg) = [–0.2185 × 7572.3/(T/K)] + 8.18330; temp range –70 to 40.7°C (Antoine eq., Weast 1972–73)

58275, 57270 (calculated-Antoine eq., Boublik et al. 1973)

log (P/mmHg) = 9.72567 – 2979.516/(395.553 + t/°C); temp range 30–40°C (Antoine eq. from reported exptl. data, Boublik et al. 1973)

48200 (20°C, McConnell et al. 1975; Pearson & McConnell 1975)

21065, 57062 (1.5, 25°C, Dow Chemicals data, Dilling 1977)

57950, 57980 (calculated-Antoine eq., Boublik et al. 1984)

log (P/kPa) = 5.96841 – 1014.441/(216.227 + t/°C); temp range 30–40°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)

log (P/kPa) = 6.18791 – 1127.232/(229.764 + t/°C); temp range –9.05 to 38.4°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)

47990 (selected, Daniels et al. 1985)

log (P/mmHg) = 7.4092 – 1325.9/(252.6 + t/°C); temp range –40 to 40°C (Antoine eq., Dean 1985, 1992)

58100 (selected, Riddick et al. 1986)

log (P/kPa) = 6.07622 – 1070.07/(223.24 + t/°C); temp range not specified (Antoine eq., Riddick et al. 1986)

57990 (calculated-Antoine eq., Stephenson & Malanowski 1987)

log (P_L/kPa) = 6.18649 – 1126.53/(–43.46 + T/K); temp range 264–312 K (Antoine eq.-I, Stephenson & Malanowski 1987)

log (P_L/kPa) = 6.88926 – 1545.323/(3.375 + T/K); temp range 311–383 K (Antoine eq.-II, Stephenson & Malanowski 1987)

log (P_L/kPa) = 5.87285 – 861.817/(–94.102 + T/K); temp range 379–455 K (Antoine eq.-III, Stephenson & Malanowski 1987)

log (P_L/kPa) = 5.20540 – 449.586/(–193.701 + T/K); temp range 450–510 K (Antoine eq., Stephenson & Malanowski 1987)

47660, 71000, 85640, 102540 (20, 30, 35, 40°C, quoted from DIPPR, Tse et al. 1992)

log (P/mmHg) = 32.5069 – 2.5166 × 10^3/(T/K) –8.8015·log (T/K) + 1.2934 × 10^{-10}·(T/K) + 3.3194 × 10^{-6}·$(T/K)^2$; temp range 178–510 K (vapor pressure eq., Yaws 1994)

57844 (selected summary of literature data, temp range 178.25–338.15 K, Xiang 2002)

70486 (30°C, vapor-liquid equilibrium study, Pathare et al. 2004)

Henry's Law Constant (Pa m³/mol at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):

231.3 (calculated as $1/K_{AW}$, C_W/C_A, reported as exptl., Hine & Mookerjee 1975)

301.0 (McConnell et al. 1975; Pearson & McConnell 1975)

322.3 (calculated, Neely 1976)

292, 271.5 (exptl., calculated-C_A/C_W, Dilling 1977)

111.3 (20°C, calculated-P/C, Kavanaugh & Trussell 1980)

log (k_H/atm) = 7.92 – 1821.84/(T/K) (least-square regression of data from lit., Kavanaugh & Trussell 1980)

295 (equilibrium cell-concn ratio-GC/FID, Leighton & Calo 1981)

295* (24.9°C equilibrium cell-concn ratio-GC/FID, measured range 1.9–24.9°C Leighton & Calo 1981)

ln (k_H/atm) = 17.42 – 3645/(T/K); temp range 1.9–24.9°C (equilibrium cell-concn ratio measurements, Leighton & Calo 1981)

205.7 (calculated-P/C, Mabey et al. 1982)

303.9 (calculated-P/C, Thomas 1982)

229.1 (20°C, EPICS-GC, Lincoff & Gossett 1983)

227.9 (20°C, EPICS-GC, Lincoff & Gossett 1984)

199.6 (20°C, batch air stripping-GC, Lincoff & Gossett 1984)
ln [H/(atm m^3/mol)] = 8.200 – 4191/(T/K); temp range 10–30°C (EPICS measurements, Lincoff & Gossett 1984)
ln [H/(atm m^3/mol)] = 9.035 – 4472/(T/K); temp range 10–30°C (batch air stripping measurements, Lincoff & Gossett 1984)
222.0 (EPICS-GC, Gossett 1987)
173.0* (20°C, EPICS-GC/FID, measured range 9.6–34.6°C, Gossett 1987)
ln [H/(atm m^3/mol)] = 9.843 – 5612/(T/K); temp range: 9.6–34.6°C (EPICS measurements, Gossett 1987)
187.7 (20°C, EPICS, Yurteri et al. 1987)
323 (gas stripping-GC, Warner et al. 1987)
300* (EPICS-GC/FID, measured range 10–30°C, Ashworth et al. 1988)
ln [H/(atm·m^3/mol)] = 8.483 – 4268/(T/K); temp range 10–30°C (EPICS measurements, Ashworth et al. 1988)
451.1 (calculated-QSAR, Nirmalakhandan & Speece 1988)
202.6 (20–25°C and low ionic strength, Pankow & Rosen 1988; Pankow 1990)
254.4 (calculated-P/C, Suntio et al. 1988)
251 (computed value, Yaws et al. 1991)
213, 314, 375, 456 (20, 30, 35, 40°C, infinite dilution activity coeff. γ^∞-GC, Tse et al. 1992)
128, 209, 308 (10, 20, 30°C, activity coeff. γ^∞-differential pressure transducer, Wright et al. 1992)
266 (γ^∞ from gas stripping-GC, Li et al. 1993)
16.72, 26.04 (35, 50°C, from infinite dilution activity coefficient determined by relative GC technique, Bhatia & Sandler 1995)
197 (20°C, inert gas stripping-GC, Hovorka & Dohnal 1997)
244.1 (modified EPICS method-GC, Ryu & Park 1999)
260; 221; 211 (EPICS-GC; quoted lit.; calculated-P/C, David et al. 2000)
220 (20°C, selected from reported experimental determined values, Staudinger & Roberts 1996, 2001)
log K_{AW} = 4.561 – 1644/(T/K) (summary of literature data, Staudinger & Roberts 2001)

Octanol/Water Partition Coefficient, log K_{OW} at 25°C or as indicated. Additional data at other temperatures designated * are compiled at the end of this section:
1.25 (shake flask-GC, Hansch et al. 1975; Hansch & Leo 1979; Hansch & Leo 1985)
1.51 (Hansch & Leo 1979)
1.22 (HPLC-k′ correlation, Hafkenscheid & Tomlinson 1983)
1.25 (HPLC-k′ correlation, Tomlinson & Hafkenscheid 1986)
1.25 (recommended, Sangster 1989)
1.35* (infinite dilution activity coefficient determined by relative GC technique, measured range 25–50°C, Bhatia & Sandler 1995)
1.25 (recommended, Hansch et al. 1995)
1.25 (calculated-fragment const. with correction factors in multiCASE program, Damborsky et al. 2001)

Octanol/Air Partition Coefficient, log K_{OA} at 25°C:
2.27 (head-space GC, Abraham et al. 2001)

Bioconcentration Factor, log BCF:
0.699 (calculated as per Lyman et al. 1982, Howard 1990)
0.778 (microorganism-water, calculated from K_{OW}, Mabey et al. 1982)
0.600 (calculated-MCI χ, Koch 1983)
0.362 (selected, Daniels et al. 1985)

Sorption Partition Coefficient, log K_{OC}:
0.944 (calculated-K_{OW}, Mabey et al. 1982)
1.440 (calculated- MCI χ, Koch 1983; quoted, Bahnick & Doucette 1988)
1.000 (selected, Daniels et al. 1985)
1.390 (calculated-MCI χ, Bahnick & Doucette 1988)

Sorption Partition Coefficient, log K_{OM}:
1.44, 1.23 (quoted, calculated-MCI χ, Sabljic 1984)

Environmental Fate Rate Constants, and Half-Lives, $t_{1/2}$:

Volatilization: $t_{1/2}$(calc) = 2.23 min (Mackay & Wolkoff 1973; quoted, Dilling et al. 1975; Callahan et al. 1979);

$t_{1/2}$(calc) = 20.7 min (Mackay & Leinonen 1975; quoted, Dilling 1977; Callahan et al. 1979);

$t_{1/2}$(exptl) = (21 ± 3) min for 1 ppm in water at 25°C when stirred at 200 rpm in water (Dilling et al. 1975; quoted, Callahan et al. 1979; Mills et al. 1982);

evaporation $t_{1/2}$(exptl) = (18.3–25.2) min, $t_{1/2}$(calc) = 2.23 and 20.7 min at 25°C and $t_{1/2}$(exptl.) = 34.9 min, $t_{1/2}$ = 24.5 min at 1.5°C (Dilling 1977)

$t_{1/2}$ ~ 3.0 h from water (estimated, Thomas 1982);

$t_{1/2}$ ~ 100 d from soil (estimated, Jury et al. 1990).

Photolysis: estimated photodecomposition $t_{1/2}$ > 250 h from a simulated environmental sunlight exposure (> 290 nm at 27 ± 1°C) study (Dilling et al. 1976; quoted, Callahan et al. 1979);

photodegradation $t_{1/2}$ = 30–120 d (Darnall et al. 1976; quoted, Daniels et al. 1985);

photocatalyzed mineralization by the presence of TiO_2 with a rate of 1.6 ppm/min per gram of catalyst (Ollis 1985).

Oxidation: rate constant k, for gas-phase second order rate constants, k_{OH} for reaction with OH radical, k_{NO3} with NO_3 radical and k_{O3} with O_3 or as indicated, *data at other temperatures and/or the Arrhenius expression see reference:

$k_{OH} = 1.24 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1} at 298 K corresponding to a lifetime of 0.30 yr (relative rate method, Cox et al. 1976; quoted, Callahan et al. 1979)

$k_{OH}^* = (1.16 \pm 0.05) \times 10^{-13}$ cm^3 molecule^{-1} s^{-1} at 298 K with lifetime of 0.39 yr, measured range 245–375 K (flash photolysis-resonance fluorescence, Davis et al. 1976)

$k_{OH} = 1.55 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1} at 298 K (discharge flow-LMR, Howard & Evenson 1976a)

$k_{OH} = (14.5 \pm 2.0) \times 10^{-14}$ cm^3 molecule^{-1} s^{-1} at 298.5 K and the calculated tropospheric half-life of ~ 0.05 yr in lower troposphere (flash photolysis-RF, Perry et al. 1976)

$k_{OH} = 1.5 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1}, residence time of 77 d, loss of 1.3% in 1d or 12 sunlit hours at 300 K in urban environments (Singh et al. 1981)

$k_{OH}^* = 1.53 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1} at 292 K, measured range 251–455 K (discharge flow-resonance fluorescence, Jeong & Karfman 1982)

k << 360 M^{-1} h^{-1} for singlet oxygen and 0.2 M^{-1} h^{-1} for peroxy radical at 25°C (Mabey et al. 1982)

k ≤ 0.1 M^{-1} s^{-1} for reaction with O_3 in water as scavenger at pH 2 and 20–23°C (Hoigné & Bader 1983)

photooxidation $t_{1/2}$ = 458–4584 h based on measured rate data for the vapor phase reaction with OH radical in air (Atkinson 1985; quoted, Howard et al. 1991)

$k = 4.0 \times 10^7$ M^{-1} s^{-1} with reference to CH_3CCl_3 (Buxton et al. 1988; quoted, Haag & Yao 1992)

$k_{OH} = 1.42 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1}; k(soln) = 9.6×10^{-14} cm^3 molecule^{-1} s^{-1} for reaction with OH radical in aqueous solution (Wallington et al. 1988b)

$k_{OH}^* = 1.42 \times 10^{-13}$ cm^3 molecule^{-1} s^{-1} at 298 K (recommended, Atkinson 1989)

$k_{OH}^* = 1.76 \times 10^{-14}$ cm^3 molecule^{-1} s^{-1} at 295 K, measured range 298–775 K (laser photolysis/laser induced fluorescence technique, Taylor et al. 1989)

$k = (9 \pm 6) \times 10^7$ M^{-1} h^{-1} for the reaction with OH radical in aqueous solution at pH 8.5 (Haag & Yao 1992)

Hydrolysis: a minimum hydrolysis $t_{1/2}$ = 18 months was estimated from aqueous reactivity experiments (Dilling et al. 1975; quoted, Callahan et al. 1979; Howard 1990);

rate constant $k = 3.2 \times 10^{-11}$ s^{-1} with a maximum $t_{1/2}$ = 704 yr for hydrolysis at pH 7 and 25°C was reported from the extrapolated experimental data obtained at 100–150°C (Radding et al. 1977; quoted, Callahan et al. 1979; Mabey et al. 1982)

$t_{1/2}$ = 260000 d in natural waters at pH 7 (Capel & Larson 1995)

Biodegradation: completely biodegradable under aerobic conditions with sewage seed or activated sludge between 6 h to 7 d (Rittman & McCarty 1980; Davis et al. 1981; Tabak et al. 1981; Klecka 1982; Stover & Kincannon 1983; quoted, Howard 1990)

$t_{1/2}$(aq. aerobic) = 168–672 h based on unacclimated aerobic screening test data (Kawasaki 1980; Tabak et al. 1981; quoted, Howard et al. 1991); $t_{1/2}$(aq. anaerobic) = 672–2688 h based on unacclimated aerobic biodegradation half-life (Howard et al. 1991).

$t_{1/2}$(aerobic) = 7 d, $t_{1/2}$(anaerobic) = 28 d in natural waters (Capel & Larson 1995)

Biotransformation:

Bioconcentration and Uptake and Elimination Rate Constants (k_1 and k_2):

Half-Lives in the Environment:

Air: tropospheric $t_{1/2}$ = 33 wk when exposed outdoors to diurnal and climatic variations of incident radiation and temperature (Pearson & McConnell 1975)

disappearance $t_{1/2}$ = 2.4–24 h from air for the reaction with OH radical (USEPA 1974; quoted, Darnall et al. 1976)

lifetime of 4.4 yr in troposphere for the reaction with OH radical (Altshuller 1980)

estimated disappearance time to be 12 h to 1.0 year in simulated troposphere chamber (Dilling & Goersch 1979; quoted, Lyman 1982)

residence time of 77 d, loss of 1.3% in 1d or 12 sunlit hours at 300 K in urban environments estimated as toxic chemical for the reaction with OH radical (Singh et al. 1981)

estimated residence time in troposphere to be 160–250 d (Lyman 1982);

$t_{1/2}$ = 458–4584 h, based on photooxidation half-life in air (Atkinson 1985; quoted, Howard et al. 1991)

Surface water: estimated $t_{1/2}$ = 33–38 d in various locations in the Netherlands in case of a first order reduction process (Zoeteman et al. 1980)

$t_{1/2}$ = 168–672 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991)

biodegradation $t_{1/2}$(aerobic) = 100 d, $t_{1/2}$(anaerobic) = 400 d, hydrolysis $t_{1/2}$ = 3800 d at pH 7 in natural waters (Capel & Larson 1995)

$t_{1/2}$ = 1–1.2 d for the first days up to 4 d and 2.71–2.80 d for a period of up to 14 d for disappearance from water calculated from a pseudo first order equation of mesocosms experiment (Merlin et al. 1992)

Ground water: estimated for the first days up to 4 d and $t_{1/2}$ = 2.71–2.80 d for a period of up to 14 d of 10 yr in the ground water of The Netherlands (Zoeteman et al. 1981)

$t_{1/2}$ = 336–1344 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Sediment:

Soil: $t_{1/2}$ = 10–50 d (Ryan et al. 1988);

volatilization $t_{1/2}$ ~ 100 d from soil (Jury et al. 1990);

biodegradation $t_{1/2}$(aerobic) = 1.3 d (0.16 ppm, conc of dichloromethane), $t_{1/2}$ = 9.4 d (0.5 ppm), $t_{1/2}$ = 191.4 d (5 ppm), all in sandy loam soil; $t_{1/2}$ = 54.8 d in sand (0.5 ppm); $t_{1/2}$ = 12.7 d (0.5 ppm) in sandy clay loam soil; $t_{1/2}$ = 7.2 d (0.5 ppm) in clay with 50 d lag and $t_{1/2}$(anaerobic) = 21.5 d (5 ppm) with 70 d lag (Davis & Madsen 1991);

$t_{1/2}$ = 168–672 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Biota: $t_{1/2}$ = 10–50 d, subject to plant uptake in soil via volatilization (Ryan et al. 1988);

$t_{1/2}$ = 0.4–0.5 d to eliminate from small fish (McCarty et al. 1992).

TABLE 5.1.1.2.1
Reported aqueous solubilities of dichloromethane at various temperatures

$$S/(\text{wt}\%) = 1.961 - 4.4883 \times 10^{-2}\cdot(t/°C) + 8.6617 \times 10^{-4}\cdot(t/°C)^2 + 4.9463 \times 10^{-6}\cdot(t/°C)^3 \qquad (1)$$

1.

Rex 1906		Andelman 1978		Horvath 1982		Stephenson 1992	
volumetric method				summary of literature data		shake flask-GC	
t/°C	$S/g \cdot m^{-3}$	t/°C	$S/g \cdot m^{-3}$	t/°C	$S/g \cdot m^{-3}$	t/°C	$S/g \cdot m^{-3}$
0	23630	0	23100	0	19610	0	20300
10	21220	10	20800	10	15938	9.2	19200
20	20000	20	19600	20	13702	17.3	18000
30	19690	25	20000	25	13030	26.8	17200
		30	19000	30	12605	35.7	17700
				40	12350		
				50	12640		
				eq.1	S/wt%		

TABLE 5.1.1.2.1 (*Continued*)

2.

Tse et al. 1992		Wright et al. 1992	
activity coefficient -GC		activity coefficient	
t/°C	S/g·m⁻³	t/°C	S/g·m⁻³
20	19260	10	20080
30	19830	20	18880
35	19500	30	18880
40	19500		

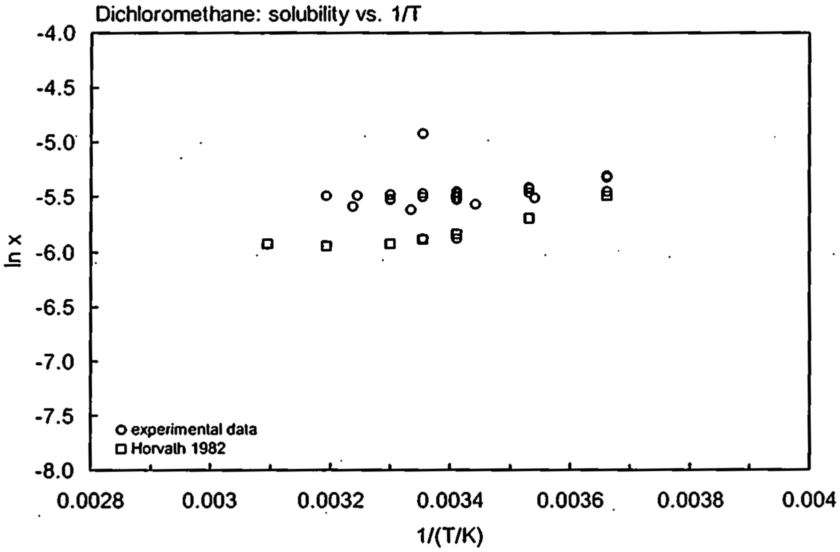


FIGURE 5.1.1.2.1 Logarithm of mole fraction solubility (ln *x*) versus reciprocal temperature for dichloromethane.

TABLE 5.1.1.2.2
Reported vapor pressures of dichloromethane at various temperatures and the coefficients for the vapor pressure equations

$\log P = A - B/(T/K)$ (1) $\ln P = A - B/(T/K)$ (1a)
$\log P = A - B/(C + t/°C)$ (2) $\ln P = A - B/(C + t/°C)$ (2a)
$\log P = A - B/(C + T/K)$ (3)
$\log P = A - B/(T/K) - C \cdot \log (T/K)$ (4)

Stull 1947		Mueller & Ignatoswski 1960		Boublik 1960, thesis	
summary of literature data				in Boublik et al. 1984	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
−70.0	133.3	29.993	70530	−9.03	12046
−52.1	666.6	34.993	85175	−5.45	14549
−43.3	1333	38.993	98070	−1.322	17921
−33.4	2666	39.993	102117	2.228	21314
−22.3	5333			6.230	25780
−15.7	7999			9.457	29923
−6.30	13332			13.289	35493

(*Continued*)

TABLE 5.1.1.2.2 (*Continued*)

Stull 1947		Mueller & Ignatoswski 1960		Boublik 1960, thesis	
summary of literature data				in Boublik et al. 1984	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
8.0	26664			16.693	41470
24.1	53329			21.199	49704
40.7	101325			26.393	61295
				32.337	77123
mp/°C	−96.7			39.429	96484
				eq. 2	P/kPa
				A	6.18791
				B	127.232
				C	229.764
				bp	39.767

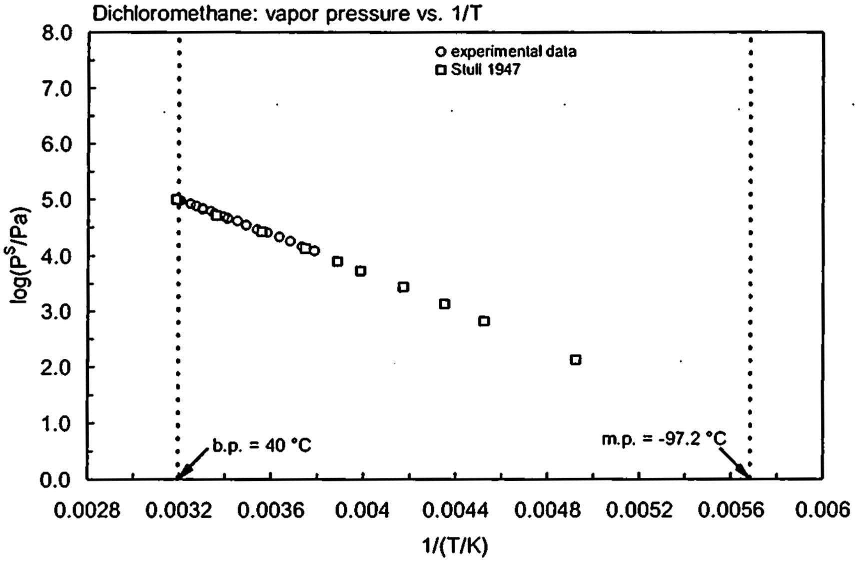


FIGURE 5.1.1.2.2 Logarithm of vapor pressure versus reciprocal temperature for dichloromethane.

TABLE 5.1.1.2.3

Reported Henry's law constants of dichloromethane at various temperatures and temperature dependence equations

$\ln K_{AW} = A - B/(T/K)$	(1)	$\log K_{AW} = A - B/(T/K)$	(1a)
$\ln (1/K_{AW}) = A - B/(T/K)$	(2)	$\log (1/K_{AW}) = A - B/(T/K)$	(2a)
$\ln (k_H/\text{atm}) = A - B/(T/K)$	(3)		
$\ln H = A - B/(T/K)$	(4)	$\log H = A - B/(T/K)$	(4a)
$K_{AW} = A - B\cdot(T/K) + C\cdot(T/K)^2$	(5)		

Leighton & Calo 1981		Gossett 1987		Ashworth et al. 1988		Tse et al. 1992	
equilibrium cell-GC		EPICS-GC		EPICS-GC		activity coefficient	
t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)
1.9	112	9.6	116.5	10	142	20	213
13.5	203	17.5	132.7	15	171	30	314
15.7	222	24.8	221.9	20	247	35	375
22.0	286.5	34.6	330.3	25	300	40	456
24.9	295			30	366		
25	295.3	eq. 4	H/(atm m³/mol)				
		A	6.653	eq. 4	H/(atm m³/mol)	Wright et al. 1992	
eq. 3	k_H/atm	B	4215	A	8.483	activity coefficient	
A	17.42			B	4268		
B	3645					10	128
						20	209
						30	308

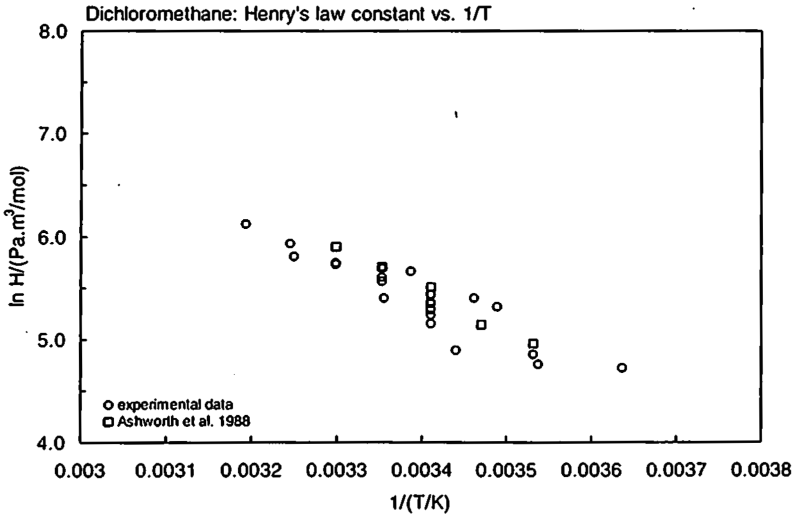


FIGURE 5.1.1.2.3 Logarithm of Henry's law constant versus reciprocal temperature for dichloromethane.

TABLE 5.1.1.2.4
Reported octanol-water partition coefficients of dichloromethane at various temperatures

Bhatia & Sandler 1995	
relative GC-RT technique	
t/°C	log K_{OW}
25	1.35
35	1.34
50	1.37
enthalpy of transfer	
$\Delta H/(kJ\ mol^{-1}) = -20.2$	
log $K_{OW} = A - \Delta H/2.303RT$	
A	1.0195
ΔH	−20.2

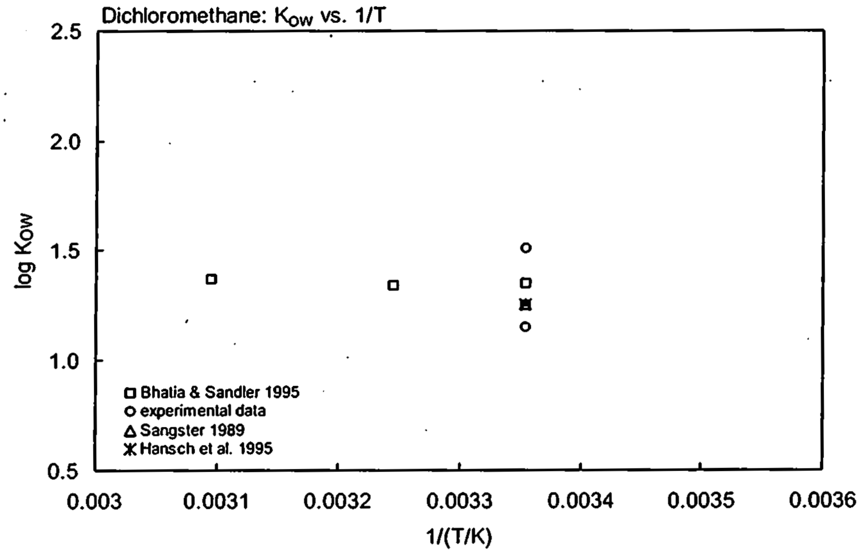
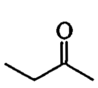


FIGURE 5.1.1.2.4 Logarithm of K_{OW} versus reciprocal temperature for dichloromethane.

12.1.2.2 2-Butanone (Methyl ethyl ketone)



Common Name: Methyl ethyl ketone
Synonym: 2-butanone, butan-2-one, MEK
Chemical Name: 2-butanone, methyl ethyl ketone
CAS Registry No: 78-93-3
Molecular Formula: C_4H_8O, $CH_3CH_2COCH_3$
Molecular Weight: 72.106
Melting Point (°C):
 −86.64 (Lide 2003)
Boiling Point (°C):
 79.59 (Lide 2003)
Density (g/cm^3 at 20°C):
 0.8054 (Weast 1982–83)
 0.7997 (25°C, Riddick et al. 1986)
Molar Volume (cm^3/mol):
 89.9 (calculated-density, Rohrschneider 1973)
 96.2 (calculated-Le Bas method at normal boiling point)
Dissociation Constant:
 14.7 (pK_a, Riddick et al. 1986)
 −7.2 (pK_{BH^+}, Riddick et al. 1986)
Enthalpy of Fusion ΔH_{fus} (kJ/mol):
 8.439 (Riddick et al. 1986)
Entropy of Fusion ΔS_{fus} (J/mol K):
Fugacity Ratio at 25°C (assuming ΔS_{fus} = 56 J/mol K), F: 1.0

Water Solubility (g/m^3 or mg/L at 25°C or as indicated. Additional data at other temperatures designated * are compiled at the end of this section):
 240000 (20°C, synthetic method, Jones 1929; quoted, Palit 1947; Dean 1985; Riddick et al. 1986)
 255700* (shake flask-volumetric method, measured range 20–30°C Ginnings et al. 1940)
 343550 (shake flask-volumetric, Ginnings et al. 1940)
 228020 (estimated, McGowan 1954)
 12420 (20°C, Amidon et al. 1975)
 136280 (generator column-GC, Wasik et al. 1981; Tewari et al. 1982)
 353000 (20°C, Verschueren 1983)
 249000 (selected, Yaws et al. 1990)
 276000*, 235000 (19.3°C, 29.7°C, shake flask-GC, measured range 0–70.2°C, Stephenson 1992)

Vapor Pressure (Pa at 25°C and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
 12954* (interpolated-regression of tabulated data, temp range −48.3 to 79.6°C, Stull 1947)
 $\log (P/\text{mmHg}) = 7.22200 - 1343.6/(230 + t/°C)$, (Antoine eq., Dreisbach & Martin 1949)
 16500* (31.84°C, ebulliometry, measured range 31.84–79.5°C, Dreisbach & Shrader 1949)
 25158* (41.46°C, flow calorimetry, measured range 41.46–79.5°C, Nickerson et al. 1961)
 26568* (42.778°C, ebulliometry, measured range 42.778–88.444°C, Collerson et al. 1965)
 $\log (P/\text{mmHg}) = 7.06376 - 1261.455/(221.982 + t/°C)$; temp range 42.778–88.444°C (Antoine eq., ebulliometric measurements, Collerson et al. 1965)
 $\log (P/\text{mmHg}) = 19.48322 - 2328.0/(T/K) - 3.92657 \cdot \log (T/K)$; temp range 42.778–88.444°C (Kirchhoff eq., ebulliometric measurements, Collerson et al. 1965)
 $\log (P/\text{mmHg}) = [-0.2185 \times 8149.5/(T/K)] + 7.959295$; temp range −48.3 to 79.6°C (Antoine eq., Weast 1972–73)

12079* (ebulliometry, Ambrose et al. 1975a; quoted, Riddick et al. 1986; Howard 1990)
12000, 12060, 12640 (extrapolated-Antoine eq., Boublik et al. 1984)
log (P/kPa) = 6.02273 – 1167.861/(211.199 + t/°C); temp range 41.46–97.42°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)
log (P/kPa) = 6.18397 – 1258.948/(221.725 + t/°C); temp range 42.78–86.44°C (Antoine eq. from reported exptl. data of Ambrose et al. 1975, Boublik et al. 1984)
log (P/kPa) = 6.18838 – 1261.297/(222.964 + t/°C); temp range 42.79–88.4°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)
12020 (extrapolated-Antoine eq., Dean 1985)
log (P/mmHg) = 7.06356 – 1261.34/(221.97 + t/°C); temp range 43–88°C (Antoine eq., Dean 1985, 1992)
12700 (Howard et al. 1986; quoted, Banerjee et al. 1990)
12120 (interpolated-Antoine eq.-I, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.24715 – 1294.53/(–47.442 + T/K); temp range 294–352 K (Antoine eq-I., Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.18479 – 1259.519/(–51.359 + T/K); temp range 315–363 K (Antoine eq-II., Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.22518 – 1286.794/(–47.766 + T/K); temp range 353–403 K (Antoine eq-III., Stephenson & Malanowski 1987)
5425 (calculated-solvatochromic parameters, Banerjee et al. 1990)
log (P/mmHg) = 47.706 – 3.0965 × 10^3/(T/K) – 15.184·log (T/K) + 7.4846 × 10^{-3}·(T/K) – 1.7084 × 10^{-13}·$(T/K)^2$; temp range 186–536 K (vapor pressure eq., Yaws 1994)
12071* (static method-manometry, measured range 0–50°C, Garriga et al. 1996)

Henry's Law Constant (Pa m^3/mol or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
4.710 (shake flask, partial vapor pressure-GC, Buttery et al. 1969)
4.723 (quoted, exptl., Hine & Mookerjee 1975)
5.549, 4.408 (calculated-group contribution, calculated-bond contribution, Hine & Mookerjee 1975)
3.87 (headspace-GC, Vitenberg et al. 1975)
6.191, 4.215 (calculated-γ·P, calculated-MW, Rathbun & Tai 1982)
0.987, 5.76 (0, 25°C, gas stripping-GC, Snider & Dawson 1985)
13.17* (EPICS-GC/FID, measured range 10–30°C, Ashworth et al. 1988)
ln [H/(atm·m^3/mol)] = –26.32 – 5214/(T/K), temp range 10–30°C, (EPICS measurements, Ashworth et al. 1988)
5.210 (gas stripping-HPLC/UV, Zhou & Mopper 1990)
5.117* (gas-stripping-HPLC-UV, measured range 10–45°C, Zhou & Mopper 1990)
ln [K_H'/(M/atm)] = –6.03 + 2184/(T/K), temp range 10–45°C (gas stripping-HPLC measurements, freshwater, Zhou & Mopper 1990)
ln [K_H'/(M/atm)] = –5.97 + 2138/(T/K), temp range 10–45°C (gas stripping-HPLC measurements, seawater (salinity 35 ± 1 l), Zhou & Mopper 1990)
18.28* (45°C, equilibrium headspace-GC, measured range 45–80°C, Ettre et al. 1993)
log (1/K_{AW}) = –3.7973482 + 1889.5294/(T/K), temp range 45–80°C (equilibrium headspace-GC measurements, Ettre et al. 1993)
3.85 (20°C, selected from literature experimentally measured data, Staudinger & Roberts 1996)
3.95 (20°C, selected from literature experimentally measured data, Staudinger & Roberts 2001)
log K_{AW} = 4.764 – 2213/(T/K), (van't Hoff eq. derived from literature data, Staudinger & Roberts 2001)
5.04 – 3.54 (27°C, equilibrium headspace-GC, solute concn 10.01–85.10 mg/L, measured range 300–315 K, Cheng et al. 2003)
5.04* (27°C, equilibrium headspace-GC, measured range 27–42°C, Cheng et al. 2003)

Octanol/Water Partition Coefficient, log K_{OW}:
0.26 (shake flask-CR, Collander 1957)
0.28 (shake flask-UV, Fujita et al. 1964, Hansch & Leo 1979)
0.32 ± 0.01 (shake flask-UV, calculated, Iwasa et al. 1965)
0.29 (shake flask-UV, GC, Hansch & Anderson 1967; Hansch et al. 1968; Leo et al. 1969, 1971)
0.28 ± 0.02 (shake flask at pH 7, Unger et al. 1978)

0.69 (generator column-GC, Wasik et al. 1981; Tewari et al. 1982)
0.26 (shake flask-GC, Tanii et al. 1986)
0.62 (calculated-activity coeff. γ from UNIFAC, Banerjee & Howard 1988)
0.29 (recommended, Sangster 1989, 1993)
0.29 (recommended, Hansch et al. 1995)

Octanol/Air Partition Coefficient, log K_{OA}:
2.77 (head-space GC, Abraham et al. 2001)

Bioconcentration Factor, log BCF:
0.00 (estimated-K_{OW}, Lyman et al. 1982; quoted, Howard 1990)

Sorption Partition Coefficient, log K_{OC}:
1.53 (soil, estimated-K_{OW}, Lyman et al. 1982; quoted, Howard 1990)
1.47 ± 0.55, 1.53 ± 0.88; 1.50 (Captina silt loam, McLaurin sandy loam; weighted mean, batch equilibrium-sorption isotherm, Walton et al. 1992)
0.070 (predicted-K_{OW}, Walton et al. 1992)
–0.03 (calculated-K_{OW}, Kollig 1993)

Environmental Fate Rate Constants, k, or Half-Lives, $t_{1/2}$:

Volatilization: based on lab. data for evaporation relative to the reaeration rate of 0.27 (Mackay et al. 1982; Rathbun & Tai 1982; quoted, Howard 1990) and typical reaeration rates of rivers and lakes (Mill et al. 1982; quoted, Howard 1990),

$t_{1/2}$ = 3 d for evaporation from a river and $t_{1/2}$ = 12 d from lake (Howard 1990).

Photolysis: rate constant k = 1.4×10^{-5} s^{-1} in the atmosphere (Carlier et al. 1986); calculated lifetime τ ~4 d in air (Atkinson 2000)

Oxidation: rate constant k, for gas-phase second order rate constants, k_{OH} for reaction with OH radical, k_{NO3} with NO_3 radical and k_{O3} with O_3 or as indicated, *data at other temperatures and/or the Arrhenius expression see reference:

photooxidation $t_{1/2}$ = 48.8 – 81.4 yr, based on measured rate data for the reaction with hydroxyl radical in aqueous solution (Anbar & Neta 1967; selected, Howard et al. 1991)

photooxidation $t_{1/2}$ = 2.4 – 24 h in air for the gas-phase reaction with hydroxyl radical, based on the rate of disappearance of hydrocarbon due to reaction with hydroxyl radicals (Darnall et al. 1976)

k_{OH} = $(0.20 \pm 0.06) \times 10^{10}$ cm^3 M^{-1} s^{-1} at 1 atm and 305 ± 2 K (relative rate method, Winer et al. 1976)

k < 2.0×10^2 M^{-1} s^{-1} for oxidation with singlet oxygen at 25°C in aquatic systems with $t_{1/2}$ > 00 yr (Foote 1976; Mill 1979; quoted, Mill 1982)

k_{OH} = 1.9×10^9 M^{-1} s^{-1} at 25°C with $t_{1/2}$ = 2.9 d (Hendry & Kenley 1979; quoted, Mill 1982)

k_{OH} = $(0.95 \pm 0.09) \times 10^{-12}$ cm^3 $molecule^{-1}$ s^{-1} at (295 ± 2) K in air (relative rate technique to ethene Cox et al. 1981; quoted, Atkinson 1985)

k_{OH} = $(1.20 \pm 0.20) \times 10^{-12}$ cm^3 $molecule^{-1}$ s^{-1} at 300 K in air (flash photolysis-resonance fluorescence, Zetzsch 1982; quoted, Atkinson 1985)

k = (0.12 ± 0.02) M^{-1} s^{-1} for the reaction with ozone in water using 20–300 mM *t*-BuOH as scavenger at pH 2 and 20–23°C (Hoigné & Bader 1983)

k_{OH}(calc) = 1.38×10^{-12} cm^3 $molecule^{-1}$ s^{-1}, k_{OH}(obs.) = 1.0×10^{-12} cm^3 $molecule^{-1}$ s^{-1} at room temp. (SAR structure-activity relationship, Atkinson 1985)

k_{OH} = 0.97×10^{-12} cm^3 $molecule^{-1}$ s^{-1} at 24°C with an atmospheric lifetime τ = 12 d (Edney et al. 1986)

k_{OH} = 1.15×10^{-13} cm^3 $molecule^{-1}$ s^{-1} at 296 K and k(soln) = 1.50×10^{-13} cm^3 $molecule^{-1}$ s^{-1} for the aqueous-phase reaction with OH radical in solution (Wallington & Kurylo 1987; quoted, Wallington et al. 1988)

k_{OH}* = 1.15×10^{-12} cm^3 $molecule^{-1}$ s^{-1} at 298 K (recommended, Atkinson 1989)

photooxidation $t_{1/2}$ = 64.2 – 642 h, based on measured rate data for the vapor phase reaction with hydroxyl radical (Howard et al. 1991)

k_{OH}(calc) = 1.65×10^{-12} cm^3 $molecule^{-1}$ s^{-1} (molecular orbital calculations, Klamt 1996)

Hydrolysis: first-order hydrolysis $t_{1/2}$ > 0 yr, based on nonreactive hydrolysis from pH 5 to 9 at 15°C (Kollig et al. 1987; selected, Howard et al. 1991).

Biodegradation:

k = 0.021 – 0.025 h^{-1} in 30 mg/L activated sludge after a time lag of 5 h (Urano & Kato 1986b)

$t_{1/2}$(aq. aerobic) = 24 – 168 h, based on unacclimated grab sample of aerobic freshwater (Dojilido 1979; selected, Howard et al. 1991) and aerobic aqueous screening test data (Takemoto et al. 1981; selected, Howard et al. 1991)

$t_{1/2}$(aq. anaerobic) = 96 – 672 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991)

$t_{1/2}$(aerobic) = 1 d, $t_{1/2}$(anaerobic) = 28 d in natural waters (Capel & Larson 1995)

Biotransformation:

Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants:

Half-Lives in the Environment:

Air: $t_{1/2}$ = 2.4–24 h in air for the gas-phase reaction with hydroxyl radical, based on the rate of disappearance of hydrocarbon due to reaction with hydroxyl radical (Darnall et al. 1976);

photodecomposition $t_{1/2}$ = 9.8 h under simulated atmospheric conditions, with NO (Dilling et al. 1976)

$t_{1/2}$ = 2.3 d for the atmospheric reaction with photochemically produced hydroxyl radical (Cox et al. 1981; quoted, Howard 1990);

photooxidation $t_{1/2}$ = 64.2–642 h, based on measured rate data for the vapor phase reaction with hydroxyl radical (Atkinson 1985; selected, Howard et al. 1991);

calculated atmospheric lifetime τ = 12 d due to reaction with OH radical (Edney et al. 1986) atmospheric transformation lifetime τ < 1 d (estimated, Kelly et al. 1994);

calculated lifetime τ = 10 d for reaction with OH radical (Atkinson 2000).

Surface water: photooxidation $t_{1/2}$ = 48.8–81.4 yr, based on measured rate data for the reaction with hydroxyl radical in aqueous solution (Anbar & Neta 1967; quoted, Howard et al. 1991); $t_{1/2}$ = 24–168 h, based on unacclimated grab sample of aerobic freshwater (Dojlido 1979; selected, Howard et al. 1991) and aerobic aqueous screening test data (Takemoto et al. 1981; selected, Howard et al. 1991)

$t_{1/2}$(aerobic) = 1 d, $t_{1/2}$(anaerobic) = 28 d in natural waters (Capel & Larson 1995).

Ground water: $t_{1/2}$ = 48–336 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Sediment:

Soil: calculated $t_{1/2}$ = 4.9 d from first-order kinetic of degradation under both sterile and nonsterile conditions (Anderson et al. 1991);

$t_{1/2}$ = 24–168 h, based on estimated unacclimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Biota:

TABLE 12.1.2.2.1

Reported aqueous solubilities of 2-butanone (methyl ethyl ketone) at various temperatures

Ginnings et al. 1940		Stephenson 1992	
volumetric method		shake flask-GC/TC	
t/°C	S/g·m^{-3}	t/°C	S/g·m^{-3}
20	273300	0	367000
25	255700	9.6	310000
30	240700	19.3	276000
		29.7	245000
bp/°C	80.7–80.8	39.6	220000
d^{25}	0.8007	49.7	206000
		60.6	180000
		70.2	182000

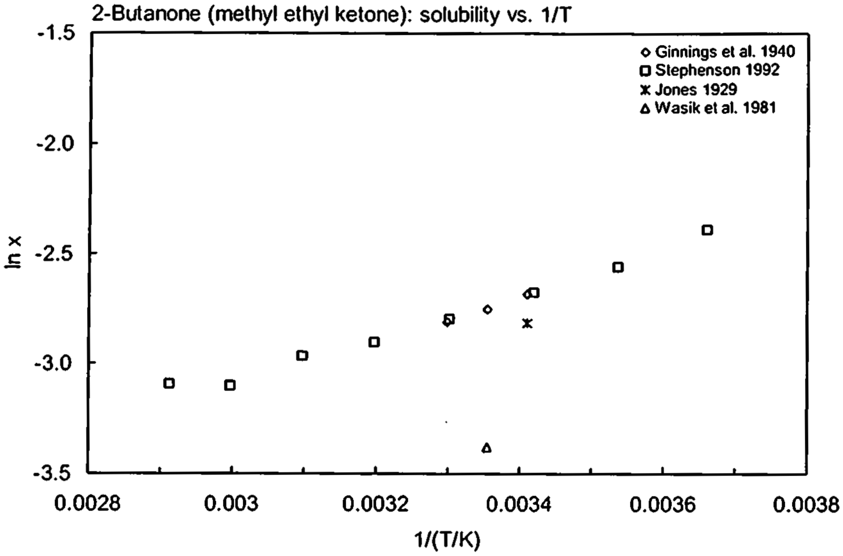


FIGURE 12.1.2.2.1 Logarithm of mole fraction solubility (ln *x*) versus reciprocal temperature for 2-butanone.

TABLE 12.1.2.2.2
Reported vapor pressures of 2-butanone (methyl ethyl ketone) at various temperatures and the coefficients for the vapor pressure equations

$\log P = A - B/(T/K)$	(1)	$\ln P = A - B/(T/K)$	(1a)
$\log P = A - B/(C + t/°C)$	(2)	$\ln P = A - B/(C + t/°C)$	(2a)
$\log P = A - B/(C + T/K)$	(3)	$\ln P = A - B/(C + T/K)$	(3a)
$\log P = A - B/(T/K) - C \cdot \log(T/K)$	(4)		

1.

Stull 1947		Dreisbach & Shrader 1949		Nickerson et al. 1961		Collerson et al. 1965	
summary of literature data		ebulliometry		flow calorimetry		ebulliometry	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
–48.3	133.3	31.84	16500	41.46	25158	42.778	26568
–28.0	666.6	54.29	42066	65.54	63368	48.148	33024
–17.7	1333	67.36	67661	79.39	101098	53.026	39963
–6.50	2666	79.5	101325	89.43	137282	57.08	46591
6	5333			97.42	173212	60.821	53469
14	7999					64.005	59954
25	13332			eq. 4	P/mm Hg	67.009	66625
41.6	26664			A	21.78963	69.734	73184
60	53329			B	2441.9	72.343	79933
79.6	101325			C	4.70504	74.839	86849
						76.95	93063
mp/°C	–85.9					79.221	100135
						81.268	106887
						83.161	113428
						85.013	120126
						86.715	126547
						88.44	133353
						mp/°C	-86.69
						bp/°C	79.589

TABLE 12.1.2.2.2 *(Continued)*

Stull 1947		Dreisbach & Shrader 1949		Nickerson et al. 1961		Collerson et al. 1965	
summary of literature data		ebulliometry		flow calorimetry		ebulliometry	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
						Antoine eq.	
						eq. 2	P/mmHg
						A	7.06376
						B	1261.455
						C	221.982
						Kirchhoff eq.	
						eq. 4	P/mmHg
						A	19.48322
						B	2328
						C	3.92657
						$\Delta H_V/(\mathrm{kJ\ mol^{-1}})$ = 31.67	

2.

Ambrose et al. 1975(a)		Garriga et al. 1996	
comparative ebulliometry		static method-manometry	
t/°C	P/Pa	t/°C	P/Pa
25	12079	5	4277
42.778	26568	10	5644
48.137	33023	15	7334
53.016	39963	20	9435
57.07	46591	25	12071
60.812	53468	30	15281
63.996	59953	35	19110
67.001	66625	40	23682
69.726	73184	45	29132
72.335	79933	50	35540
74.832	86848		
76.944	93063	Antoine eq.	
79.215	100136	eq. 3a	P/kPa
81.262	106887	A	14.133009
83.156	113427	B	2843.871
85.009	120125	C	−53.875
86.711	126545		
88.444	133352		
bp/°C	79.583		
eq. 2	P/kPa		
A	6.18444		
B	1259.223		
C	−51.392		
$\Delta H_V/(\mathrm{kJ\ mol^{-1}})$ =			
at 25°C	34.7		
at bp	31.8		

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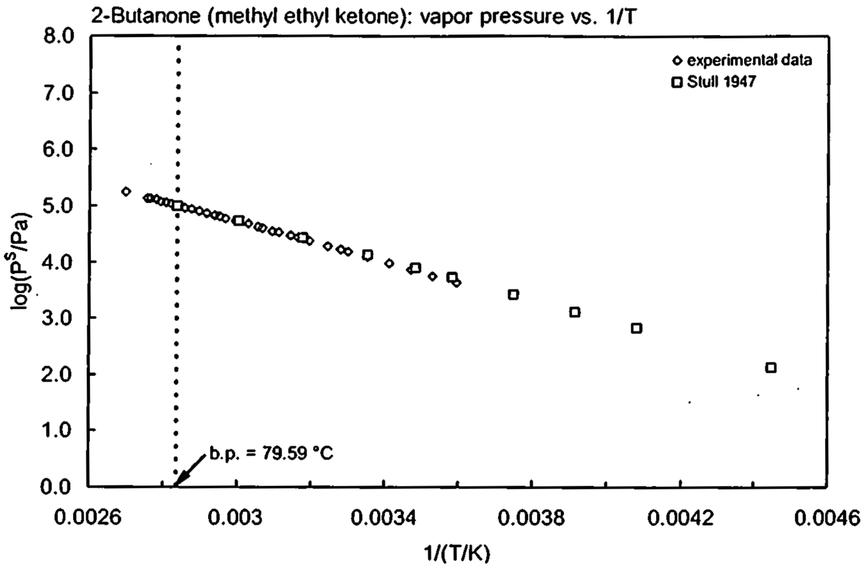


FIGURE 12.1.2.2.2 Logarithm of vapor pressure versus reciprocal temperature for 2-butanone.

TABLE 12.1.2.2.3
Reported Henry's law constants of 2-butanone (methyl ethyl ketone) at various temperatures and temperature dependence equations

$\ln K_{AW} = A - B/(T/K)$ (1)
$\ln (1/K_{AW}) = A - B/(T/K)$ (2)
$\ln (k_H/atm) = A - B/(T/K)$ (3)
$\ln [H/(Pa\ m^3/mol)] = A - B/(T/K)$ (4)
$K_{AW} = A - B\cdot(T/K) + C\cdot(T/K)^2$ (5)

$\log K_{AW} = A - B/(T/K)$ (1a)
$\log (1/K_{AW}) = A - B/(T/K)$ (2a)
$\ln [H/(atm\cdot m^3/mol)] = A - B/(T/K)$ (4a)

Snider & Dawson 1985		Ashworth et al. 1988		Zhou & Mopper 1990			
gas stripping-GC		EPICS-GC		gas stripping-HPLC/UV		gas stripping-HPLC/UV	
t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)
					fresh water		sea water
0	0.9873	10	28.37	10	2.068	10	2.702
25	5.765	15	39.52	17	-	17	3.943
		20	19.25	25	5.117	25	6.666
enthalpy of transfer:		25	13.17	30	7.186	30	8.735
$\Delta H/(kJ\ mol^{-1}) = 46.024$		30	11.15	35	9.296	35	10.78
				40	-	40	14.07
		eq. 4a	H/(atm m³/mol)	45	14.27	45	18.09
		A	−26.32				
		B	−5214	eq. 1a	K_H'/(M/atm)	eq. 1a	K_H'/(M/atm)
				A	−6.03	A	−5.97
				B	−2184	B	−2138

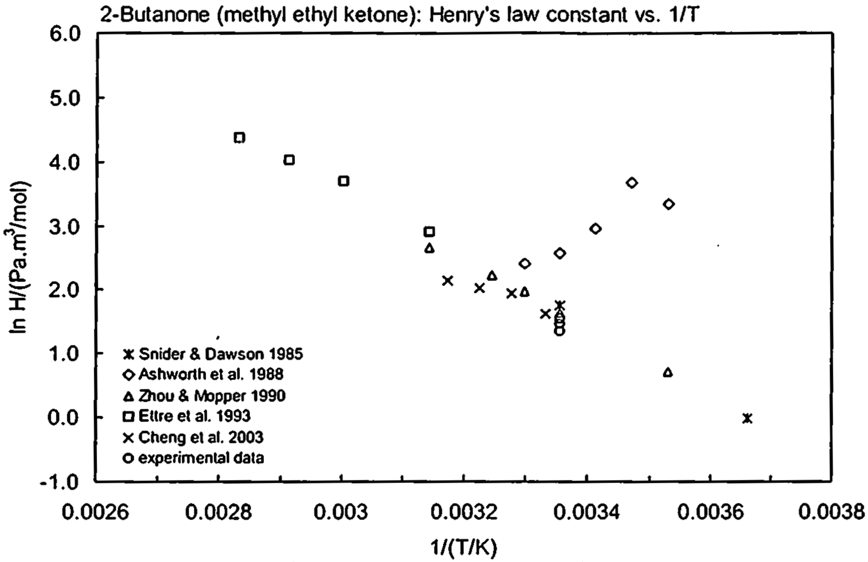
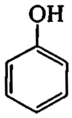


FIGURE 12.1.2.2.3 Logarithm of Henry's law constant versus reciprocal temperature for 2-butanone.

14.1 LIST OF CHEMICALS AND DATA COMPILATIONS

14.1.1 ALKYLPHENOLS AND OTHER SUBSTITUTED PHENOLS

14.1.1.1 Phenol



Common Name: Phenol
Synonym: carbolic acid, phenic acid, phenylic acid, phenyl hydrate, phenyl hydroxide, hydroxybenzene, oxybenzene
Chemical Name: phenol
CAS Registry No: 108-95-2
Molecular Formula: C_6H_5OH
Molecular Weight: 94.111
Melting Point (°C):
40.89 (Lide 2003)
Boiling Point (°C):
181.87 (Lide 2003)
Density (g/cm^3 at 20°C):
1.5479 (supercooled liq., Ericksen & Dobbert 1955)
1.0576 (Weast 1982)
Acid Dissociation Constant, pK_a:
9.90 (Blackman et al. 1955, McLeese et al. 1979)
10.02 (Herington & Kynaston 1957; Callahan et al. 1979)
9.82 (Sillén & Martell 1971; Kaiser et al. 1984; Shigeoka et al. 1988)
10.0 (Serjeant & Dempsey 1979; Paris et al. 1982; Miyake et al. 1987; Tratnyek & Hoigné 1991)
9.92 (Könemann 1981; Könemann & Musch 1981; Ugland et al. 1981; Varhaníčková et al. 1995)
10.05 (Saarikoski 1982; Saarikoski & Viluksela 1982)
9.90 (UV absorption, Hoigné & Bader 1983; Scully & Hoigné 1987)
9.99 (Dean 1985; Schultz & Cajina-Quezada 1987; Hersey et al. 1989)
10.93 (Miyake et al. 1987)
10.12 (UV spectrophotometry, Nendza & Seydel 1988)
Molar Volume (cm^3/mol):
89.0 (20°C, calculated-density)
103.4 (calculated-Le Bas method at normal boiling point)
Enthalpy of Vaporization, ΔH_V (kJ/mol):
56.13, 45.83 (25°C, bp, Dreisbach 1955)
47.30 (at normal bp, Biddiscombe & Martin 1958)
45.689 (at normal boiling point, Andon et al. 1960)
Enthalpy of Sublimation, ΔH_{subl} (kJ/mol):
68.66 (at 25°C, Biddiscombe & Martin 1958; Andon et al. 1960)
Enthalpy of Fusion, ΔH_{fus} (kJ/mol):
11.514 (Riddick et al. 1986)
Entropy of Fusion, ΔS_{fus} (J/mol K):
36.63 (Tsonopoulos & Prausnitz 1971)
36.0, 56.5 (observed, estimated, Yalkowsky & Valvani 1980)
Fugacity Ratio at 25°C (assuming ΔS_{fus} = 56 J/mol K), F: 0.698 (mp at 40.89°C)

Water Solubility (g/m^3 or mg/L at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
86600* (synthetic method, measured range 20–65.86°C, Hill & Malisoff 1926)
83000 (20°C, synthetic method, Jones 1929)
89300* (22.7°C, thermostatic and synthetic methods, measured range 22.7–60.9°C, Morrison 1944)

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88360 (shake flask-UV at pH 5.1, Blackman et al. 1955)
79000* (20°C, synthetic method/shake flask-optical, measured range 0–68.3°C, Ericksen & Dobbert 1955)
80000 (20°C, Mulley & Metcalf 1966)
78000 (shake flask-spectrophotometry, Roberts et al. 1977)
79750 (shake flask-GC, Kraij & Sincic 1980)
76514 (generator column-HPLC, Wasik et al. 1981)
150580 (20°C, shake flask-UV, Hashimoto et al. 1984)
87000 (solid-phase microextraction SPME-GC, Buchholz & Pawliszyn 1994)
84045* (shake flask-conductimetry, measured range 15.1–35°C, Achard et al. 1996)
94100* (25.35°C, shake flask-optical method, measured range 298.5–336.7 K, Jaoui et al. 1999)
83119* (23.15°C, shake flask-optical method, measured range 292.5–333.6 K, Jaoui et al. 2002)
ln [S/(mol kg^{-1})] = 7.3013 – 853.62/(T/K); temp range 288–313 K (eq.-I derived using reported exptl. data, Jaoui et al. 2002)
ln [S/(mol kg^{-1})] = 10.731 – 1931.7/(T/K); temp range 313–332 K (eq.-II derived using reported exptl. data, Jaoui et al. 2002)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):

133.3* (44.8 °C, static method-manometer, measured range 44.8–181.4 °C, Kahlbaum 1898)
28531* (141.1 °C, mercury manometer, measured range 141.1–181.1 °C, Goldblum et al. 1947)
log (P/mmHg) = –2510/(T/K) + 8.395; temp range: 141.1–181.1°C (Hg manometer, Goldblum et al. 1947)
55.54* (extrapolated-regression of tabulated data, temp range 40.1–181.9°C, Stull 1947)
7605* (107.15 °C, ebulliometry, measured range 107.15–181.75 °C, Dreisbach & Shrader 1949)
1333* (70.50 °C, ebulliometry, measured range 70.50–181.7 °C, Vonterres et al. 1955)
70.75 (calculated-Antoine eq., Dreisbach 1955)
log (P/mmHg) = 7.57893 – 1817.0/(205.0 + t/°C), temp range: 93–240°C, (Antoine eq. for liquid state, Dreisbach 1955)
44.26* (24.85°C, gas saturation and diaphragm manometer measurements, measured range 0–37.5°C, Biddiscombe & Martin 1958)
45.71 (gas saturation and diaphragm manometer fitted to Antoine eq., Biddiscombe & Martin 1958)
log (P/mmHg) = 11.5638 – 3586.36/(t/°C + 273); temp range 9–40°C (Antoine eq. from gas-saturation and diaphragm manometer methods, Biddiscombe & Martin. 1958; Andon et al. 1960)
log (P_L/mmHg) = 7.13457 – 1615.072/(t/°C + 174.569); temp range 110–200°C (Antoine eq. from gas-saturation and diaphragm manometer methods, Biddiscombe & Martin. 1958; Andon et al. 1960)
45.07 (interpolated- Antoine eq., Andon et al. 1960)
70.70 (20°C, supercooled liq., Andon et al. 1960)
83.95 (extrapolated supercooled liquid value, Antoine eq., Weast 1972–73)
log (P/mmHg) = [–0.2185 × 11891.5/(T/K)] + 8.513843; temp range 40.1–418.7°C (Antoine eq., Weast 1972–73)
47.01 (extrapolated-Antoine eq., Boublik et al. 1973)
log (P/mmHg) = 7.13301 – 1516.79/(174.954 + t/°C); temp range 107–182°C (Antoine eq. from reported exptl. data of Dreisbach & Shrader 1949, Boublik et al. 1973)
26.66, 133.3 (20°C, 40°C, Verschueren 1977, 1983)
16.27 (extrapolated-Cox eq., Chao et al. 1983)
log (P/mmHg) = [1– 454.610/(T/K)] × 10^{1.00375 – 8.88757 × 10^{-4}·(T/K) + 6.83750 × 10^{-7}·(T/K)^2}; temp range: 323.205–694.25 K, (Cox eq., Chao et al. 1983)
46.91, 54.74 (extrapolated-Antoine eq., Boublik et al. 1984)
log (P/kPa) = 6.25543 – 1515.182/(174.182 + t/°C); temp range 107–181.75°C (Antoine eq. from reported exptl. data of Dreisbach & Shrader 1949, Boublik et al. 1984)
log (P/kPa) = 6.70346 – 1793.899/(200.218 + t/°C); temp range 70.5–181.7°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)
47.00 (extrapolated-Antoine eq., Dean 1985)
log (P/mmHg) = 7.1330 – 1516.79/(174.95 + t/°C); temp range 107–182°C (Antoine eq., Dean 1985, 1992)
55.00 (selected, Riddick et al. 1986)
45.7, 45.32 (interpolated-Antoine eq., Stephenson & Malanowski 1987)

log (P_S/kPa) = 10.6887 – 3586.36/(T/K); temp range 282–313 K (Antoine eq.-I, solid, Stephenson & Malanowski 1987)
log (P_S/kPa) = 10.71099 – 3594.703/(T/K); temp range 273–313 K (Antoine eq.-II, solid, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.25947 – 1516.072/(–98.581 + T/K); temp range 383–473 K (Antoine eq.-III, liquid, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.34757 – 1482.82/(–113.862 + T/K); temp range 455–655 K (Antoine eq.-IV, liquid, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.57957 – 1710.287/(–80.273 + T/K); temp range 314–395 K (Antoine eq.-V, liquid, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.26694 – 1522.07/(–97.834 + T/K); temp range 387–456 K (Antoine eq.-VI, liquid, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.30177 – 1548.368/(–94.612 + T/K); temp range 449–526 K (Antoine eq.-VII, liquid, Stephenson & Malanowski 1987)
log (P_L/kPa) = 6.92874 – 2146.053/(–17.025 + T/K); temp range 520–625 K (Antoine eq.-VIII, liquid, Stephenson & Malanowski 1987)
61.16 (extrapolated-four-parameter vapor pressure eq., Nesterova et al. 1990)
log (P/Pa) = 37.91650 – 4155.615/(T/K) – 9.02308·log (T/K) + 0.04526 × 10^{-2}·(T/K); temp range: 394–455 K (four-parameter vapor pressure eq. using exptl data of Biddiscombe & Martin 1958, Nesterova et al. 1990)
log (P/Pa) = 127.08645 – 7292.585/(T/K) – 42.92601·log (T/K) + 1.76834 × 10^{-2}·(T/K); temp interval of investigation 380–455 K (four-parameter vapor pressure eq. derived using data of Dreisbach & Shrader 1949, Nesterova et al. 1990)
log (P/mmHg) = 23.5332 – 3.4961 × 10^3/(T/K) – 4.899·log (T/K) + 1.216 × 10^{-4}·(T/K) + 9.6537 × 10^{-13}·$(T/K)^2$; temp range 314–694 K (vapor pressure eq., Yaws 1994)
173* (40.09°C, ebulliometry, measured range 40–90°C, Tabai et al. 1997)

Henry's Law Constant (Pa m^3/mol at 25°C or as indicated and reported temperature dependence equations. Additional data at other temperatures designated * are compiled at the end of this section):
0.0402 (exptl., Hine & Mookerjee 1975; Howard 1989)
0.065, 1.082 (calculated-group contribution, calculated-bond contribution, Hine & Mookerjee 1975)
0.0718* (27.0°C, gas stripping-GC, measured range –2.0 to 27.0°C Abd-El-Bary et al. 1986)
k_H/kPa = 2.69 × 10^9 exp[–6120/(T/K)], temp range –2 to 90°C (gas stripping-GC measurements plus reported data at higher temp., Abd-El-Bary et al. 1986)
1.245, 2.193, 3.322 (75.9, 88.7, 98.5°C, vapor-liquid equilibrium-GC, Dohnal & Fenclová 1995)
0.0607* (extrapolated from temp dependence eq., Dohnal & Fenclová 1995)
ln K_{AW} = 8.701 – 5760/(T/K), temp range 20–100°C (vapor-liquid equilibrium measurements with additional literature data, Dohnal & Fenclová 1995)
0.0342* (313.24 K, derived from measured P, temp range 313.240–363.14 K, Tabai et al. 1997)
k_H/kPa = 670.117 – 39274.5/(T/K) – 94.6679; temp range 313-363 K (activity coefficient by ebulliometric method, Tabai et al. 1997)
< 0.240 (gas stripping-GC, Altschuh et al. 1999)
0.0536 (20°C, single equilibrium static technique SEST, Sheikheldin et al. 2001)
0.0320* (gas stripping-UV, measured range 284–302 K, Harrison et al. 2002)
ln [H/(M atm^{-1})] = 5850/(T/K) – 11.6; temp range 284–302 K, Harrison et al. 2002)
0.157* (dynamic equilibrium/gas stripping-GC/MS, measured range 5–25°C, Feigenbrugel et al. 2004)

Octanol/Water Partition Coefficient, log K_{OW}. Additional data at other temperatures designated * are compiled at the end of this section:
1.46 (shake flask-UV, Fujita et al. 1964)
1.46 ± 0.01 (shake flask-UV, Iwasa et al. 1965)
1.42 (shake flask-UV at pH 7.4, Rogers & Cammarata 1969)
1.60 (shake flask, Kiezyk & Mackay 1971)
1.47 (Leo et al. 1971)
1.51 (shake flask-UV at pH 7.45, Umeyama et al. 1971)
1.49 (shake flask, Korenman 1972)

1.510* (20 °C, shake flask-concn ratio, measured range 10–60 °C, Korenman & Udalova 1974)
1.46, 1.61 (LC-k′ correlation, calculated-π const., Carlson et al. 1975)
1.54 (shake flask-UV, Davis et al. 1976)
1.45 (HPLC-RT correlation, Mirrlees et al. 1976)
1.48 ± 0.02 (shake flask at pH 7, Unger et al. 1978)
1.48, 1.46, 1.49, 1.51, 0.62, 2.20 (literature values, Hansch & Leo 1979)
1.46 (HPLC-k′ correlation, Butte et al. 1981; Butte et al. 1987)
1.45 (generator column-HPLC/UV, Wasik et al. 1981)
1.54 (RP-HPLC-k′ correlation, D'Amboise & Hanai 1982)
1.28, 1.54 (RP-LC-k′ correlation, calculated-fragment const. as per Rekker 1977, Hanai & Hubert 1982)
1.54 (HPLC-k′ correlation, Miyake & Terada 1982; Miyake et al. 1987)
1.62 (inter-laboratory, shake flask average, Eadsforth & Moser 1983)
1.16 (inter-laboratory, HPLC average, Eadsforth & Moser 1983)
1.49, 1.53 ± 0.09 (selected best lit. value, exptl.-ALPM, Garst 1984)
1.46, 1.55 ± 0.07 (selected best lit. value, exptl.-ALPM, Garst & Wilson 1984)
1.08 (calculated-activity coeff. γ from UNIFAC, Campbell & Luthy 1985)
1.46 (RP-HPLC-RT correlation, Chin et al. 1986)
1.00, 1.42 (HPLC-k′ correlation, Eadsforth 1986)
1.46 (shake flask-CPC centrifugal partition chromatography, Berthod et al. 1988)
1.46 (RP-HPLC-capacity ratio correlation, Minick et al. 1988)
1.46 (HPLC-RT correlation, Shigeota et al. 1988)
1.52 ± 0.01 (filter chamber-UV, Hersey et al. 1989)
1.50 (recommended, Sangster 1989, 1993)
1.52, 1.58, 1.69 (CPC-RV correlation, Gluck & Martin 1990)
1.47 (shake flask-UV, Kramer & Henze 1990)
1.37 ± 0.06 (liquid-liquid extraction-flow injection-UV, Kubá 1991)
1.57 (shake flask-GC, Kishino & Kobayashi 1994)
1.46 (recommended, Hansch et al. 1995)

Bioconcentration Factor, log BCF:
4.16 (total ^{14}C in fathead minnow, mean exposure level 0.0025 μg·mg^{-1}, Call et al. 1980)
4.23 (total ^{14}C in fathead minnow, mean exposure level 0.0327 μg·mg^{-1}, Call et al. 1980)
4.20 (total ^{14}C in fathead minnow, mean value, Call et al. 1980)
2.20 (goldfish, rate constant ratio k_1/k_2, Nagel & Urich 1980)
0.97 (microorganisms-water, calculated-K_{OW}, Mabey et al. 1982)
1.30, 2.30, 3.34 (golden ide, algae, activated sludge, Freitag et al. 1985)
2.30 (*chlorella fusca*, Freitag et al. 1985; quoted, Howard 1989)
1.20 (algae, maximum apparent BCF, Hardy et al. 1985)
0.544 (algae, real BCF with biotransformation, Hardy et al. 1985)
3.14 (*daphnia magna*, estimated-^{14}C activity and on dry wt. basis, Dauble et al. 1986)
2.44 (*daphnia magna*, based on elimination phase, Dauble et al. 1986)
1.28 (*daphnia magna*, Dauble et al. 1986; quoted, Geyer et al. 1991)
1.24 (zebrafish, Butte et al. 1987)

Sorption Partition Coefficient, log K_{OC}:
1.43 (soil, Kenaga & Goring 1980)
1.48 (20°C, sorption isotherm, converted form K_{OM} organic carbon in soils, Briggs 1981)
1.15 (sediment-water, calculated-K_{OW}, Mabey et al. 1982)
1.57, 1.96 (silt loams, Scott et al. 1983, quoted, Howard 1989)
3.46 (untreated fine sediment, Isaacson & Frink 1984)
3.49 (untreated coarse sediment, Isaacson & Frink 1984)
1.35 (HPLC-k′ correlation, mobile phase buffered to pH 3, Hodson & Williams 1988)
2.17 (soil, calculated-K_{OW}, Howard 1989)
2.4, 2.43 (soil: quoted, calculated-MCI χ, Meylan et al. 1992)

2.68, 2.38 (natural zeolite modified with a cation surfactant HDTMA with surface coverage of 100, 200 mmol/kg at pH 7, shake flask-sorption isotherm, Li et al. 2000)
1.43 (soil, calculated-MCI $^1\chi$, Sabljic et al. 1995)
1.42, 1.00. 1.24 (RP-HPLC-k′ correlation on 3 different stationary phases, Szabo et al. 1995)
1.59, 1.67 (HP:LC-k′ correlation, C_{18} column, Hong et al. 1996)
1.32; 2.43 (HPLC-screening method; calculated-PCKOC fragment method, Müller & Kördel 1998)
1.56, 1.556, 1.255, 1.307, 1.52 (soil, first generation Eurosoils ES-1, ES-2, ES-3, ES-4, ES-5, shake flask/batch equilibrium-HPLC/UV, Gawlik et al. 1998, 1999)
1.310, 1.750, 1.281, 1.601, 1.544 (soil, second generation Eurosoils ES-1, ES-2, ES-3, ES-4, ES-5, shake flask/batch equilibrium-HPLC/UV, Gawlik et al. 1999)
1.310, 1.750, 1.281, 1.601, 1.544 (soil, second generation Eurosoils ES-1, ES-2, ES-3, ES-4, ES-5, shake flask/batch equilibrium-HPLC/UV and HPLC-k′ correlation, Gawlik et al. 2000)
1.37, 1.34 (soils: organic carbon OC ≥ 0.1% and pH 3.2–7.4, OC ≥ 0.5%, average, Delle Site 2001)

Environmental Fate Rate Constants, k, or Half-lives, $t_{1/2}$:

Volatilization: estimated $t_{1/2}$ ~ 3.2 months for evaporation from water (Howard 1989);
$t_{1/2}$ = 88 d, calculated for evaporation from a model river of 1 m deep with a current of 3 m/s and with a wind velocity of 3 m/s (Lyman et al. 1982; quoted, Howard 1989).

Photolysis: phototransformation rate $k = 0.015\ h^{-1}$ with $t_{1/2}$ = 46 h in the summer (mean temp 24°C) and $k = 0.0040\ h^{-1}$ with $t_{1/2}$ = 173 h in the winter (mean temp 10°C) in distilled water; $k = 0.018\ h^{-1}$ with $t_{1/2}$ = 39 h in the summer and $k = 0.0074\ h^{-1}$ with $t_{1/2}$ = 94 h in the winter in estuarine water when exposed to full sunlight and microbes (Hwang et al. 1986);
photomineralization rate $k = 0.04\ h^{-1}$ with $t_{1/2}$ = 16 d in the summer and $k = 0.0041\ h^{-1}$ with $t_{1/2}$ = 169 d in the winter in distilled water; $k = 0.095\ h^{-1}$ with $t_{1/2}$ = 7 d in the summer and $k = 0.010\ h^{-1}$ with $t_{1/2}$ = 73 d in winter in estuarine water when exposed to full sunlight and microbes (Hwang et al. 1986);
atmospheric $t_{1/2}$ = 46 to 173 h, based on reported half-life for photolysis under sunlight for phenol in distilled water in the summer and winter; aquatic photolysis $t_{1/2}$ = 46 to 173 h, based on reported half-life for photolysis under sunlight for phenol in distilled water in the summer and winter (Howard et al. 1991)
Apparent first-order rate constant phototransformation at $\lambda > 285$ nm, $k = (3.10 \pm 0.10) \times 10^{-2}\ h^{-1}$ in purified water (Zamy et al. 2004)

Oxidation: rate constant k, for gas-phase second order rate constants, k_{OH} for reaction with OH radical, k_{NO3} with NO_3 radical and k_{O3} with O_3 or as indicated, *data at other temperatures see reference:
$k = 1 \times 10^4\ M^{-1}\ s^{-1}$ for the reaction with RO_2 radical at 30°C in aquatic systems with $t_{1/2}$ = 0.8 d (Howard 1972; Hendry et al. 1974; quoted, Mill 1982)
$k < 2 \times 10^2\ M^{-1}\ s^{-1}$ for the reaction with singlet oxygen at 25°C with $t_{1/2}$ > 100 yr (Foote 1976; Mill 1979; quoted, Mill 1982)
$k_{NO3} = (2.0 \pm 0.4) \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at (300 ± 1) K (Carter et al. 1981)
$k = 6.5 \times 10^3\ s^{-1}$, dye-sensitized photooxidation first-order rate constant, second order $k = (1.3 \pm 0.2) \times 10^3\ M^{-1}\ s^{-1}$ for the reaction with ozone in water using 1 mM PrOH as scavenger at pH 1.7–2.0 and 20–23°C (Hoigné & Bader 1983a)
$k_{NO3} = (2.10 \pm 0.50) \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at 296 ± 2 K (Atkinson et al. 1984)
$k_{NO3} = (3.64 \pm 0.14) \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at 294 K with reference to reaction for NO_3 radical with 2-methyl-2-butene (Atkinson et al. 1984; quoted, Atkinson 1991)
$k_{OH}(exptl) = 28.0 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$, $k_{OH}(calc) = 45.5 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at room temp. (Atkinson et al. 1985)
$k_{OH}(calc) = 36 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$, and $k_{OH}(obs) = 28.3 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at room temp. (SAR, Atkinson 1987; quoted, Sabljic & Güsten 1990; Müller & Klein 1991)
$k = (2\ to\ 3) \times 10^6\ M^{-1}\ s^{-1}$ at pH 8, $1.9 \times 10^7\ M^{-1}\ s^{-1}$ at pH 9, $4.6 \times 10^7\ M^{-1}\ s^{-1}$ at pH 9.5, $9.0 \times 10^7\ M^{-1}\ s^{-1}$ at pH 10 and $1.8 \times 10^8\ M^{-1}\ s^{-1}$ at pH 11.5 for the reaction with singlet oxygen at (19 ± 2)°C in water (Scully & Hoigné 1987)
$k_{NO3} = 3.63 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at 298 K (Atkinson et al. 1988; quoted, Sabljic & Güsten 1990; Müller & Klein 1991)
$k_{OH} = 26.3 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at 298 K (recommended, Atkinson 1989, 1990)
$k_{NO3} = (2.59 \pm 0.52) \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at 300 ± 1 K with reference to reaction for NO_3 radicals with *cis*-2-butene (Atkinson 1991)

$k = (2.6 \pm 4) \times 10^6\ M^{-1}\ s^{-1}$ for the reaction with singlet oxygen in aqueous phosphate buffer at (27 ± 1)°C (Tratynyek & Hoigné 1991)
$k_{OH} = 10.45 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$, $k_{NO3} = 11.44 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ (Müller & Klein 1991)
$k_{NO3} = (3.92 \pm 0.25) \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at 296 ± 2 K with reference to reaction for NO_3 radical with 2-methyl-2-butene; $k_{OH} = 26.5 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ at room temp. (Atkinson et al. 1992)
$k_{OH}(calc) = 12 \times 10^{-12}\ cm^3\ molecule^{-1}\ s^{-1}$ (molecular orbital estimation method, Klamt 1993)
$k_{OH} = 2.6 \times 10^{-11}\ cm^3\ mol^{-1}\ s^{-1}$, and $k_{OH}(aq.) = 6.7 \times 10^9\ M^{-1}\ s^{-1}$, the calculated atmospheric lifetime $\tau = 0.45$ d under clear sky; $\tau = 0.38$ d under cloudy conditions at 298 K, reduced to 0.26 d due the average temperature of tropospheric clouds at 283 K (Feigenbrugel et al. 2004)
Hydrolysis: no hydrolyzable function group (Howard et al. 1991).
Biodegradation: $t_{1/2}$ =1–2 d for bacteria to utilize 95% of 300 ppm in parent substrate (Tabak et al. 1964)
decomposition by soil microflora within 1 d (Alexander & Lustigman 1966; quoted, Verschueren 1983)
complete disappearance in soil suspensions in 2 d (Woodcock 1971; quoted, Verschueren 1983)
$k_B = 80.0$ mg COD $g^{-1}\ h^{-1}$ based on measurements of COD decrease using activated sludge inoculum with 20–d of adaptation to the substrate (Pitter 1976; quoted, Scow 1982)
$k_B = (0.094 \pm 0.003)\ h^{-1}$ at feed concentration of 180 mg/L at 20°C and $k = (0.095 \pm 0.007)\ h^{-1}$ at feed concentration of 360 mg/L at 20°C in a continuous stirred reactor (Beltrame et al. 1984)
$k_B = 0.035\ d^{-1}$ with $t_{1/2} = 20$ d in ground water; $k_B = 0.065\ d^{-1}$ with $t_{1/2} = 11$ d in Lester River water; $k_B = 0.247\ d^{-1}$ with $t_{1/2} = 3$ d in Superior harbor waters (Vaishnav & Babeu 1987)
$k_B = 0.03\ h^{-1}$ and $t_{1/2} = 28$ h for estuarine water in summer (mean temp 24°C) and $k_B = 0.011\ h^{-1}$ with $t_{1/2} = 62$ h in winter (mean temp. 10°C); $k_B = 0.4\ h^{-1}$ with $t_{1/2} = 2$ d in summer and $k_B = 0.0051\ h^{-1}$ with $t_{1/2} = 146$ d in winter in darkness with microbes (Hwang et al. 1986)
$k_B = 0.041–0.028\ h^{-1}$ in 10–100 mg/L sludge (Urano & Kato 1986)
complete degradation within 1 d in water from 3 lakes, and degradation is somewhat slower in salt water with $t_{1/2} = 9$ d in estuary river (Howard 1989)
k_B(exptl., average) = $0.0498\ h^{-1}$; $k_B(calc) = 0.0545\ h^{-1}$ (nonlinear) and $k_B(calc) = 0.0503\ h^{-1}$ (linear) (group contribution method, Tabak & Govind 1993)
$t_{1/2}$(aerobic) = 0.25 d, $t_{1/2}$(anaerobic) = 8.0 d in natural waters (Capel & Larson 1995)
Biotransformation: microbial transformation $k = (7.1 \pm 1.3) \times 10^{-12}$ L·organism$^{-1}\ h^{-1}$ (Paris et al. 1982);
estimated bacterial transformation $k = 3 \times 10^{-6}$ mL cell$^{-1}\ h^{-1}$ in water (Mabey et al. 1982);
microbial transformation rate constants in pond and river samples $k = (2.0 \pm 1.5) \times 10^{-10}$ to $(4.8 \pm 3.1) \times 10^{-10}$ L organism$^{-1}\ h^{-1}$ at five different sites (Paris et al. 1983; quoted, Steen 1991);
degradation rate constants $k = 1.08 \times 10^{-16}$ mol cell$^{-1}\ h^{-1}$ from pure culture studies and $k = 0.90 \times 10^{-12}$ to 3.00×10^{-12} mol cell$^{-1}\ h^{-1}$ with microorganisms in Seneca River waters (Banerjee et al. 1984).
Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants:
$k_1 = 3.15\ h^{-1}$; $k_2 = 0.02\ h^{-1}$ (goldfish, Nagel & Urich 1980)

Half-Lives in the Environment:
Air: $t_{1/2} = 0.61$ d by reaction with OH radicals in air (Howard 1989);
$t_{1/2} = 2.28$ to 22.8 h, based on reaction with OH radical (Howard et al. 1991)
degradation $k = 0.0462\ d^{-1}$ corresponding to $t_{1/2} = 360$ h in air (Guinee & Heijungs 1993);
atmospheric transformation lifetime was estimated to be < 1 d (Kelly et al. 1994);
calculated lifetimes of 5.3 h and 9.0 min for reactions with OH, NO_3 radical, respectively (Atkinson 2000).
atmospheric lifetime $\tau = 0.45$ d under clear sky and $\tau = 0.38$ d under cloudy conditions based on reactions with OH radical in gas and aqueous phases at 298 K, reduced to $\tau = 0.26$ d due to average temperature of tropospheric cloud at 283 K (Feigenbrugel et al. 2004)
Surface water: rate constant $k = (1.3 \pm 0.2) \times 10^3\ M^{-1}\ s^{-1}$ for the reaction with ozone at pH 2.0–6.0 (Hoigné & Bader 1983);
$t_{1/2} = 46$ h in summer, $t_{1/2} = 173$ h in winter in distilled water and $t_{1/2} = 39$ h in summer, $t_{1/2} = 94$ h in winter in estuarine water, based on phototransformation rate when exposed to full sunlight and microbes (Hwang et al. 1986)
$t_{1/2} = 43$ h in summer, $t_{1/2} = 118$ h in winter in poisoned estuarine water, based on photo-transformation rate and $t_{1/2} = 384$ h or 16 d in summer, $t_{1/2} = 2640$ h or 110 d in winter in poisoned estuarine water, based on photomineralization rate (Hwang et al. 1986);

$t_{1/2}$ = 384 h or 16 d in summer, $t_{1/2}$ = 4056 h or 169 d in winter in distilled water; and $t_{1/2}$ = 168 h or 7 d in summer, $t_{1/2}$ = 1752 h or 73 d in winter in estuarine water, based on photo-mineralization rate when exposed to full sunlight and microbes (Hwang et al. 1986);

$t_{1/2}$ = 2000 h in water at pH 8 and 19 ± 2°C for the reaction with singlet oxygen (Scully & Hoigné 1987);

biodegradation $t_{1/2}$ = 11 d in river waters and $t_{1/2}$ = 3 d in Superior harbor waters (Vaishnav & Babeu 1987);

complete degradation within 1 d in water from 3 lakes, and degradation is somewhat slower in salt water with $t_{1/2}$ = 9 d in estuary river (Howard 1989);

$t_{1/2}$ = 77 to 3840 h in water, based on reported reaction rate constant for RO_2 radical with the phenols class, $t_{1/2}$ = 5.3 to 56.5 h, based on estimated aqueous aerobic biodegradation half-life (Howard et al. 1991);

degradation rate constant $k = 0.0217\ d^{-1}$ corresponding to a $t_{1/2}$ = 766 h in water (quoted from Howard 1989, Guinee & Heijungs 1993)

$t_{1/2}$(aerobic) = 0.25 d, $t_{1/2}$(anaerobic) = 8 d in natural waters (Capel & Larson 1995)

Groundwater: biodegradation $t_{1/2}$ = 20 d (Vashinav & Babeu 1987);

$t_{1/2}$ = 12 to 168 h, based on estimated aqueous aerobic biodegradation half-life (Howard et al. 1991).

Soil: Days for complete disappearance by microbial decomposition in soil suspension: 2 d in Dunkirk silt loam, 1 d in Mardin silt loam (Alexander & Aleem 1961)

degradation in soil completed in 2–5 d even in subsurface soils and $t_{1/2}$ = 2.70 and 3.51 h of low concentration of phenol in 2 silt loam soils (Howard 1989);

$t_{1/2}$ = 24 to 240 h, based on aerobic soil die-away data (Howard et al. 1991);

$t_{1/2}$ = 4.1 d in a slightly basic sandy loam soil containing 3.25% organic matter and $t_{1/2}$ = 23 d in acidic clay soil with < 1.0% organic matter, based on aerobic batch lab microcosm experiments (Loehr & Matthews 1992)

degradation rate constant $k = 0.227\ d^{-1}$ corresponding to a $t_{1/2}$ = 73.3 h in soil (quoted from Howard 1989, Guinee & Heijungs 1993).

Biota: elimination from goldfish within 4 h (Nagel & Urich 1980);

depuration $t_{1/2}$(obs) = 336 h, $t_{1/2}$(calc) = 385 h for exposure level of 0.0025 μg mL^{-1} and $t_{1/2}$(obs.) = 438 h, $t_{1/2}$(calc) = 497 h for exposure level of 0.0375 μg mL^{-1} (Call et al. 1980);

depuration $t_{1/2}$(calc) = 8 to 44 min in algae (Hardy et al. 1985);

half-lives in fish $t_{1/2}$ < 1 d for goldfish, $t_{1/2}$ = 14–18 d for minnow (Niimi 1987)

TABLE 14.1.1.1.1
Reported aqueous solubilities of phenol at various temperatures

1.

Hill & Malisoff 1926		Morrison 1944		Erichsen & Dobbert 1955		Achard et al. 1996	
volumetric method		thermostatic and synthetic		shake flask-optical method		shake flake-conductivity	
t/°C	$S/g\cdot m^{-3}$	t/°C	$S/g\cdot m^{-3}$	t/°C	$S/g\cdot m^{-3}$	t/°C	$S/g\cdot m^{-3}$
20.0	83600	22.7	89300	0	73000.	15.1	76044
25.0	86600	26.9	93159	10	75000	25.0	84045
30.0	92200	32.3	98617	20	79000	35.0	93098
35.0	99100	36.0	104169	30	86000		
57.30	148700	43.7	108968	40	97000		
62.74	193500	47.7	128823	50	115000		
65.79	277700	50.5	138892	60	153000		
66.01	291300	53.5	149807	62	166000		
65.79	202100	55.8	162323	64	183000		
65.84	313500	57.8	174650	66	215000		
65.86	322300	60.9	203538	67	252000		
65.84	327900			68	316000		
				68.3	365000		

(Continued)

TABLE 14.1.1.1.1 *(Continued)*

2.

Jaoui et al. 1999		Jaoui et al. 2002	
static visual method		static visual method*	
T/K	S/g·m^{-3}	T/K	S/g·m^{-3}
298.5	94100	292.5	81011
307.5	99328	296.1	82959
313.4	104556	296.3	83119
313.7	143764	300.2	86290
319.8	118149	302.7	88341
324.8	134877	305.8	90901
331.5	151606	308.4	93065
336.7	182970	313.3	97186
		315.4	100169
		322.4	114416
		326.8	124024
		331.3	134394
		333.6	139814

some data from Achard et al. 1996, Jaoui et al. 1999

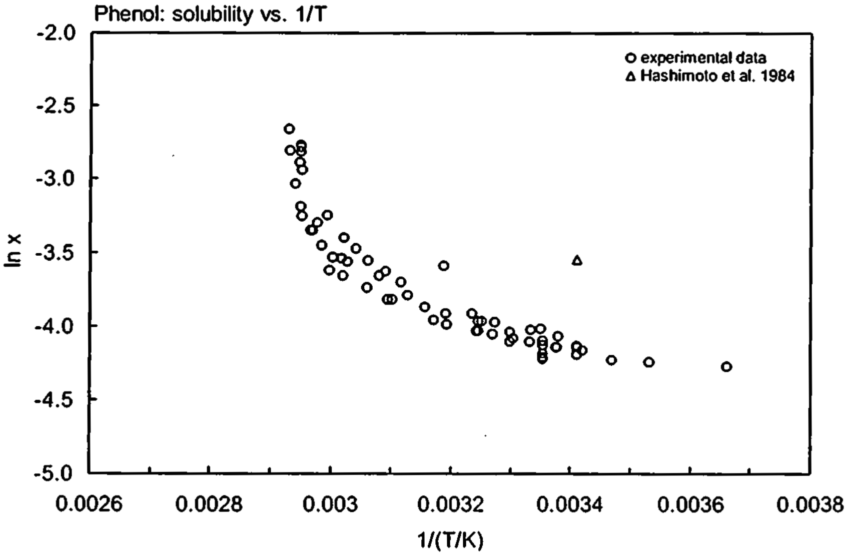

FIGURE 14.1.1.1.1 Logarithm of mole fraction solubility (ln *x*) versus reciprocal temperature for phenol.

TABLE 14.1.1.1.2

Reported vapor pressures of phenol at various temperatures and the coefficients for the vapor pressure equations

$\log P = A - B/(T/K)$	(1)	$\ln P = A - B/(T/K)$	(1a)
$\log P = A - B/(C + t/°C)$	(2)	$\ln P = A - B/(C + t/°C)$	(2a)
$\log P = A - B/(C + T/K)$	(3)		
$\log P = A - B/(T/K) - C\cdot\log (T/K)$	(4)		

1.

Kahlbaum 1898*		Stull 1947		Goldblum et al. 1947		Dreisbach & Shrader 1949	
static-manometer		summary of literature data		mercury manometer		ebulliometry	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
44.8	133.3	40.1	133.3	141.1	28531	107.15	7605
51.5	266.6	62.5	666.6	152.6	42263	113.81	10114
55.8	400.0	73.8	1333	164.4	61061	125.95	16500
59.3	533.3	86.0	2666	168.3	68661	152.37	42066
62.5	666.6	100.1	5333	173.5	80127	167.63	67661
73.5	1333.2	108.4	7999	181.0	98659	181.75	101325
85.8	2666.4	121.4	13332	140.2	27598		
93.8	3999.7	139.0	26664	145.1	32797	bp/°C	181.75
99.8	5533	160.0	53329	171.4	75194		
104.4	6661	181.9	101325	176.6	87060		
113.7	9992			181.1	98525		
120.2	13332	mp/°C	40.6				
139.0	26664			eq. 1	P/mmHg		
151.0	39997			A	8.395		
160.0	53329			B	2510		
167.0	66661						
173.0	79993						
179.0	93326						
181.4	101325						

*complete list see ref.

2.

Vonterres et al. 1955		Biddiscombe & Martin 1958				Tabai et al. 1997	
ebulliometry		gas saturation/diaphragm manometer				ebulliometry	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
		solid		liquid			
70.50	1333	0	3.746	121.25	13583	40.09	173
90.20	3333	5.1	6.159	131.183	20005	50.0	345
104.2	6666	9.25	9.413	138.014	25635	60.0	655
113.0	9999	9.85	10.40	140.704	28226	70.03	1187
121.5	13332	10.4	10.47	147.204	35310	79.97	2048
132.5	19998	14.5	16.0	155.343	46139	89.99	3415
140.1	26664	18.25	22.93	156.196	47902		
147.0	33330	18.25	23.20	156.528	53130		
152.0	39997	19.6	26.66	159.799	54843		
153.0	43330	22.0	35.60	160.124	58843		
156.0	46663	24.85	44.26	163.795	60104		
160.0	53329	28.15	63.73	168.945	70154		

(Continued)

TABLE 14.1.1.1.2 *(Continued)*

Vonterres et al. 1955		Biddiscombe & Martin 1958				Tabai et al. 1997	
ebulliometry		gas saturation/diaphragm manometer				ebulliometry	
t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa	t/°C	P/Pa
164.0	59995	30.5	74.39	169.991	72357		
167.0	73327	32.95	92.93	171.025	74590		
170.5	73327	35.0	108.5	172.635	78154		
173.0	79993	37.45	138.7	173.066	79148		
176.0	86659			175.767	85526		
179.0	93325	bp/°C	181.839	178.196	91590		
181.7	101325			179.878	94918		
		Antoine eq. for temp range:		180.863	98625		
		0–40°C		181.551	100497		
		eq. 1	P/mmHg	182.053	101904		
		A	11.5638				
		B	3586.36	Antoine eq. for temp range:			
		C	273	110–200°C			
				eq. 2	P/mmHg		
		ΔH_V/(kJ mol^{-1})		A	7.13457		
		at bp	47.304	B	1516.072		
		at 25°C	68.66	C	174.569		

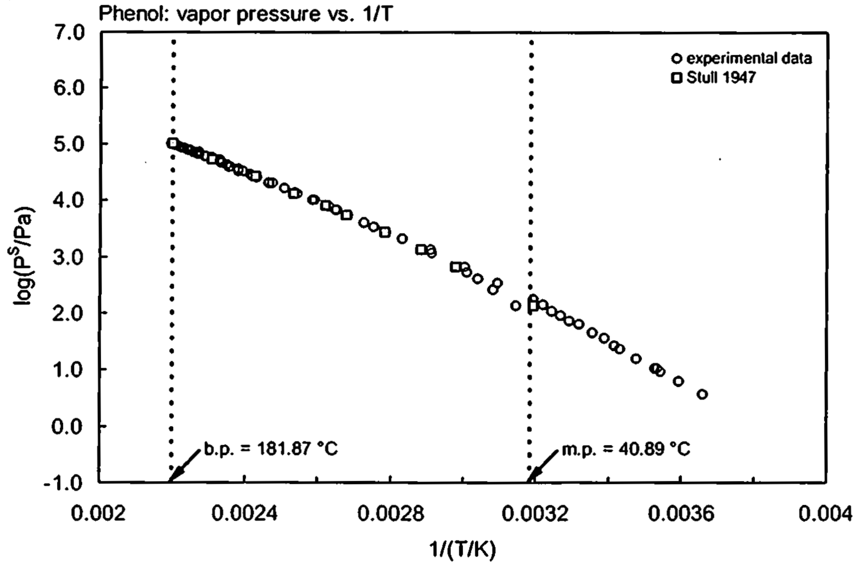

FIGURE 14.1.1.1.2 Logarithm of vapor pressure versus reciprocal temperature for phenol.

TABLE 14.1.1.1.3
Reported Henry's law constants of phenol at various temperatures and temperature dependence equations

$\ln K_{AW} = A - B/(T/K)$ (1)
$\ln (1/K_{AW}) = A - B/(T/K)$ (2)
$\ln (k_H/\text{atm}) = A - B/(T/K)$ (3)
$\ln H = A - B/(T/K)$ (4)
$\ln k_H = A - B/(T/K) - C\cdot\ln (T/K)$ (5)
$\log K_{AW} = A - B/(T/K)$ (1a)
$\log (1/K_{AW}) = A - B/(T/K)$ (2a)
$\log H = A - B/(T/K)$ (4a)

Abd-El-Bary et al. 1986		Dohnal & Fenclová 1995		Tabai et al. 1997		Feigenbrugel et al. 2004	
gas stripping-GC/FID		vapor-liquid equilibrium		derived from measured P		gas stripping-GC/MS	
t/°C	H/(Pa m³/mol)	t/°C	H/(Pa m³/mol)	T/K	H/(Pa m³/mol)	T/K	H/(Pa m³/mol)
−2.0	0.0072	4.0	0.0127*	313.24	0.0342	278.15	0.0222
4.0	0.0127	18.3	0.0373*	323.15	0.090	278.15	0.0299
18.3	0.0373	27.0	0.0721*	333.15	0.202	278.20	0.0280
27.0	0.0718	80.3	1.552*	343.18	0.355	278.25	0.0337
44.4	0.193*	100.0	3.537*	353.12	0.506	283.05	0.0340
56.3	0.437*	75.9	1.245	363.14	0.999	283.15	0.0456
75.0	1.233*	88.7	2.193			283.15	0.0328
90.0	2.376*	98.6	3.322	eq. 5	k_H/kPa	283.25	0.0428
		25.0	0.0607#	A	670.117	283.25	0.0404
*data from literature		25.0	0.0605$	B	29374.5	288.15	0.0590
		#calculated from eq. 1		C	94.6679	288.15	0.0928
		$calculated from eq. 3		temp range 313–363 K		288.25	0.0560
		*data from literature				293.15	0.1166
eq. 3	k_H/kPa					293.15	0.169
A	21.7128	eq. 1	K_{AW}	Harrison et al. 2002		293.15	0.1093
B	6120.0	A	8.701	gas stripping-UV		293.15	0.1065
eq. derived included lit. data		B	5760	T/K	H/(Pa m³/mol)	293.25	0.0960
		enthalpy of hydration:				293.25	0.1071
		$\Delta H_K/(\text{kJ mol}^{-1}) = 47.9 \pm 0.5$		284	0.0122	298.15	0.0904
		OR		284.5	0.0110	298.15	0.2022
		eq. 3	k_H/kPa	289.5	0.0199	298.15	0.1375
		A	21.443	293.5	0.0262		
		B	6032	298	0.0320		
		$\Delta H_K/(\text{kJ mol}^{-1}) = 50.2 \pm 0.4$		302	0.0379		
				eq. 4	H/(M atm⁻¹)		
				A	−11.6		
				B	−5850		

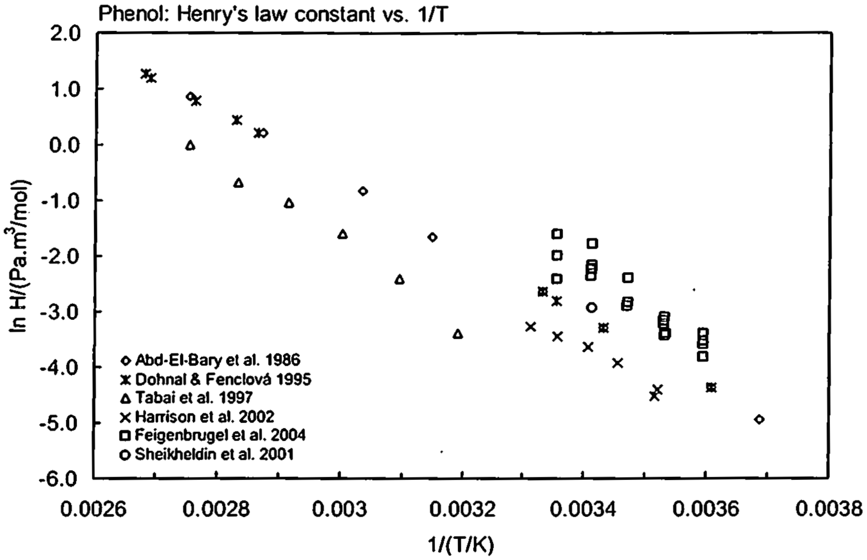

FIGURE 14.1.1.1.3 Logarithm of Henry's law constant versus reciprocal temperature for phenol.

TABLE 14.1.1.1.4
Reported octanol-water partition coefficients of phenol at various temperatures

Korenman & Udalova 1974	
shake flask-concn ratio	
t/°C	log K_{OW}
10	1.531
20	1.510
30	1.461
40	1.433
50	1.396
60	1.369
log K_{OW} = A – B/(T/K)	
A	0.4479
B	–305.877

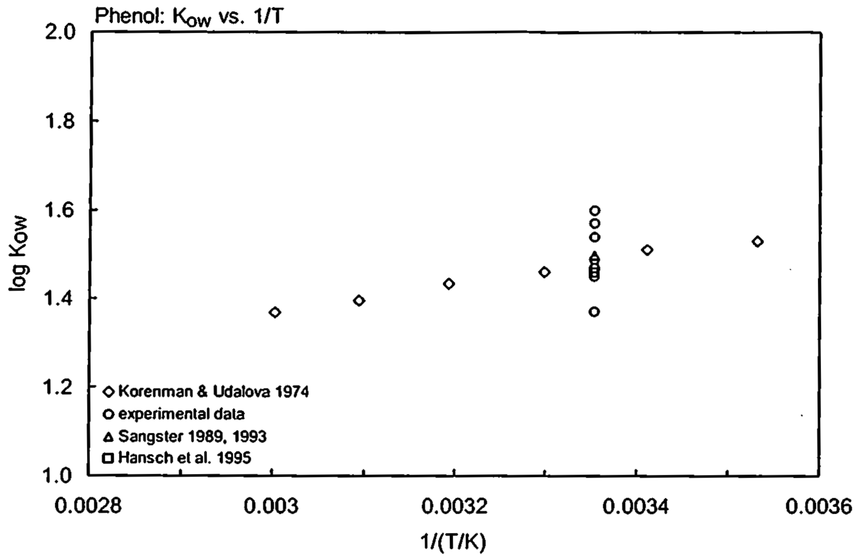

FIGURE 14.1.1.1.4 Logarithm of K_{OW} versus reciprocal temperature for phenol.

10.1.1.11 Tetrahydrofuran

Common Name: Tetrahydrofuran
Synonym: 1,4-epoxybutane, diethylene oxide, oxacyclopentane, tetramethylene oxide
Chemical Name: 1,4-epoxybutane, diethylene oxide, oxacyclopentane, tetrahydrofuran, tetramethylene oxide
CAS Registry No: 109-99-9
Molecular Formula: C_4H_8O
Molecular Weight: 72.106
Melting Point (°C):
 −108.44 (Lide 2003)
Boiling Point (°C):
 65 (Lide 2003)
Density (g/cm^3 at 20°C):
 0.8880 (Verschueren 1983)
 0.8892 (Riddick et al. 1986)
Molar Volume (cm^3/mol):
 81.1 (20°C, calculated-density)
 88.3 (calculated-Le Bas method at normal boiling point)
Enthalpy of Fusion, ΔH_{fus} (kJ/mol):
 8.535 (quoted, Riddick et al. 1986)
 8.54 (exptl., Chickos et al. 1999)
Entropy of Fusion, ΔS_{fus} (J/mol K):
Fugacity Ratio at 25°C, F: 1.0

Water Solubility (g/m^3 or mg/L at 25°C):
 miscible (Verschueren 1983; Riddick et al. 1986)

Vapor Pressure (Pa at 25°C or as indicated and reported temperature dependence equations Additional data at other temperatures designated * are compiled at the end of this section):
 23465* (dynamic-ebulliometry, measured 15–65°C, Flom et al. 1951)
 434076* (121.11°C, static-Bourdon gauge, measured range 121.11–265.56°C, Kobe et al. 1956)
 19920* (23.139°C, measured range 23.2–99.7°C, Scott et al. 1970)
 21646* (measured range 0.35–35°C, Koizumi & Ouchi 1970; quoted, Boublik et al. 1984)
 $\log (P/\text{mmHg}) = [1- 339.244/(T/K)] \times 10^{\wedge}\{0.830424 - 6.81525 \times 10^{-4}\cdot(T/K) + 6.84786 \times 10^{-7}\cdot(T/K)^2\}$; temp range 253.15–540.15 K (Cox eq., Chao et al. 1983)
 17530, 26340 (20°C, 30°C, quoted, Verschueren 1983)
 21610, 21630 (calculated-Antoine eq., Boublik et al. 1984)
 $\log (P/\text{kPa}) = 6.59372 - 1446.15/(249.982 + t/°C)$; temp range 0.35–35°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)
 $\log (P/\text{kPa}) = 6.12023 - 1202.394/(226.267 + t/°C)$; temp range 23.139–99.7°C (Antoine eq. from reported exptl. data, Boublik et al. 1984)
 $\log (P/\text{mmHg}) = 6.97231 - 540.5/(260.10 + t/°C)$; temp range not specified (Antoine eq., Dean 1985, 1992)
 19920, 21600, 26870 (23.139, 25, 30°C, Riddick et al. 1986)
 $\log (P/\text{kPa}) = 6.79696 - 1157.06/(t/°C + 206.75)$, temp range: 90–140°C, (Antoine eq., Riddick et al. 1986)
 21620, 21900 (calculated-Antoine eq., Stephenson & Malanowski 1987)
 $\log (P_L/\text{kPa}) = 5.92617 - 1101.47/(-57/95 + T/K)$; temp range 273–339 K (Antoine eq.-I, Stephenson & Malanowski 1987)
 $\log (P_L/\text{kPa}) = 6.12052 - 1202.561/(-46.863 + T/K)$; temp range 296–373 K (Antoine eq.-II, Stephenson & Malanowski 1987)
 $\log (P_L/\text{kPa}) = 6.63507 - 1626.656/(15.041 + T/K)$; temp range 399–479 K (Antoine eq.-III, Stephenson & Malanowski 1987)

log (P_L/kPa) = 6.73137 – 1702.922/(23.613 + T/K); temp range 467–541 K (Antoine eq.-IV, Stephenson & Malanowski 1987)

log (P/mmHg) = 34.870 – 2.7523 × 10^3/(T/K) – 9.5958·log (T/K) + 1.9889 × 10^{-10}·(T/K) + 3.5465 × 10^{-6}·$(T/K)^2$; temp range 165–540 K (vapor pressure eq., Yaws 1994)

Henry's Law Constant (Pa m^3/mol at 25°C):

7.15 (calculated-1/K_{AW}, C_W/C_A, reported as exptl., Hine & Mookerjee 1975)

10.33, 142.6 (calculated-group contribution calculated-bond contribution method, Hine & Mookerjee 1975)

Octanol Water Partition Coefficient, log K_{OW}:

0.46	(calculated-f const., Hansch & Leo 1979)
0.22	(shake flask-GC, Funasaki et al. 1985)
0.46	(shake flask, Log P Database, Hansch & Leo 1987)
0.46	(recommended, Sangster 1989)
0.46	(recommended, Hansch et al. 1995)

Octanol/Air Partition Coefficient, log K_{OA}:

2.86 (head-space GC, Abraham et al. 2001)

Bioconcentration Factor, log BCF:

Sorption Partition Coefficient, log K_{OC}:

1.37, 1.26; 1.33 (Captina silt loam, McLaurin sandy loam; weighted mean, batch equilibrium-sorption isotherm, Walton et al. 1992)

Environmental Fate Rate Constants, k, and Half-Lives, $t_{½}$:

Volatilization:

Photolysis:

Oxidation: rate constant k, for gas-phase second order rate constants, k_{OH} for reaction with OH radical, k_{NO3} with NO_3 radical and k_{O3} with O_3 or as indicated, *data at other temperatures see reference:

k_{OH} = (1.59 – 1.63) × 10^{-11} cm^3 $molecule^{-1}$ s^{-1} at 298 K (FP-RF flash photolysis-resonance fluorescence, Ravishankara & Davis 1978)

k_{OH}(calc) = 1.66 × 10^{-11} cm^3 $molecule^{-1}$ s^{-1}, k_{OH}(obs.) = 1.5 × 10^{-11} cm^3 $molecule^{-1}$ s^{-1} at room temp. (SAR structure-activity relationship, Atkinson 1987)

k_{OH}(exptl) = 1.50 × 10^{-11} cm^3·$molecule^{-1}$ s^{-1}, k_{OH}(calc) = 1.28 × 10^{-11} cm^3 $molecule^{-1}$ s^{-1} at room temp. (Atkinson 1986, 1987; quoted, Sabljic & Güsten 1990)

k_{OH}(calc) = 1.28 × 10^{-11} cm^3 $molecule^{-1}$ s^{-1} at room temp. (SAR structure-activity relationship, Atkinson 1987, 1988; quoted, Müller & Klein 1991)

k_{NO3} = 4.875 × 10^{-15} cm^3 $molecule^{-1}$ s^{-1} at 296 ± 2 K (Atkinson et al. 1988; quoted, Sabljic & Güsten 1990; Atkinson 1991)

k_{NO3} = 4.88 × 10^{-12} cm^3 $molecule^{-1}$ s^{-1} at 296 K (relative rate method, Atkinson et al. 1988, Atkinson 1991)

k_{OH} = 1.78 × 10^{-11} cm^3·$molecule^{-1}$ s^{-1} at 296 K (RP-RF method, Wallington et al. 1988b)

k_{OH} = 1.61 × 10^{-11} cm^3·$molecule^{-1}$ s^{-1} cm^3 $molecule^{-1}$ s^{-1} at 298 K (recommended, Atkinson 1989)

k_{OH}* = 18.0 × 10^{-12} cm^3 $molecule^{-1}$ s^{-1} by relative rate method; k_{OH} = 16.7 × 10^{-12} cm^3 $molecule^{-1}$ s^{-1} by pulse laser photolysis-laser induced fluorescence and atmospheric lifetime calculated to be 16 h at 298 ± 2 K; measured range 263–372 K (Moriarty et al. 2003)

Hydrolysis:

Biodegradation:

Biotransformation:

Bioconcentration, Uptake (k_1) and Elimination (k_2) Rate Constants or Half-Lives:

Half-Lives in the Environment:

Air: disappearance $t_{½}$ < 0.24 h from air for the reaction with OH radical (USEPA 1974; quoted, Darnall et al. 1976).

Surface water:

Ground water:

Sediment:
Soil: disappearance $t_{1/2}$ = 5.7 d was calculated from measured first-order rate constant (Anderson et al. 1991).
Biota:

TABLE 10.1.1.11.1
Reported vapor pressures of tetrahydrofuran at various temperatures and the coefficients for the vapor pressure equations

$\log P = A - B/(T/K)$ (1) $\ln P = A - B/(T/K)$ (1a)
$\log P = A - B/(C + t/°C)$ (2) $\ln P = A - B/(C + t/°C)$ (2a)
$\log P = A - B/(C + T/K)$ (3)
$\log P = A - B/(T/K) - C \cdot \log (T/K)$ (4)

Flom et al. 1951		**Kobe et al. 1956**		**Koizumi & Ouchi 1970**		**Scott 1970**	
dynamic-ebulliometry		**static-Bourdon gauge**		**in Boublik et al. 1984**		**comparative ebulliometry**	
t/°C	**P/Pa**	**t/°C**	**P/Pa**	**t/°C**	**P/Pa**	**t/°C**	**P/Pa**
15	15199	121.11	434076	0.35	567	23.139	19920
25	23465	126.67	509867	10	10732	28.362	25007
35	35064	132.22	578768	15	13687	33.62	31160
45	51329	137.78	661450	20	17240	38.917	38547
55	73327	143.33	744131	25	21646	44.251	47359
65	101325	148.89	833702	30	26842	49.62	57803
		154.44	909493	35	35031	55.029	70109
bp/°C	66.1	160	1005955			60.475	84525
		165.56	1116196			65.965	101325
		171.11	1233328			71.489	120.789
		176.67	1364240			77.054	143.268
		182.22	1502042			82.659	169052
		187.78	1653624			88.3	198530
		193.33	1777646			93.98	232087
		198.89	1984349			99.7	270110
		204.44	2156601				
		210	2349524			mp/°C	
		215.56	2549337				
		21.11	2769820				
		226.67	3004084				
		232.22	3252127				
		237.78	3507061				
		243.33	3782655				
		248.89	4078939				
		254.44	4388994				
		260	4705938				
		265.56	5050443				

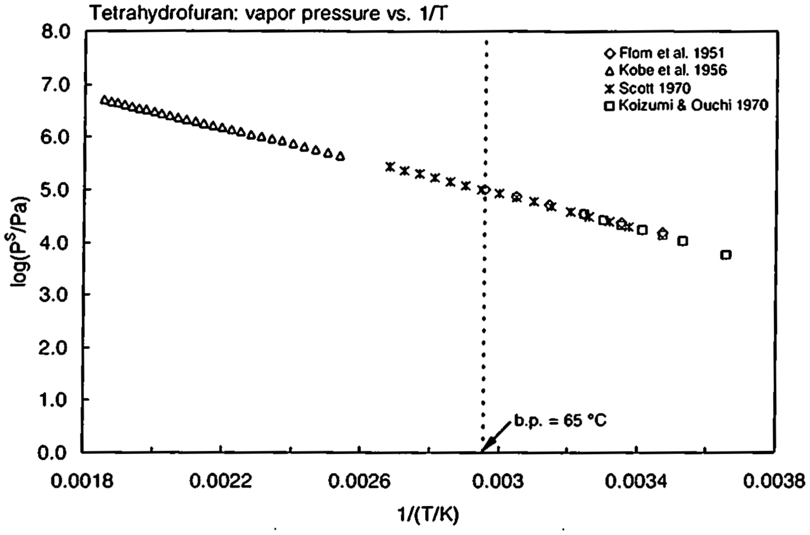

FIGURE 10.1.1.11.1 Logarithm of vapor pressure versus reciprocal temperature for tetrahydrofuran.

17

ENVIRONMENTAL IMPACT OF SOLVENTS

17.1 THE ENVIRONMENTAL FATE AND MOVEMENT OF ORGANIC SOLVENTS IN WATER, SOIL, AND AIR[a]

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17.1.1 INTRODUCTION

Organic solvents are released into the environment by air emissions, industrial and waste-treatment effluents, accidental spillages, leaking tanks, and the land disposal of solvent-containing wastes. For example, the polar liquid acetone is used as a solvent and as an intermediate in chemical production. ATSDR[1] estimated that about 82 million kg of acetone was released into the atmosphere from manufacturing and processing facilities in the U.S. in 1990. About 582,000 kg of acetone was discharged to water bodies from the same type of facilities in the U.S. ATSDR[2] estimated that in 1988 about 48,100 kg of tetrachloroethylene was released to land by manufacturing facilities in the U.S.

Once released, there are numerous physical and chemical mechanisms that will control how a solvent will move in the environment. As solvents are released into the environment, they may partition into air, water, and soil phases. While in these phases, solvents may be chemically transformed into other compounds that are less problematic to the environment. Understanding how organic solvents partition and behave in the environment has led to better management approaches to solvents and solvent-containing wastes. There are many published reference books written about the environmental fate of organic chemicals in air, water, and soil.[3-7] The purpose of this section is to summarize the environmental fate of six groups of solvents (Table 17.1.1) in air, water, and soil. A knowledge of the likely pathways for the environmental fate of organic solvents can serve as the technical basis for the management of solvents and solvent-containing wastes.

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[a] Publication authorized by the Chief, Illinois State Geological Survey

Table 17.1.1. The six groups of solvents discussed in this section

Alcohols
n-Butyl alcohol
Isobutyl alcohol
Methanol

Benzene Derivatives
Benzene
Chlorobenzene
o-Cresol
o-Dichlorobenzene
Ethylbenzene
Nitrobenzene
Toluene
o-Xylene

Chlorinated Aliphatic Hydrocarbons
Carbon tetrachloride
Dichloromethane
Tetrachloroethylene
1,1,1-Trichloroethane
Trichloroethylene

Chlorinated Fluorocarbons
Trichlorofluoromethane (F-11),
1,1,2,2-Tetrachloro-1,2-difluoroethane (F-112)
1,1,2-Trichloro-1,2,2-trifluoroethane (F-113)
1,2,-Dichlorotetrafluoroethane (F-114)

Ketones
Acetone
Cyclohexanone
Methyl ethyl ketone
Methy isobutyl ketone

Others
Carbon disulfide
Diethyl ether
Ethyl acetate
Hexane
Decane (a major component of mineral spirits)
Pyridine
Tetrahydrofuran

17.1.2 WATER

17.1.2.1 Solubility

One of the most important properties of an organic solvent is its solubility in water. The greater a compound's solubility, the more likely that a solvent or a solvent-containing waste will dissolve into water and become part of the hydrological cycle. Hence, water solubility can affect the extent of leaching of solvent wastes into groundwater, and the movement of dissolved solvent into rivers and lakes. Aqueous solubility also determines the efficacy of removal from the atmosphere through dissolution into precipitation. The solubility of solvents in water may be affected by temperature, salinity, dissolved organic matter, and the presence of other organic solvents.

17.1.2.2 Volatilization

Solvents dissolved in water may volatilize into the atmosphere or soil gases. A Henry's Law constant (K_H) can be used to classify the behavior of dissolved solvents. Henry's Law describes the ratio of the partial pressure of the vapor phase of an ideal gas (P_i) to its mole fraction (X_i) in a dilute solution, viz.,

$$K_{H(i)} = P_i \,/\, X_i \tag{17.1.1}$$

In the absence of measured data, a Henry's Law constant for a given solvent may be estimated by dividing the vapor pressure of the solvent by its solubility in water (S_i) at the same temperature;

$$K_{H(i)} = P_i\,(atm) \,/\, S_i\,(mol/m^3\ solvent) \tag{17.1.2}$$

A K_H value of less than 10^{-4} atm-mol/m^3 suggests that volatilization would probably not be a significant fate mechanism for the dissolved solvent. The rate of volatilization is more complex, and depends on the rate of flow, depth, and turbulence of both the body of water and the atmosphere above it. In the absence of measured values, there are a number of estimation techniques to predict the rate of removal from water.[8]

17.1.2.3 Degradation

The disappearance of a solvent from solution can also be the result of a number of abiotic and biotic processes that transform or degrade the compound into daughter compounds that may have different physicochemical properties from the parent solvent. Hydrolysis, a chemical reaction where an organic solvent reacts with water, is not one reaction, but a family of reactions that can be the most important processes that determine the fate of many organic compounds.[9] Photodegradation is another family of chemical reactions where the solvent in solution may react directly under solar radiation, or with dissolved constituents that have been made reactive by solar radiation. For example, the photolysis of water yields a hydroxyl radical:

$$H_2O + h\nu \rightarrow HO\bullet + H \qquad [17.1.3]$$

Other oxidants such as peroxy radicals ($RO_2\bullet$) and ozone can react with solvents in water. The subject of photodegradation is treated in more detail under atmospheric processes (17.1.4).

Biodegradation is a family of biologically mediated (typically by microorganisms) conversions or transformations of a parent compound. The ultimate end-products of biodegradation are the conversion of organic compounds to inorganic compounds associated with normal metabolic processes.[10] This topic will be addressed under Soil (17.1.3.3).

17.1.2.4 Adsorption

Adsorption is a physicochemical process whereby a dissolved solvent may be concentrated at solid-liquid interfaces such as water in contact with soil or sediment. In general, the extent of adsorption is inversely proportional to solubility; sparingly soluble solvents have a greater tendency to adsorb or partition to the organic matter in soil or sediment (see Soil, 17.1.3.2).

17.1.3 SOIL

17.1.3.1 Volatilization

Volatilization from soil may be an important mechanism for the movement of solvents from spills or from land disposed solvent-containing wastes. The efficacy and rate of volatilization from soil depends on the solvent's vapor pressure, water solubility, and the properties of the soil such as soil-water content, airflow rate, humidity, temperature and the adsorption and diffusion characteristics of the soil.

Organic-solvent vapors move through the unsaturated zone (the interval between the ground surface and the water-saturated zone) in response to two different mechanisms; convection and diffusion. The driving force for convective movement is the gradient of total gas pressure. In the case of diffusion, the driving force is the partial-pressure gradient of each gaseous component in the soil air. The rate of diffusion of a solvent in bulk air can be described by Fick's Law, viz.,

$$Q = -D_f \nabla_a \qquad [17.1.4]$$

where:

Q	diffusive flux (mass/area-time)
D_f	diffusion coefficient (area/time)
∇_a	concentration gradient (mass/volume/distance)

Compared with the relatively unobstructed path for the diffusion of solvents in the atmosphere, diffusion coefficients for solvents in soil air will be less because of the tortuosity of the soil matrix pathways. Several functional relationships have been developed that relate the soil diffusion coefficient (D_s) to various soil properties (see Roy and Griffin[11]), such as the Millington Equation[12]

$$D_s = D_f \eta_a^{3.3} / \eta_t^2 \qquad [17.1.5]$$

where:

η_a	the air-filled porosity, and
η_t	total soil porosity

17.1.3.2 Adsorption

As discussed in 17.1.2.4., adsorption by soil components can remove solvents dissolved in water. Furthermore, the rate of movement of dissolved solvents through soil may be retarded by adsorption-desorption reactions between the solvents and the solid phases. The partitioning of solvents between the liquid phase and soil is usually described by an adsorption isotherm. The adsorption of solvents may be described by the Freundlich Equation:

$$x / m = K_f C^{1/n} \qquad [17.1.6]$$

where:

x	the mass adsorbed
m	mass of sorbent
K_f	the Freundlich constant, a soil-specific term
C	the equilibrium concentration of the solvent in water, and
n	the Freundlich exponent which describes the degree of non-linearity of the isotherm

When n is equal to one, the Freundlich Equation becomes a relatively simple partition function:

$$x/m = KC \qquad [17.1.7]$$

where K is an adsorption or distribution coefficient which is sometimes written as K_d. It has been known since the 1960s that the extent of adsorption of hydrophobic (sparingly soluble in water) solvents often correlates with the amount of organic matter in the soil.[13] When K_d is divided by the amount of organic carbon in the soil, the resulting coefficient is the organic carbon-water partition coefficient (K_{oc}):

$$K_d \times 100 / organic\ carbon(\%) = K_{oc} \qquad [17.1.8]$$

The organic carbon-water partition coefficient is a compound-specific term that allows the user to estimate the mobility of a solvent in saturated-soil water systems if the amount or organic carbon is known. For hydrophilic solvents, K_{oc} values have been measured for many compounds. Other values were derived from empirical relationships drawn between water solubility or octanol-water partition coefficients.[13]

17.1.3.3 Degradation

Solvents may be degraded in soil by the same mechanisms as those in water. In biodegradation, microorganisms utilize the carbon of the solvents for cell growth and maintenance. In general, the more similar a solvent is to one that is naturally occurring, the more likely that it can be biodegraded into other compound(s) because the carbon is more available to the microbes. Moreover, the probability of biodegradation increases with the extent of water solubility of the compound. It is difficult to make generalities about the extent or rate of solvent biodegradation that can be expected in soil. Biodegradation can depend on the concentration of the solvent itself, competing processes that can make the solvent less available to microbes (such as adsorption), the population and diversity of microorganisms, and numerous soil properties such as water content, temperature, and reduction-oxidation potential. The rate and extent of biodegradation reported in studies appears to depend on the conditions under which the measurement was made. Some results, for example, were based on sludge-treatment plant simulations or other biological treatment facilities that had been optimized in terms of nutrient content, microbial acclimation, mechanical mixing of reactants, or temperature. Hence, these results may overestimate the extent of biodegradation in ambient soil in a spill or waste-disposal scenario.

First-order kinetic models are commonly used to describe biodegradation because of their mathematical simplicity. First-order biodegradation is to be expected when the organisms are not increasing in abundance. A first-order model also lends itself to calculating a half-life ($t_{1/2}$) which is a convenient parameter to classify the persistence of a solvent. If a solvent has a soil half-life of 6 months, then about half of the compound will have degraded in six months. After one year, about one fourth the initial amount would still be present, and after 3 half-lives (1.5 years), about 1/8 of the initial amount would be present.

Howard et al.[14] estimated ranges of half-lives for solvents in soil, water, and air. For solvents in soil, the dominant mechanism in the reviewed studies may have been biodegradation, but the overall values are indicative of the general persistence of a solvent without regard to the specific degradation mechanism(s) involved.

17.1.4 AIR

17.1.4.1 Degradation

As introduced in 17.1.2.3, solvents may be photodegraded in both water and air. Atmospheric chemical reactions have been studied in detail, particularly in the context of smog formation, ozone depletion, and acid rain. The absorption of light by chemical species generates free radicals which are atoms, or groups of atoms that have unpaired electrons. These free radicals are very reactive, and can degrade atmospheric solvents. Atmospheric ozone, which occurs in trace amounts in both the troposphere (sea level to about 11 km) and in the stratosphere (11 km to 50 km elevation), can degrade solvents. Ozone is produced by the photochemical reaction:

$$O_2 + h\nu \rightarrow O + O \qquad [17.1.9]$$

$$O + O_2 \rightarrow O_3 + M \qquad [17.1.10]$$

where M is another species such as molecular nitrogen that absorbs the excess energy given off by the reaction. Ozone-depleting substances include the chlorofluorocarbons (CFC) and carbon tetrachloride in the stratosphere.

17.1.4.2 Atmospheric residence time

Vapor-phase solvents can dissolve into water vapor, and be subject to hydrolysis reactions and ultimately, precipitation (wet deposition), depending on the solubility of the given solvent. The solvents may also be adsorbed by particulate matter, and be subject to dry deposition. Lyman[16] asserted that atmospheric residence time cannot be directly measured; that it must be estimated using simple models of the atmosphere. Howard et al.[14] calculated ranges in half-lives for various organic compounds in the troposphere, and considered reaction rates with hydroxyl radicals, ozone, and by direct photolysis.

17.1.5 THE 31 SOLVENTS IN WATER

17.1.5.1 Solubility

The solubility of the solvents in Table 17.1.1 ranges from those that are miscible with water to those with solubilities that are less than 0.1 mg/L (Table 17.1.2). Acetone, methanol, pyridine and tetrahydrofuran will readily mix with water in any proportion. The solvents that have an aqueous solubility of greater than 10,000 mg/L are considered relatively hydrophillic as well. Most of the benzene derivatives and chlorinated fluorocarbons are relatively hydrophobic. Hexane and decane are the least soluble of the 31 solvents in Table 17.1.1. Most material safety data sheets for decane indicate that the n-alkane is "insoluble" and that the solubility of hexane is "negligible." How the solubility of each solvent affects its fate in soil, water, and air is illustrated in the following sections.

Table 17.1.2. The solubility of the solvents in water at 25°C

Solubility, mg/L	Solvent (reference)	
∞	Acetone (1) Methanol (1) Pyridine (1) Tetrahydrofuran (1)	Miscible
239,000	Methyl ethyl ketone (4)	
77,000	n-Butyl alcohol (4)	Relatively hydrophillic
76,000	Isobutyl alcohol (4)	
64,000	Ethyl acetate (4)	
60,050	Diethyl ether (4)	
25,950	o-Cresol (17)	
23,000	Cyclohexanone (4)	
20,400	Methyl isobutyl ketone (4)	
13,000	Dichloromethane (4)	
2,100	Carbon disulfide (4)	
1,900	Nitrobenzene (18)	
1,780	Benzene (19)	
1,495	1,1,1-Trichloroethane (4)	
1,100	Trichloroethylene (4)	
1,080	F-11 (4)	

Solubility, mg/L	Solvent (reference)	
805	Carbon tetrachloride (4)	Relatively hydrophobic
535	Toluene (20)	
472	Chlorobenzene (17)	
175	o-Xylene (4)	
170	F-113 (4)	
161	Ethylbenzene (17)	
156	o-Dichlorobenzene (17)	
150	Tetrachloroethylene (4)	
130	F-114 (4)	
120	F-112 (4)	
9.5	Hexane (21)	
0.05	Decane (22)	"Insoluble"

17.1.5.2 Volatilization from water

Henry's Law constants were compiled for each of the solvents in Table 17.1.1. The numerical values ranged over 7 orders of magnitude (Table 17.1.3). Based on these values, it can be expected that volatilization from water will be a significant fate mechanism for decane, hexane, the chlorinated fluorocarbons, carbon tetrachloride, tetrachloroethylene and trichloroethylene. Many of the solvents in Table 17.1.1 are characterized by K_H values of 10^{-3} to 10^{-2} atm-m^3/mole; volatilization from water can be an important pathway for these solvents, depending on the specific situation. Volatilization may be a relatively slow process for the remaining solvents. The actual rate of volatilization of some solvents from water has been experimentally measured.[4,17] However, experimental data are lacking for some compounds, and the diversity of experimental conditions makes generalizations difficult. Thomas[8] described a two-layer model of the liquid-gas interface that is based on a Henry's Law constant and mass-transfer coefficients. To illustrate the relative volatilities of the solvents in water, the half-lives of each solvent in a shallow stream were compiled (Table 17.1.4). The stream was assumed to be 1 meter deep and flowing at a rate of 1 meter per second. With the exception of hexane, it was also assumed that there was a breeze blowing across the stream at a rate of 3 meters per second. Under these conditions, the predicted half-lives of many of the solvents in Table 16.1.1 are less than 10 hours, indicating that volatilization into the atmosphere can be a relatively rapid pathway for solvents released to surface water. The volatilization of pyridine, isobutyl alcohol, and cyclohexanone may be a slow process, and other fate processes may be more important in water.

17.1.5.3 Degradation in water

As mentioned in 17.1.3.3, Howard et al.[14] compiled ranges of half-life values for most of the organic solvents given in Table 17.1.1. If a "rapid" half-life is defined as in the range of 1 to 10 days, then about 12 of the solvents in Table 17.1.1 may degrade rapidly in surface water by primarily biodegradation (Figures 17.1.1 and 17.1.2). Abiotic mechanisms such as photo-oxidation, photolysis, and hydrolysis appear to be either slow or not significant. If "slow degradation" is defined as that taking longer than 100 days, then it appears that F-11 and most of the chlorinated hydrocarbons may be relatively persistent in surface water. The available data suggest that the half-life of nitrobenzene and isobutyl alcohol may be variable. Note that data were not available for all of the solvents listed in Table 17.1.1. In

Table 17.1.3. Henry's Law constants (K_H) for the solvents at 25°C

K_H, atm-m^3/mole	Solvent (reference)
6.98	Decane (22)
2.8	F-114 (4)
1.69	Hexane (21)
0.53	F-113 (4)
9.74×10^{-2}	F-112 (4)
9.70×10^{-2}	F-11 (4)
3.04×10^{-2}	Carbon tetrachloride (4)
1.49×10^{-2}	Tetrachloroethylene (4)
1.03×10^{-2}	Trichloroethylene (4)
9.63×10^{-3}	Tetrahydrofuran (4)
8.4×10^{-3}	Ethylbenzene (17)
8.0×10^{-3}	1,1,1-Trichloroethane (4)
7.0×10^{-3}	Pyridine (4)
5.94×10^{-3}	Toluene (4)
5.43×10^{-3}	Benzene (4)
5.1×10^{-3}	o-Xylene (4)
3.58×10^{-3}	Chlorobenzene (23)
2.68×10^{-3}	Dichloromethane (4)
1.4×10^{-3}	Carbon disulfide (4)
1.2×10^{-3}	o-Dichlorobenzene (4)
7.48×10^{-4}	Diethyl ether (11)
4×10^{-4}	Isobutyl alcohol (4)
1.35×10^{-4}	Methanol (4)
1.2×10^{-4}	Ethyl acetate (4)
9.4×10^{-5}	Methyl isobutyl ketone (4)
4.26×10^{-5}	Acetone (1)
2.44×10^{-5}	Nitrobenzene (2)
1.2×10^{-5}	Cyclohexanone (4)
1.05×10^{-5}	Methyl ethyl ketone (4)
5.57×10^{-6}	n-Butyl alcohol (4)
1.2×10^{-6}	o-Cresol (4)

Table 17.1.4. Estimated half-lives for the solvents in water at 20°C

Half life, h	Solvent
1.6	Tetrahydrofuran
2.6	Carbon disulfide
2.7	Hexane[a]
2.9	Toluene
3.0	Dichloromethane
3.1	Ethylbenzene
3.2	o-Xylene
3.4	Trichloroethylene, F-11
3.7	Carbon tetrachloride
4.0	F-112, F-113, F-114
4.2	Tetrachloroethylene
4.4	o-Dichlorobenzene
4.6	Chlorobenzene
5.3	Methanol
10	Ethyl acetate
18	Acetone
45	Nitrobenzene
74	Cyclohexanone
80	Isobutyl alcohol
90	Pyridine

[a] Based on a wind speed of 1 meter per second.[21]

groundwater, the half-life values proposed by Howard et al.[14] appear to be more variable than those for surface water. For example, the half-life of benzene ranges from 10 days in aerobic groundwater to 2 years in anaerobic groundwater.[19] Such ranges in half-lives make meaningful generalizations difficult. However, it appears that methanol, n-butyl alcohol, and other solvents (see Figures 17.1.1 and 17.1.2) may biodegrade in groundwater with a half-life that is less than 60 days. As with surface water, the chlorinated hydrocarbons may be relatively persistent in groundwater. Howard et al.[14] cautioned that some of their proposed half-life generalizations were based on limited data or from screening studies that were extrapolated to surface and groundwater. Scow[10] summarized that it is currently not possible to predict rates of biodegradation because of a lack of standardized experimental methods, and because the variables that control rates are not well understood. Hence, Figures 17.1.1 and 17.1.2 should be viewed as a summary of the potential for each solvent to degrade, pending more site-specific information.

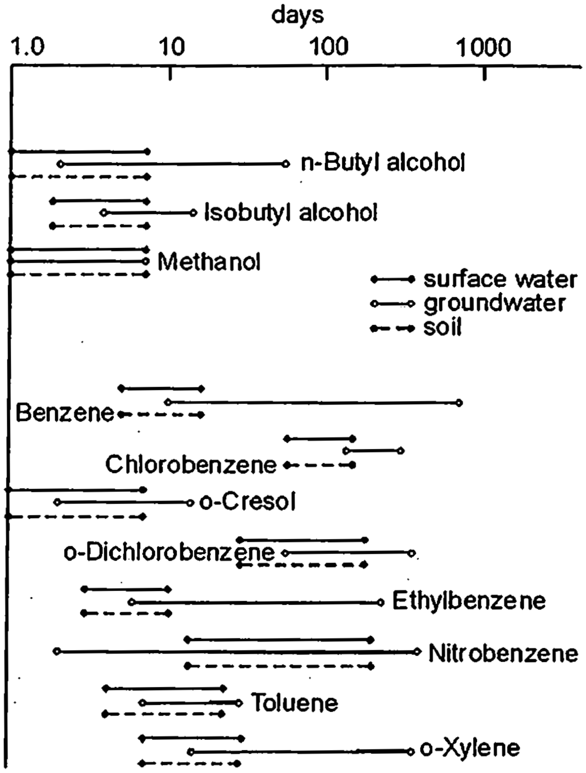

Figure 17.1.1. The ranges in degradation half-lives for the alcohols and benzene derivatives in surface water, groundwater, and soil (data from Howard et al.[14]).

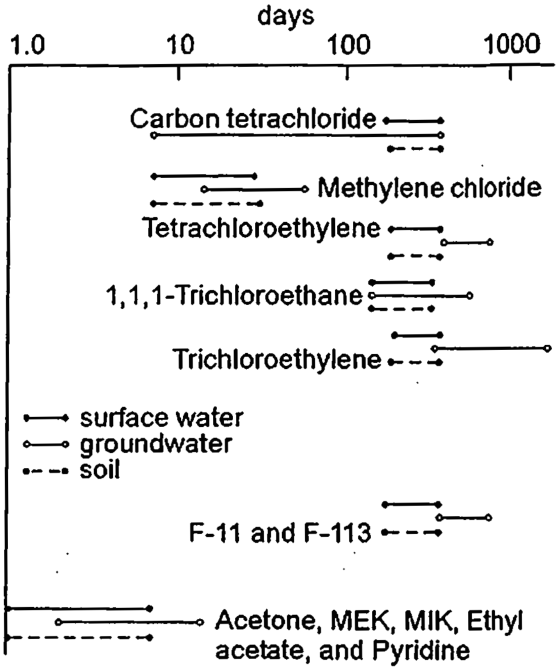

Figure 17.1.2. The ranges in degradation half-lives for the chlorinated aliphatic hydrocarbons, F-11 and F-113, and ketones in surface water, groundwater, and soil (data from Howard et al.[14]).

17.1.6 SOIL

17.1.6.1 Volatilization

Soil diffusion coefficients were estimated for most of the solvents in Table 17.1.1. Using the Millington Equation, the resulting coefficients (Table 17.1.5) ranged from 0.05 to 0.11 m^2/day. Hence, there was little variation in magnitude between the values for these particular solvents. As discussed in Thomas[24] the diffusion of gases and vapors in unsaturated soil is a relatively slow process. The coefficients in Table 17.1.5 do not indicate the rate at which olvents can move in soil; such rates must be either measured experimentally or predicted using models that require input data such as soil porosity, moisture content, and the concentrations of the solvents in the vapor phase to calculate fluxes based solely on advective movement. Variations in water content, for example, will control vapor-phase movement. The presence of water can reduce the air porosity of soil, thereby reducing the soil diffusion coefficient (Eq. 17.1.5). Moreover, relatively water-soluble chemicals may dissolve into water in the vadose zone. Hence, water can act as a barrier to the movement of solvent vapors from the subsurface to the surface.

Solvents spilled onto the surface of soil may volatilize into the atmosphere. The Dow Method[24] was used in this section to estimate half-life values of each solvent if spilled on the surface of a dry soil. The Dow Method is a simple relationship that was derived for the evaporation of pesticides from bare soil;

$$t_{1/2}\,(days) = 1.58 \times 10^{-8}\,(K_{oc}S/P_v) \qquad [17.1.11]$$

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Table 17.1.5. Estimated soil diffusion coefficients D_s (from Roy and Griffin[11])

Solvent	D_s, m^2/day
n-Butyl alcohol	0.062 (25°C)
Isobutyl alcohol	0.050 (0°C)
Methanol	0.111 (25°C)
Benzene	0.060 (15°C)
Chlorobenzene	0.052 (30°C)
o-Cresol	0.053 (15°C)
o-Dichlorobenzene	0.049 (20°C)
Ethylbenzene	0.046 (0°C)
Nitrobenzene	0.050 (20°C)
Toluene	0.058 (25°C)
o-Xylene	0.049 (15°C)
Carbon tetrachloride	0.051 (25°C)
Dichloromethane	0.070 (15°C)
Tetrachloroethylene	0.051 (20°C)
1,1,1-Trichloroethane	0.075 (20°C)
Trichloroethylene	0.058 (15°C)
F-11	0.060 (15°C)
F-112	-
F-113	0.053 (15°C)
F-114	0.056 (15°C)
Acetone	0.076 (0°C)
Cyclohexanone	-
Methyl ethyl ketone	-
Methyl isobutyl ketone	-
Carbon disulfide	0.074 (25°C)
Diethyl ether	0.054 (0°C)
Ethyl acetate	0.059 (25°C)
Hexane	-
Mineral spirits	-
Pyridine	-
Tetrahydrofuran	-

Table 17.1.6. Estimated soil-evaporation half lives

Solvent	Half-life, min.
o-Cresol	38
Nitrobenzene	19
n-Butyl alcohol	18
Pyridine	8
Decane	4
Isobutanol Cyclohexanone	1
All other solvents	<1

where:

$t_{1/2}$	evaporation half-life (days)
K_{oc}	organic carbon-water partition coefficient (L/kg)
S	solubility in water (mg/L), and
P_v	vapor pressure (mm Hg at 20°C)

The resulting estimated half-life is inversely proportional to vapor pressure; the greater the vapor pressure, the greater the extent of volatilization. Conversely, the rate of volatilization will be reduced if the solvent readily dissolves into water or is adsorbed by the soil. Organic carbon-water partition coefficients were compiled for each solvent (see 17.1.6.2.), and vapor pressure data (not shown) were collected from Howard.[4] The resulting half-life estimates (Table 17.1.6) indicated that volatilization would be a major pathway if the liquid solvents were spilled on soil; all of the half-life estimates were less than one hour. Thomas[24] cautioned, however, that soil moisture, soil type, temperature, and wind conditions were not incorporated in the simple Dow Model.

Table 17.1.7. The organic carbon-water partition coefficients (K_{oc}) of the solvents at 25°C

K_{oc}, L/kg	Solvent (reference)	
<1	Methanol (13), Tetrahydrofuran[a]	
1	Acetone (13)	Mobile
4	Methyl ethyl ketone (13)	
7	Pyridine (13)	
8	Ethyl acetate, isobutyl alcohol (13)	
9	Diethyl ether (13)	
10	Cyclohexanone (13)	
20	o-Cresol (17)	
24	Methyl isobutyl ketone (13)	
25	Dichloromethane (13)	
63	Carbon disulfide (13)	
67	Nitrobenzene (13)	
72	n-Butyl alcohol (4)	
97	Benzene (13)	
110	Carbon tetrachloride (4)	Relatively mobile
152	Trichloroethylene (13)	
155	1,1,1-Trichloroethane (13)	
164	Ethylbenzene (17)	
242	Toluene (26)	
303	Tetrachloroethylene (13)	
318	Chlorobenzene (13)	
343	o-Dichlorobenzene (25)	
363	o-Xylene (13)	
372	F-113 (13)	
437	F-114 (13)	
457	F-112 (13)	
479	F-11 (13)	
1,950	Hexane (21)	Relatively Immobile
57,100[a]	Decane	

[a]Calculated using the relationship $\log K_{oc} = 3.95 - 0.62 \log S$ where S = water solubility in mg/L (see Hassett et al.[25])

17.1.6.2 Adsorption

Organic carbon-water partition coefficients were compiled (Table 17.1.7) for each of the solvents in Table 17.1.1. A K_{oc} value is a measure of the affinity of a solvent to partition to organic matter which in turn will control the mobility of the solute in soil and groundwater under convective flow. Although the actual amount of organic matter will determine the extent of adsorption, a solvent with a K_{oc} value of less than 100 L/kg is generally regarded as relatively mobile in saturated materials. Hence, adsorption may not be a significant fate mechanism for 16 of the solvents in Table 17.1.1. In contrast, adsorption by organic matter may be a major fate mechanism controlling the fate of three of the benzene derivatives, and most of the chlorinated compounds. Hexane and particularly decane would likely be relatively immobile. However, when the organic C content of an adsorbent is less than about 1

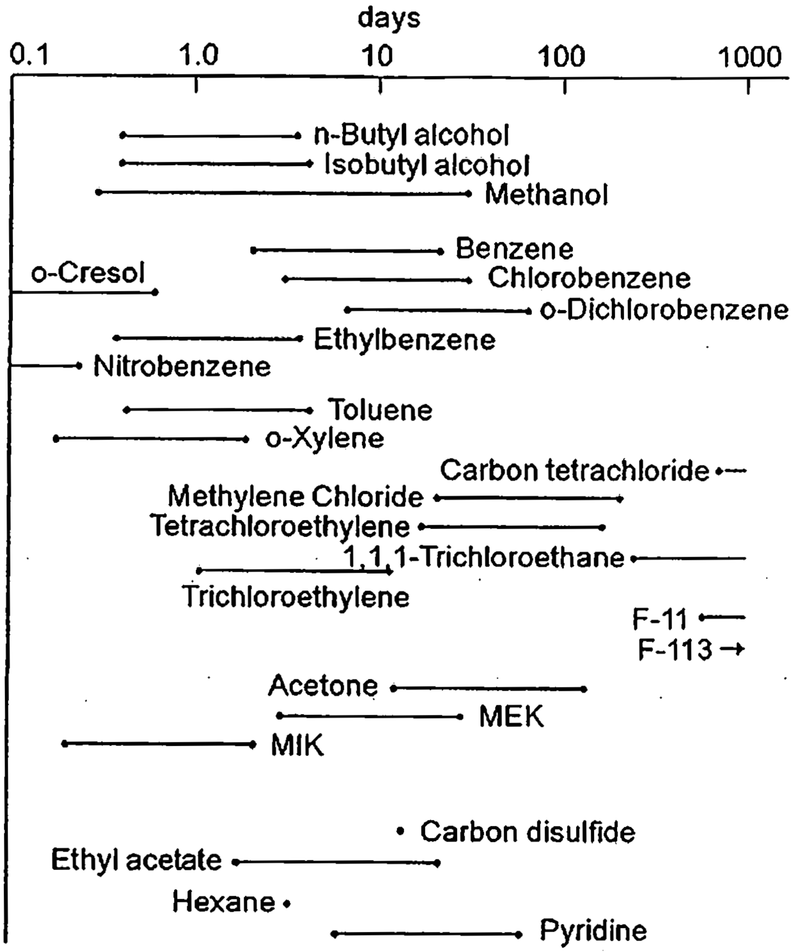

Figure 17.1.3. The ranges in atmospheric half-life of the solvents in Table 17.1.1 (data from Howard et al.[14] and ATSDR[21]).

g/kg, the organic C fraction is not a valid predictor of the partitioning of nonpolar organic compounds,[27] and other properties such as pH, surface area, or surface chemistry contribute to or dominate the extent of adsorption. Moreover, pyridine occurs at a cation (pKa = 5.25) over a wide pH range, and thus it is adsorbed by electrostatic interactions rather than by the hydrophobic mechanisms that are endemic to using K_{oc} values to predict mobility.

The desorption of solvents from soil has not been extensively measured. In the application of advection-dispersion models to predict solute movement, it is generally assumed that adsorption is reversible. However, the adsorption of the solutes in Table 17.1.1 may not be reversible. For example, hysteresis is often observed in pesticide adsorption-desorption studies with soils.[28] The measurement and interpretation of desorption data for solid-liquid systems is not well understood.[29,30] Once adsorbed, some adsorbates may react further to become covalently and irreversibly bound, while others may become physically trapped in the soil matrix.[28] The non-singularity of adsorption-desorption may sometimes result from experimental artifacts.[28,31]

17.1.6.3 Degradation

As discussed in 17.1.3.3., Howard et al.[14] also estimated soil half-life values (Figures 17.1.1 and 17.1.2) for the degradation of most of the solvents in Table 17.1.1. Biodegradation was cited as the most rapid process available to degrade solvents in a biologically active soil. The numerical values obtained were often the same as those estimated for surface water.

Consequently, it appears likely that the alcohols, ketones, o-cresol, ethyl acetate, and pyridine will degrade rapidly in soil if rapidly is defined as having a half-life of 10 days or less. Most of the benzene derivatives, F-11, and the chlorinated aliphatic hydrocarbons may be relatively persistent in soil. Analogous information was not located for diethyl ether, hexane, decane, or tetrahydrofuran. ATSDR[21] for example, found that there was little information available for the degradation of n-hexane in soil. It was suggested that n-hexane can degrade to alcohols, aldehydes, and fatty acids under aerobic conditions.

17.1.7 AIR

Once released into the atmosphere, the most rapid mechanism to attenuate most of the solvents in Table 17.1.1 appears to be by photo-oxidation by hydroxyl radicals in the troposphere. Based on the estimates by Howard et al.,[14] it appeared that nine of the solvents can be characterized by an atmospheric residence half-life of 10 days or less (Figure 17.1.3). The photo-oxidation of solvents yields products. For example, the reaction of OH radicals with n-hexane can yield aldehydes, ketones, and nitrates.[21]

The reaction of some of the solvents with ozone may be much slower. For example, the half-life for the reaction of benzene with ozone may be longer than 100 years.[19] Solvents such as carbon tetrachloride, 1,1,1-trichloroethane, and the chlorinated fluorocarbons may be relatively resistant to photo-oxidation. The major fate mechanism of atmospheric 1,1,1-trichloroethane, for example, may be wet deposition.[32]

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17.2 FATE-BASED MANAGEMENT OF ORGANIC SOLVENT-CONTAINING WASTES[a]

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17.2.1 INTRODUCTION

The wide spread detection of dissolved organic compounds in groundwater is a major environmental concern, and has led to greater emphasis on incineration and waste minimization when compared with the land disposal of solvent-containing wastes. The movement and environmental fate of dissolved organic solvents from point sources can be approximated by the use of computer-assisted, solute-transport models. These models require information about the composition of leachate plumes, and site-specific hydrogeological and chemical

[a] Publication authorized by the Chief, Illinois State Geological Survey

data for the leachate-site system. A given land-disposal site has a finite capacity to attenuate organic solvents in solution to environmentally acceptable levels. If the attenuation capacity of a site can be estimated, then the resulting information can be used as criteria to make decisions as to what wastes should be landfilled, and what quantities of solvent in a given waste can be safely accepted. The purpose of this section is to summarize studies[1-3] that were conducted that illustrate how knowledge of the environmental fate and movement of the solvents in Section 17.1 can be used in managing solvent-containing wastes. These studies were conducted by using computer simulations to assess the fate of organic compounds in leachate at a waste-disposal site.

17.2.1.1 The waste disposal site

There are three major factors that will ultimately determine the success of a land-disposal site in being protective of the environment with respect to groundwater contamination by organic solvents: (1) the environmental fate and toxicity of the solvent; (2) the mass loading rate, i.e., the amount of solvent entering the subsurface during a given time, and (3) the total amount of solvent available to leach into the groundwater. The environmental fate of the solvents was discussed in 17.1.

The hypothetical waste-disposal site used in this evaluation (Figure 17.2.1) had a single waste trench having an area of 0.4 hectare. Although site-specific dimensions may be assigned with actual sites, this hypothetical site was considered representative of many situations found in the field. The trench was 12.2 meters (40 ft) deep and was constructed with a synthetic/compacted-soil double-liner system. The bottom of the trench was in direct contact with a sandy aquifer that was 6.1 meters (20 ft) thick. The top of the water table was defined as being at the top of the sandy aquifer. Thus, this site was designed as a worst-case scenario. The sandy aquifer directly beneath the hazardous-waste trench would offer little resistance to the movement of contaminants. To further compound a worst-case situation, it was also assumed that the entire trench was saturated with leachate, generating a 12.2 meter (40 ft) hydraulic head through the liner. This could correspond to a situation where the trench had completely filled with leachate because the leachate collection system had either failed or the site had been abandoned.

The following aquifer properties, typical of sandy materials,[1] were used in the study:

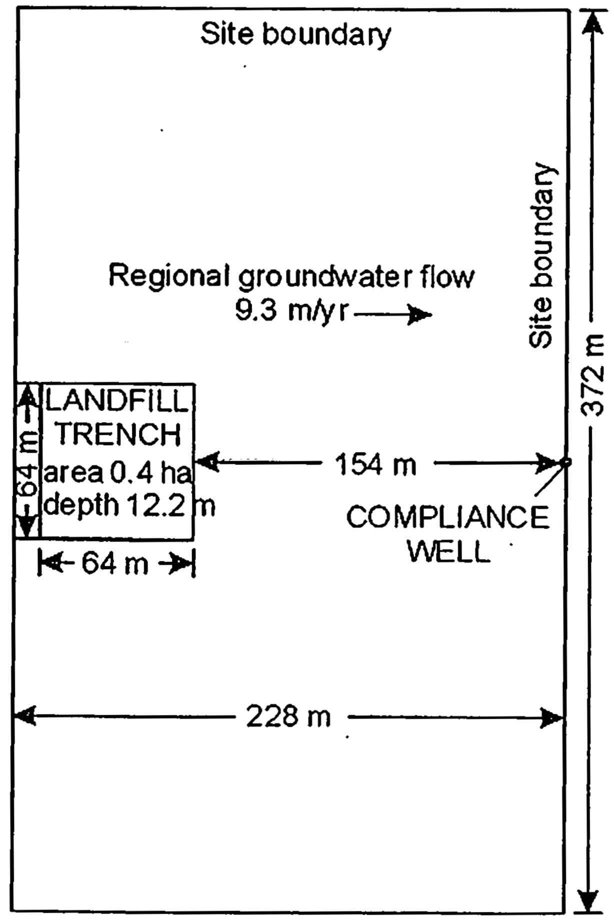

Figure 17.2.1. Design of the waste-disposal site model used in the simulations (Roy et al.[1]).

saturated hydraulic conductivity = 10^{-3} cm/sec
saturated volumetric water content = 0.36 cm^3/cm^3
dry bulk density = 1.7 g/cm^3
hydraulic gradient = 0.01 cm/cm
mean organic carbon content = 0.18%

These aquifer properties yield a groundwater flow rate of 9.3 meters (30 ft) per year. The direction of groundwater flow is shown in Figure 17.2.1 to be from left to right. The edge of the disposal trench was 154 meters (500 ft) from a monitoring well that was open to the entire thickness of the aquifer. This monitoring well served as a worst-case receptor because it was placed in the center of the flow path at the site boundary and it served as the compliance point for the site. The downgradient concentrations of organic solvents at the compliance well, as predicted by a solute-transport model, were used to evaluate whether the attenuation capacity of the site was adequate to reduce the contaminants to acceptable concentrations before they migrated beyond the compliance point.

17.2.1.2 The advection-dispersion model and the required input

The 2-dimensional, solute-transport computer program PLUME was used to conduct contaminant migration studies. Detailed information about PLUME, including boundary conditions and quantitative estimates of dispersion and groundwater dilution, were summarized by Griffin and Roy.[3] In this relatively simple and conservative approach, PLUME did not take into account volatilization from water. Volatilization is a major process for many of the solvents (see Section 17.1). Adsorption was assumed to be reversible, and soil-water partition coefficients were calculated by assuming that the aquifer contained 0.18% organic carbon (see Roy and Griffin[4]). A degradation half-life was assigned to each solvent (Table 17.2.1). In many cases, conservative half-life values were used. For example, all of the ketones were assigned a half-life of 5 years, which is much longer than those proposed for ketones in groundwater (see Section 17.1). The movement of each solvent was modeled separately whereas it should be recognized that solvents in mixtures may have different chemical properties that can ultimately affect their fate and movement.

17.2.1.3 Maximum permissible concentrations

Central to the type of assessment is a definition of an environmentally acceptable concentration of each contaminant. These acceptable levels were defined as Maximum Permissible Concentrations (MPC), and were based on the toxicological assessments of solvents in drinking water by George and Siegel.[5] These MPC levels (Table 17.2.1) are not the same levels as the current Maximum Contaminant Levels (MCL) that were promulgated by the U.S. Environmental Protection Agency for drinking water.

17.2.1.4 Distribution of organic compounds in leachate

An initial solute concentration must be selected for the application of solute transport models. An initial concentration for each solvent was based on the chemical composition of leachates from hazardous-waste sites.[1] Where available, the largest reported concentration was used in the modeling efforts (Table 17.2.1). No published data were located for some of the solvents such as cyclohexanone. In such cases, the initial concentration was arbitrarily assigned as 1,000 mg/L or it was equated to the compound's solubility in water. Hexane, decane, and tetrahydofuran were not included in these studies.

The amount of mass of each organic compound entering the aquifer via the double-liner system was calculated using these initial leachate concentrations. There was a continuous 12.2-meter head driving the leachate through the liner. Leachate was predicted to break through the liner in 30 years. Under these conditions, approximately 131,720 L/year/acre of leachate would seep through the liner. The assumptions used in deriving this flow estimate were summarized in Roy et al.[1]

Table 17.2.1. The six groups of solvents discussed in this section, their corresponding Maximum Permissible Concentrations (MPC), the largest reported concentrations in leachate (LC), and the assigned half-lives from Roy et al.[1]

	MPC, μg/L	LC, mg/L	Half-life, years
Alcohols			
n-Butyl alcohol	2,070	1,000	5
Isobutyl alcohol	2,070	1,000	5
Methanol	3,600	42.4	5
Benzene Derivatives			
Benzene	1.6	7.37	20
Chlorobenzene	488	4.62	20
o-Cresol	304	0.21	20
o-Dichlorobenzene	400	0.67	50
Ethylbenzene	1,400	10.1	10
Nitrobenzene	19,800	0.74	20
Toluene	14,300	100	10
o-Xylene	14,300	19.7	10
Chlorinated Aliphatic Hydrocarbons			
Carbon tetrachloride	0.4	25.0	50
Dichloromethane	0.19	430	20
Tetrachloroethylene	0.80	8.20	20
1,1,1-Trichloroethane	6.00	590	50
Trichloroethylene	2.70	260	20
Chlorinated Fluorocarbons			
Trichlorofluoromethane (F-11)	0.19	0.14	50
1,1,2,2-Tetrachloro-1,2-difluoroethane (F-112)	0.19	120	50
1,1,2-Trichloro-1,2,2-trifluoroethane (F-113)	0.19	170	stable
1,2,-Dichlorotetrafluoroethane (F-114)	0.19	130	stable
Ketones			
Acetone	35,000	62	5
Cyclohexanone	3,500	1,000	5
Methyl ethyl ketone	30,000	53.0	5

	MPC, μg/L	LC, mg/L	Half-life, years
Methyl isobutyl ketone	143	10.0	5
Others			
Carbon disulfide	830	1,000	10
Diethyl ether	55,000	1,000	5
Ethyl acetate	55,000	1,000	5
Pyridine	207	1,000	20

A mass-loading rate was conservatively calculated for each solvent as,

$$M_{lr} = Q \times C_l \qquad [17.2.1]$$

where:

M_{lr}	the mass loading rate (mass/time/area),
Q	calculated leachate flux (131.7 kL/year/hectare), and
C_l	largest concentration of the solvent in leachate (mg/L)

17.2.2 MOVEMENT OF SOLVENTS IN GROUNDWATER

Ketones and alcohols have little tendency to be adsorbed by soil materials (see Section 17.1), and would appear at the compliance point only a few years after liner breakthrough (Figure 17.2.2). Because the mass loading rates were held constant, the ketones and alcohols assumed maximum steady-state concentrations after approximately 40 to 50 years (Figure 17.2.3). These two classes of organic solvents degrade readily, reducing their downgradient concentrations. The distribution of the benzene derivatives at the compliance well depended substantially on their soil-water partition coefficients, their tendencies to de-

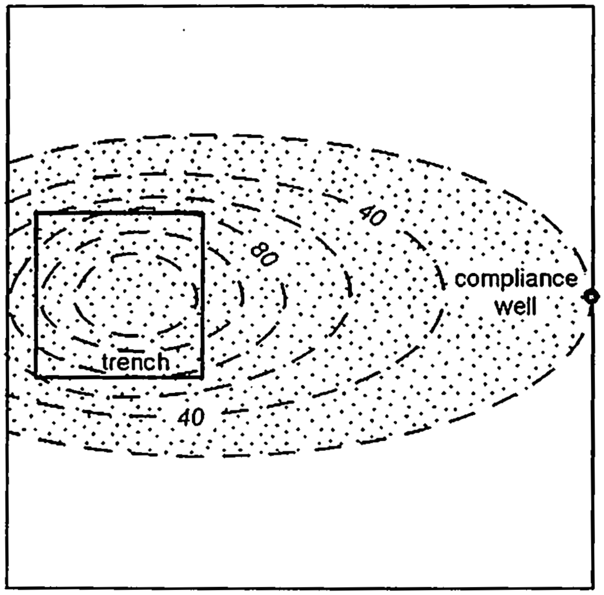

Figure 17.2.2. The predicted distribution of methyl ethyl ketone (mg/L) in the aquifer 100 years after the leachate has broken through the liner (Griffin and Roy[3]).

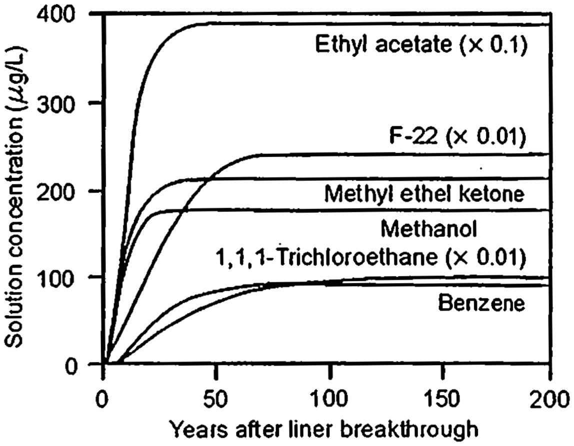

Figure 17.2.3. The predicted concentrations of methyl ethyl ketone, methanol, benzene, 1,1,1-trichloroethane, ethyl acetate, and F-22 at the compliance point as a function of time (Roy et al.[1]).

grade, and the initial concentrations. Under the conditions described, the relative steady-state concentrations of the benzene derivatives were: toluene > benzene > chlorobenzene > p-xylene > nitrobenzene > o-dichlorobenzene > o-cresol > ethyl benzene. Methylene chloride and 1,1,1-trichlorethane would dominate the chlorinated hydrocarbons. Among the group of unrelated organic solvents, the concentration of pyridine at the well was predicted to increase rapidly. Pyridine would eventually dominate this group in the relative order: pyridine > carbon disulfide > ethyl acetate > diethyl ether. The relative order of fluorocarbons at the compliance well in terms of concentration was: F-21, F-22 >> F-12 > F-113 > F-114 > F-112 > R-112a > FC-115 >> F-11.

In brief, the computer simulations predicted that all 28 organic compounds would eventually migrate from the waste trench, and be detected at the compliance well. The predicted concentrations varied by four orders of magnitude, and were largely influenced by the initial concentrations used in calculating the mass loading rate to the aquifer.

17.2.3 MASS LIMITATIONS

The next step in this analysis was to determine whether these predicted concentrations would pose an environmental hazard by evaluating whether the site was capable of attenuating the concentrations of the organic compounds to levels that are protective of human health. In Figure 17.2.4 the predicted steady-state concentrations of the organic compounds

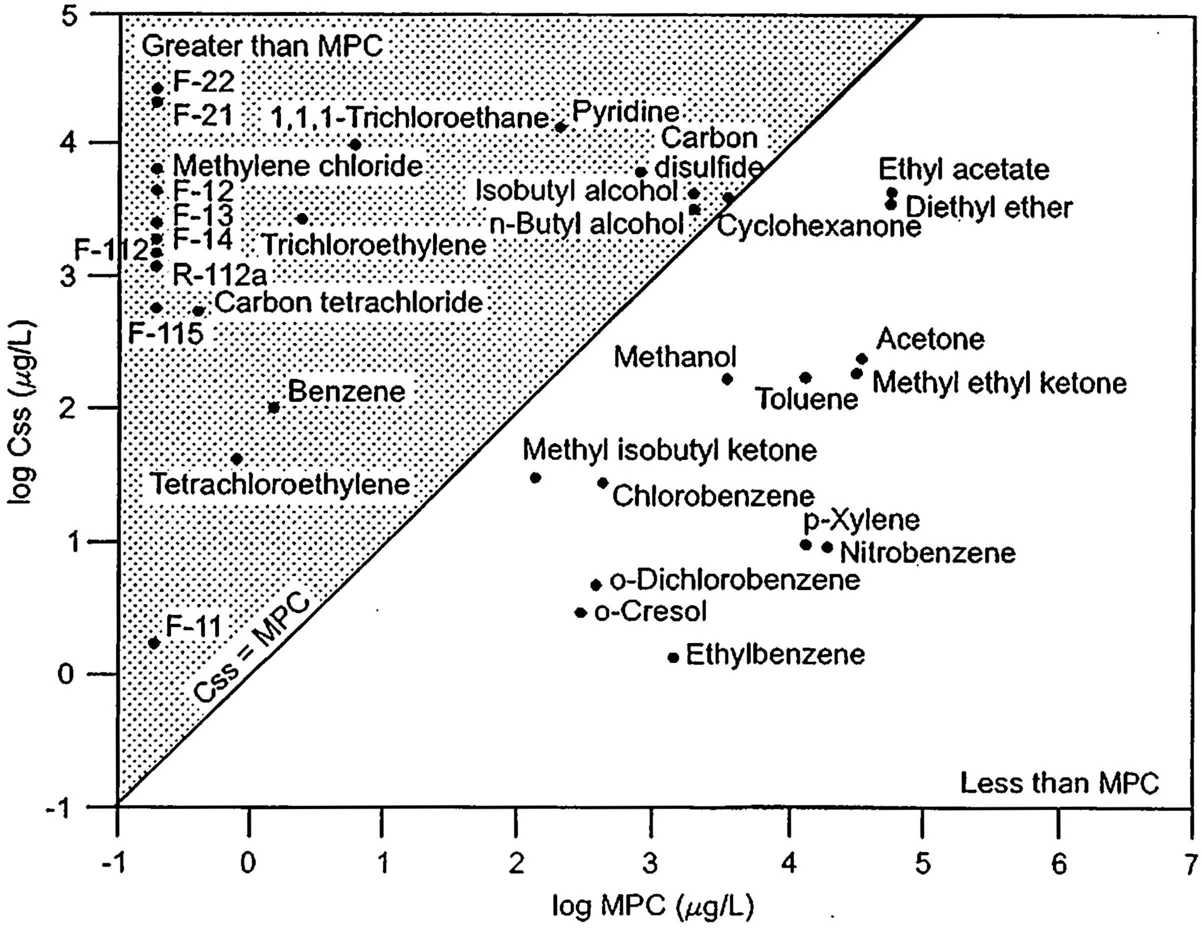

Figure 17.2.4. The predicted steady-state concentrations (Css) of each solvent in groundwater at the compliance point as a function of its Maximum Permissible (MPC) Concentration (Roy et al.[1]).

in groundwater at the compliance well were plotted against their MPCs. The boundary shown in Figure 17.2.4 represents the situation where the steady-state concentration (Css) equals the MPC. Consequently, the predicted Css is less than its corresponding MPC when the Css of a given compound plots in the lower-right side. In this situation, these organic compounds could enter the aquifer at a constant mass loading rate without exceeding the attenuation capacity of the site. The steady-state concentrations of twenty solvents exceeded their corresponding MPCs. The continuous addition of these organic compounds (i.e., a constant mass loading rate) would exceed the site's ability to attenuate them to environmentally acceptable levels in this worst-case scenario. There are two avenues for reducing the steady-state concentrations downgradient from the trench: (1) reduce the mass loading rate, and/or (2) reduce the mass of organic compound available to leach into the aquifer. Because, the RCRA-required double liner was regarded as the state-of-the-art with respect to liner systems, it was not technically feasible to reduce the volume of leachate seeping into the aquifer under the conditions imposed. The worst-case conditions could be relaxed by assuming a lower leachate head in the landfill or by providing a functional leachate-collection system. Either condition would be reasonable and would reduce the mass loading rate. Another alternative is to reduce the mass available for leaching. In the previous simulations, the mass available to enter the aquifer was assumed to be infinite. Solute transport models can be used to estimate threshold values for the amounts of wastes initially landfilled.[2] A threshold mass (M_t) can be derived so that the down-gradient, steady-state concentrations will be less than the MPC of the specific compound, viz.,

$$M_t = V(MPC \times 1000)\, t \qquad [17.2.2]$$

where:

M_t	the threshold mass in g/hectare
V	the volume of leachate entering the aquifer in L/yr/hectare
MPC	the maximum permissible concentration as g/L, and
t	time in years; the amount of time between liner breakthrough and when the predicted concentration of the compound in the compliance well equals its MPC.

Using this estimation technique, Roy et al.[1] estimated mass limitations for the compounds that exceeded their MPCs in the simulations. They found that benzene, carbon tetrachloride, dichloromethane, pyridine, tetrachloroethylene, 1,1,1-trichloroethylene, trichloroethylene and all chlorinated fluorocarbons would require strict mass limitations (<250 kg/ha). Other solvents could be safely landfilled at the site without mass restrictions: acetone, chlorobenzene, cresols, o-dichlorobenzene, diethyl ether, ethyl acetate, ethylbenzene, methanol, methyl ethyl ketone, methyl isobutyl ketone, nitrobenzene, toluene, and xylene. Some solvents (cyclohexanone, n-butyl alcohol, isobutyl alcohol, and carbon disulfide) would require some restrictions to keep the attenuation capacity of the site from being exceeded.

These studies,[1-3] demonstrated that the land disposal of wastes containing some organic solvents at sites using best-available liner technology may be environmentally acceptable. Wastes that contain chlorinated hydrocarbons, however, may require pretreatment such as incineration or stabilization before land disposal. If the mass-loading rate is controlled and the attenuation capacity of the site is carefully studied, the integrated and multidisciplinary approach outlined in this section can be applied to the management of solvent-containing wastes.

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17.3 ENVIRONMENTAL FATE AND ECOTOXICOLOGICAL EFFECTS OF GLYCOL ETHERS

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17.3.1 INTRODUCTION

Glycol ethers and their acetates are widely used as solvents in the chemical, painting, printing, mining and furniture industries. They are employed in the production of paints, coatings, resins, inks, dyes, varnisnes, lacquers, cleaning products, pesticides, deicing additives for gasoline and jet fuel, and so on.[1] In 1997, the world production of glycol ethers was about 900,000 metric tons.[2]

There are two distinct series of glycol ethers namely the ethylene glycol ethers which are produced from ethylene oxide and the propylene glycol ethers derived from propylene oxide. The former series is more produced and used than the latter. Thus, inspection of the 42,000 chemical substances recorded by INRS (France) in the SEPIA data bank, between 1983 and 1998, reveals that 10% of them include ethylene glycol ethers and about 4% propylene glycol ethers.[2] However, due to the reproductive toxicity of some ethylene glycol monoalkyl ethers,[3-5] it is important to note that the worldwide tendency is to replace these chemicals by glycol ethers belonging to the propylenic series.[2]

Given the widespread use of glycol ethers, it is obvious that these chemicals enter the environment in substantial quantities. Thus, for example, the total releases to all environmental media in the United States for ethylene glycol monomethyl ether and ethylene glycol monoethyl ether in 1992 were 1688 and 496 metric tons, respectively.[6] However, despite the potential hazard of these chemicals, the problems of the environmental contaminations with glycol ethers have not received much attention. There are two main reasons for this. First, these chemicals are not classified as priority pollutants, and hence, their occurrence in the different compartments of the environment is not systematically investigated. Thus, for example, there are no glycol ethers on the target list for the Superfund hazardous waste site cleanup program.[6] Second, glycol ethers are moderately volatile colorless liquids with a high water solubility and a high solubility with numerous solvents. Consequently, the clas-

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Table 1: Existing Unit Baseline and Sensitivity Parameters

Deposit Data		
No. of Layers		2
Laplace Transform Parameters	Tau	7
	N	20
	Sig	0
	RNU	2
Darcy Velocity	m/A	0
Distance to Zone of Attenuation	m	30.45
Time Period	A	145

Layer Data		Units	BASELINE	MIN	MAX
Layer 1 - In Situ Soil Liner	No. of Sublayer	-	10	5	20
	Thickness	m	3.05	-	-
	Dry Density	g/cm^3	1.91	1.61	2.12
	Porosity	-	0.36	0.29	0.42
	Diffusion Coefficient	m^2/A	0.018	0.00315	0.0315
	Distribution Coefficient	mL/g	0	-	-
Layer 2 - Aquifer	No. of Sublayer	-	40	20	90
	Thickness	m	27.4	-	-
	Dry Density	g/cm^3	1.69	1.13	1.99
	Porosity	-	0.41	0.32	0.5
	Diffusion Coefficient	m^2/A	0.018	0.00315	0.0315
	Distribution Coefficient	mL/g	0	-	-

Boundary Conditions							
Top Boundary Condition	Constant Concentration						
Bottom Boundary Condition	Infinite Thickness						
Variable Properties							
Property Increments within Groups	Yes						
Number of Time Periods	7						
Start Time	0						
Type of Profile	Sublayer						
Time Period	1	2	3	4	5	6	7
End Time	5	15	16	19	20	75	145
No of Increments	5	2	1	3	1	11	14
Beginning Concentration	100	100	100	100	100	100	100
Darcy Velocity	0	0.0378	0.0378	0.0378	0	0	0
Dispersivity	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Concentration Increment	0	0	0	0	0	0	0
Darcy Velocity Increment	0.00756	0	0	-0.0126	0	0	0.0027

Table 2: South Unit Baseline and Sensitivity Parameters

Deposit Data		
No. of Layers		2
Laplace Transform Parameters	Tau	7
	N	20
	Sig	0
	RNU	2
Darcy Velocity	m/A	0.00107
Distance to Zone of Attenuation	m	30.45
Time Period	A	131

Layer Data		Units	BASELINE	MIN	MAX
Layer 1 - 60 mil HDPE	No. of Sublayer	-	1	-	-
	Thickness	m	0.00152	-	-
	Dry Density	g/cm^3	0.94	-	-
	Porosity	-	1	-	-
	Diffusion Coefficient	m^2/A	0.00008	0.000008	0.0008
	Distribution Coefficient	mL/g	0	-	-
Layer 2 - Recompacted Clay Liner	No. of Sublayer	-	3	1	9
	Thickness	m	0.914	-	-
	Dry Density	g/cm^3	1.91	1.61	2.12
	Porosity	-	0.36	0.29	0.42
	Diffusion Coefficient	m^2/A	0.018	0.00315	0.0315
	Distribution Coefficient	mL/g	0	-	-
Layer 2 - Aquifer	No. of Sublayer	-	15	10	20
	Thickness	m	38.7	-	-
	Dry Density	g/cm^3	1.69	1.13	1.99
	Porosity	-	0.41	0.32	0.5
	Diffusion Coefficient	m^2/A	0.064	0.00315	0.173
	Distribution Coefficient	mL/g	0	-	-

Boundary Conditions	
Top Boundary Condition	Constant Concentration
Bottom Boundary Condition	Infinite Thickness

Table 3: Northwest Unit Baseline and Sensitivity Parameters

General Data	No. of Landfills		1			
	No. of Layers		3			
	Laplace Transform	Tau	7			
		N	11			
		Sig	0			
		RNU	1			
	Gauss Integration	Normal				
Boundary Conditions	Top Boundary	Constant Concentration - Surface				
	Bottom Boundary	Aquifer				
			Units	BASELINE	MIN	MAX
	Top Boundary Condition	Offset Distance	m	0	-	-
		Landfill Base Width	m	61	45.7	76.2
		Landfill Surface Width	m	366	351	381
		Surface Concentration	mg/L	1	-	-
	Bottom Boundary Condition	Base Thickness	m	2.44	0.305	3.81
		Base Half-Life	yrs	0	-	-
		Sink Removal	m/a	0	-	-
		Base Porosity	-	0.34	0.14	0.49
		Outflow Velocity	m/a	0.42	0.042	4.42
		Dispersion Coefficient	m2/a	1.53	0.153	15.3
Layer Data	Layer 1: 60 mil HDPE	Number of Sublayers	-	1	-	-
		Thickness	m	0.00152	-	-
		Dry Density	g/cm3	0.94	-	-
		Porosity	-	1	-	-
		Distribution Coefficient	mL/g	0	-	-
		Vertical Diffusion	m2/a	0.00008	0.000008	0.0008
		Horizontal Diffusion	m2/a	0	-	-
		Vertical Velocity	m/a	0.00107	0.000107	0.0107
		Horizontal Velocity	m/a	0	-	-
		Decay Half-Life	yrs	0	-	-
		Sink Removal	m/a	0	-	-
	Layer 2: Recompacted Clay	Number of Sublayers	-	3	1	6
		Thickness	m	0.914	-	-
		Dry Density	g/cm3	1.91	1.61	2.12
		Porosity	-	0.36	0.29	0.43
		Distribution Coefficient	mL/g	0	-	-
		Vertical Diffusion	m2/a	0.018	0.00315	0.0315
		Horizontal Diffusion	m2/a	0.018	0.00315	0.0315
		Vertical Velocity	m/a	0.00107	0.000107	0.0107
		Horizontal Velocity	m/a	0	-	-
		Decay Half-Life	yrs	0	-	-
		Sink Removal	m/a	0	-	-
	Layer 3: In situ Clay	Number of Sublayers	-	15	1	30
		Thickness	m	2.44	1.52	4.57
		Dry Density	g/cm3	1.91	1.61	2.12
		Porosity		0.36	0.29	0.43
		Distribution Coefficient	mL/g	0	-	-
		Vertical Diffusion	m2/a	0.018	0.00315	0.0315
		Horizontal Diffusion	m2/a	0.018	0.00315	0.0315
		Vertical Velocity	m/a	0.00107	0.000107	0.0107
		Horizontal Velocity	m/a	0	-	-
		Decay Half-Life	yrs	0	-	-
		Sink Removal	m/a	0	-	-
Number of Distances	8	30.48, 45.72, 49.53, 53.34, 57.15, 60.96, 64.77, 83.82				
Number of Times	25	years 5 through 115 at 5 year increments and year 116				

Table 4: Northwest Surrogate Parameters

Parameter	K_{oc}, Oct.-Water Part. Coef.				f_{oc}, Frac. of Org. C (%)	K_d, Dist. Coef (mL/g)	$t_{1/2}$, Half-Life (years)				
	Min		Max				Min		Max		
	log K_{oc}	K_{oc} (mL/g)	log K_{oc}	K_{oc} (mL/g)			$t_{1/2}$ (hrs)	$t_{1/2}$ (yrs)	$t_{1/2}$ (hrs)	$t_{1/2}$ (yrs)	$t_{1/2}$ (yrs)
Surrogate 1 (SUR001) - Pnictogen Hydride					0.0135						
Ammonia as N, total	0.199	1.58	1.58	14.3		**0.0213**	8760	1	52560	6	6
Surrogate 2 (SUR002) - Polynuclear Aromatic Hydrocarbon											
Benzo(a)anthracene	4.52	33113	7.3	19952623		**75.9**	4896	0.559	32640	3.73	**11.7**
Benzo(b)fluoranthene	5.45	281838	8.02	1.05E+08			17280	1.97	29280	3.34	
Benzo(k)fluoranthene	5.47	295121	8.02	1.05E+08			42680	4.87	102720	11.7	
Dibenzo(a,h)anthracene	3.75	5623	8.5	3.16E+08			17328	1.98	45120	5.15	
Surrogate 3 (SUR003) - Halogenated Aliphatic Hydrocarbon											
Methylene Chloride	0.944	8.79	1.44	27.5		**0.119**	336	0.0384	1344	0.153	**0.329**
1,2-Dibromoethane	1.556	36	1.699	50			470	0.0537	2880	0.329	
Surrogate 4 (SUR004) - Aliphatic Ether											
Tetrahydrofuran	1.26	18.2	1.37	23.4		**0.246**	1.6	0.000183	1.6	0.000183	**0.000183**
Surrogate 5 (SUR005) - Ketone											
Acetone	-0.586	0.259	-0.523	0.3		**0.0035**	48	0.00548	336	0.0384	**0.0384**
2-Butanone (MEK)	-0.03	0.933	2.41	257			48	0.00548	336	0.0384	
Surrogate 6 (SUR006) - Phenolics											
Phenolics	1.15	14.1	3.49	3090		**0.302**	12	0.00137	168	0.0192	**0.0192**

Table 5: Leachate and Predicted Concentrations

Parameter	Units	List	Max	AGQS	Existing Unit		South Unit		Northwest Unit	
					MPF = 1.0002E-06		MPF = 8.5377E-16		MPF = 3.215E-03	
1,1,1,2-Tetrachloroethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,1,1-Trichloroethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,1,2,2-Tetrachloroethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,1,2-Trichloroethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,1-Dichloroethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,1-Dichloroethene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,1-Dichloropropene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,2,3-Trichlorobenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,2,3-Trichloropropane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,2,4-Trichlorobenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,2,4-Trimethylbenzene	ug/L	L1	130	2.5	1.30E-04	PASS	1.11E-13	PASS	0.41795	PASS
1,2-Dibromo-3-chloropropane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,2-Dibromoethane	ug/L	L1	50	0.05	5.00E-05	PASS	4.27E-14	PASS	8.77E-25^{3}	PASS
1,2-Dichlorobenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,2-Dichloroethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,2-Dichloropropane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,3,5-Trimethylbenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,3-Dichlorobenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,3-Dichloropropane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1,3-Dichloropropene	ug/L	L1	150	2.5	1.50E-04	PASS	1.28E-13	PASS	0.48225	PASS
1,4-Dichlorobenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
1-Propanol	ug/L	L1	20000	na	-	-	-	-	-	-
2,2-Dichloropropane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
2,4,5-TP (Silvex)	ug/L	L1	1	1	1.00E-06	PASS	8.54E-16	PASS	0.003215	PASS
2,4,6-Trichlorophenol	ug/L	L1	500	na	-	-	-	-	-	-
2,4-D	ug/L	L1	190	5	1.90E-04	PASS	1.62E-13	PASS	0.61085	PASS
2,4-Dichlorophenol	ug/L	L1	100	na	-	-	-	-	-	-
2,4-Dimethylphenol	ug/L	L1	100	na	-	-	-	-	-	-
2,4-Dinitrophenol	ug/L	L1	500	na	-	-	-	-	-	-
2,4-Dinitrotoluene	ug/L	L1	100	na	-	-	-	-	-	-
2,6-Dinitrotoluene	ug/L	L1	100	na	-	-	-	-	-	-
2-Butanone (MEK)	ug/L	L1	8000	5	8.00E-03	PASS	6.83E-12	PASS	0^{5}	PASS
2-Chloroethyl vinyl ether	ug/L	L1	50	na	-	-	-	-	-	-
2-Chloronaphthalene	ug/L	L1	100	na	-	-	-	-	-	-
2-Chlorophenol	ug/L	L1	100	na	-	-	-	-	-	-
2-Chlorotoluene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
2-Hexanone (MBK)	ug/L	L1	100	5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
2-Nitrophenol	ug/L	L1	500	na	-	-	-	-	-	-
2-Propanol	ug/L	L1	12000	na	-	-	-	-	-	-
3,3'-Dichlorobenzidine	ug/L	L1	200	na	-	-	-	-	-	-
4,4'-DDD	ug/L	L1	1	na	-	-	-	-	-	-
4,4'-DDE	ug/L	L1	1	na	-	-	-	-	-	-
4,6-Dinitro-2-methylphenol	ug/L	L1	500	na	-	-	-	-	-	-
4-Bromophenyl-phenylether	ug/L	L1	100	na	-	-	-	-	-	-
4-Chlorophenyl-phenylether	ug/L	L1	100	na	-	-	-	-	-	-
4-Chlorotoluene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
4-Methyl-2-pentanone (MIBK)	ug/L	L1	170	5	1.70E-04	PASS	1.45E-13	PASS	0.54655	PASS
4-Methylphenol	ug/L	L1	1500	5	1.50E-03	PASS	1.28E-12	PASS	4.8225	PASS
4-Nitrophenol	ug/L	L1	500	na	-	-	-	-	-	-
Acenaphthene	ug/L	L1	100	1	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Acetone	ug/L	L1	2800	5	2.80E-03	PASS	2.39E-12	PASS	0^{5}	PASS
Alachlor	ug/L	L1	4	0.0445	4.00E-06	PASS	3.42E-15	PASS	0.01286	PASS
Aldicarb	ug/L	L1	17	1.725	1.70E-05	PASS	1.45E-14	PASS	0.054655	PASS
Aldrin	ug/L	L1	0.5	0.025	5.00E-07	PASS	4.27E-16	PASS	0.0016075	PASS
Alkalinity, bicarbonate	mg/L	L1	5400	na	-	-	-	-	-	-
alpha-BHC	ug/L	L1	0.5	0.05	5.00E-07	PASS	4.27E-16	PASS	0.0016075	PASS
Aluminum, total	ug/L	L1	24000	968966	2.40E-02	PASS	2.05E-11	PASS	77.16	PASS
Ammonia as N, total	mg/L	L1	850	0.346	8.50E-04	PASS	7.26E-13	PASS	0.0009376^{1}	PASS
Anthracene	ug/L	L1	100	1	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Antimony, total	ug/L	L1	60	30	6.00E-05	PASS	5.12E-14	PASS	0.1929	PASS
Arsenic, total	ug/L	L1	540	7.1	5.40E-04	PASS	4.61E-13	PASS	1.7361	PASS
Atrazine	ug/L	L1	9.7	0.151	9.70E-06	PASS	8.28E-15	PASS	0.0311855	PASS
Barium, total	ug/L	L1	1400	222	1.40E-03	PASS	1.20E-12	PASS	4.501	PASS
Benzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Benzo(a)anthracene	ug/L	L1	100	0.13	1.00E-04	PASS	8.54E-14	PASS	0^{2}	PASS
Benzo(a)pyrene	ug/L	L1	100	5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Benzo(b)fluoranthene	ug/L	L1	100	0.18	1.00E-04	PASS	8.54E-14	PASS	0^{2}	PASS
Benzo(g,h,i)perylene	ug/L	L1	100	na	-	-	-	-	-	-
Benzo(k)fluoranthene	ug/L	L1	100	0.17	1.00E-04	PASS	8.54E-14	PASS	0^{2}	PASS

Table 5: Leachate and Predicted Concentrations

Parameter	Units	List	Max	AGQS	Existing Unit		South Unit		Northwest Unit	
					MPF = 1.0002E-06		MPF = 8.5377E-16		MPF = 3.215E-03	
Beryllium, total	ug/L	L1	20	5	2.00E-05	PASS	1.71E-14	PASS	0.0643	PASS
beta-BHC	ug/L	L1	0.5	na	-	-	-	-	-	-
Biochemical Oxygen Demand	mg/L	L1	29700	6.5	-	-	-	-	-	-
bis(2-chloroethoxy)methane	ug/L	L1	100	na	-	-	-	-	-	-
bis(2-chloroethyl)ether	ug/L	L1	100	na	-	-	-	-	-	-
bis(2-chloroisopropyl)ether	ug/L	L1	100	na	-	-	-	-	-	-
bis(2-ethylhexyl)phthalate	ug/L	L1	100	1	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
bis(chloromethyl)ether	ug/L	L1	100000	na	-	-	-	-	-	-
Boron, total	ug/L	L1	9700	504	9.70E-03	PASS	8.28E-12	PASS	31.1855	PASS
Bromobenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Bromochloromethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Bromodichloromethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Bromoform	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Bromomethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Butanol	ug/L	L1	10000	na	-	-	-	-	-	-
Butylbenzylphthalate	ug/L	L1	100	na	-	-	-	-	-	-
Cadmium, total	ug/L	L1	4.5	3.1	4.50E-06	PASS	3.84E-15	PASS	0.0144675	PASS
Calcium, total	mg/L	L1	690	295.81	6.90E-04	PASS	5.89E-13	PASS	2.21835	PASS
Carbofuran	ug/L	L1	15	2.03	1.50E-05	PASS	1.28E-14	PASS	0.048225	PASS
Carbon Disulfide	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Carbon Tetrachloride	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Chemical Oxygen Demand	mg/L	L1	37400	28	-	-	-	-	-	-
Chlordane	ug/L	L1	10	0.05	1.00E-05	PASS	8.54E-15	PASS	0.03215	PASS
Chloride, total	mg/L	L1	3700	211.53	3.70E-03	PASS	3.16E-12	PASS	11.8955	PASS
Chlorobenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Chloroethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Chloroform	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Chloromethane	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Chromium, total	ug/L	L1	99	64.5	9.90E-05	PASS	8.45E-14	PASS	0.318285	PASS
Chrysene	ug/L	L1	100	1	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
cis-1,2-Dichloroethene	ug/L	L1	200	2.5	2.00E-04	PASS	1.71E-13	PASS	0.643	PASS
Cobalt, total	ug/L	L1	42	48.1	4.20E-05	PASS	3.59E-14	PASS	0.13503	PASS
Copper, total	ug/L	L1	53	97.5	5.30E-05	PASS	4.52E-14	PASS	0.170395	PASS
Cyanide, total	mg/L	L1	0.0091	0.0066	9.10E-09	PASS	7.77E-18	PASS	2.9257E-05	PASS
DDT	ug/L	L1	1	0.05	1.00E-06	PASS	8.54E-16	PASS	0.003215	PASS
delta-BHC	ug/L	L1	1.1	na	-	-	-	-	-	-
Dibenzo(a,h)anthracene	ug/L	L1	100	0.3	1.00E-04	PASS	8.54E-14	PASS	0[2]	PASS
Dibromochloromethane	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Dibromomethane	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Dichlorodifluoromethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Dieldrin	ug/L	L1	1	0.025	1.00E-06	PASS	8.54E-16	PASS	0.003215	PASS
Diethylphthalate	ug/L	L1	100	5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Dimethylphthalate	ug/L	L1	100	5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Di-n-butylphthalate	ug/L	L1	100	5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Di-n-octylphthalate	ug/L	L1	100	na	-	-	-	-	-	-
Endosulfan I	ug/L	L1	1	na	-	-	-	-	-	-
Endosulfan II	ug/L	L1	1	na	-	-	-	-	-	-
Endosulfan Sulfate	ug/L	L1	1	na	-	-	-	-	-	-
Endrin	ug/L	L1	1	0.05	1.00E-06	PASS	8.54E-16	PASS	0.003215	PASS
Endrin Aldehyde	ug/L	L1	1	na	-	-	-	-	-	-
Ethyl Acetate	ug/L	L1	540	na	-	-	-	-	-	-
Ethylbenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Fecal Coliform Bacteria	/100 mL	L1	60000	na	-	-	-	-	-	-
Fluoranthene	ug/L	L1	100	1	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Fluorene	ug/L	L1	100	1	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Fluoride, total	mg/L	L1	2.5	0.4485	2.50E-06	PASS	2.13E-15	PASS	0.0080375	PASS
gamma-BHC (Lindane)	ug/L	L1	0.5	0.025	5.00E-07	PASS	4.27E-16	PASS	0.0016075	PASS
Heptachlor	ug/L	L1	0.5	0.025	5.00E-07	PASS	4.27E-16	PASS	0.0016075	PASS
Heptachlor Epoxide	ug/L	L1	0.5	0.5	5.00E-07	PASS	4.27E-16	PASS	0.0016075	PASS
Hexachlorobenzene	ug/L	L1	100	na	-	-	-	-	-	-
Hexachlorobutadiene	ug/L	L1	100	2.5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Hexachlorocyclopentadiene	ug/L	L1	100	0.5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Hexachloroethane	ug/L	L1	100	na	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	ug/L	L1	100	0.4	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
Iodomethane	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Iron, total	ug/L	L1	1400000	29727.6	1.40E+00	PASS	1.20E-09	PASS	4501	PASS
Isopropylbenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Lead, total	ug/L	L1	14	31	1.40E-05	PASS	1.20E-14	PASS	0.04501	PASS
m&p-Xylene	ug/L	L1	100	2.5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS

Table 5: Leachate and Predicted Concentrations

Parameter	Units	List	Max	AGQS	Existing Unit		South Unit		Northwest Unit	
					MPF = 1.0002E-06		MPF = 8.5377E-16		MPF = 3.215E-03	
Magnesium, total	mg/L	L1	170	204.58	1.70E-04	PASS	1.45E-13	PASS	0.54655	PASS
Manganese, total	ug/L	L1	48000	4849	4.80E-02	PASS	4.10E-11	PASS	154.32	PASS
Mercury, total	ug/L	L1	0.9	0.1	9.00E-07	PASS	7.68E-16	PASS	0.0028935	PASS
Methoxychlor	ug/L	L1	5	1	5.00E-06	PASS	4.27E-15	PASS	0.016075	PASS
Methylene Chloride	ug/L	L1	1900	2.5	1.90E-03	PASS	1.62E-12	PASS	3.33E-23[3]	PASS
Naphthalene	ug/L	L1	100	5	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
n-Butylbenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Nickel, total	ug/L	L1	240	41.5	2.40E-04	PASS	2.05E-13	PASS	0.7716	PASS
Nitrate as N, total	mg/L	L1	3.7	4.474	3.70E-06	PASS	3.16E-15	PASS	0.0118955	PASS
Nitrobenzene	ug/L	L1	100	na	-	-	-	-	-	-
N-Nitrosodimethylamine	ug/L	L1	100	na	-	-	-	-	-	-
N-Nitroso-di-n-propylamine	ug/L	L1	100	na	-	-	-	-	-	-
N-Nitrosodiphenylamine	ug/L	L1	100	na	-	-	-	-	-	-
n-Propylbenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Oil (Hexane Soluble)	mg/L	L1	912	5	9.12E-04	PASS	7.79E-13	PASS	2.93208	PASS
o-Xylene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Parathion	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Pentachlorophenol	ug/L	L1	50	25	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
pH (field)	s.u.	L1	7.76	6.39 - 7.87	-	-	-	-	-	-
Phenanthrene	ug/L	L1	100	na	-	-	-	-	-	-
Phenolics	ug/L	L1	6700	12.2	6.70E-03	PASS	5.72E-12	PASS	0[6]	PASS
Phosphorus, total	mg/L	L1	1200	na	-	-	-	-	-	-
p-Isopropyltoluene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Polychlorinated Biphenyls(PCBs)	ug/L	L1	10	25	1.00E-05	PASS	8.54E-15	PASS	0.03215	PASS
Potassium, total	mg/L	L1	600	5.796	6.00E-04	PASS	5.12E-13	PASS	1.929	PASS
Pyrene	ug/L	L1	100	1	1.00E-04	PASS	8.54E-14	PASS	0.3215	PASS
sec-Butylbenzene	ug/L	L1	500	2.5	5.00E-04	PASS	4.27E-13	PASS	1.6075	PASS
Selenium, total	ug/L	L1	99	2.7	9.90E-05	PASS	8.45E-14	PASS	0.318285	PASS
Silver, total	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Sodium, total	mg/L	L1	2700	212.69	2.70E-03	PASS	2.31E-12	PASS	8.6805	PASS
Specific Conductance (field)	umhos/cm	L1	24000	5600	-	-	-	-	-	-
Styrene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Sulfate, total	mg/L	L1	1100	720.25	1.10E-03	PASS	9.39E-13	PASS	3.5365	PASS
tert-Butylbenzene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Tetrachlorodibenzo-p-Dioxins	ug/L	L1	500	na	-	-	-	-	-	-
Tetrachloroethene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Tetrahydrofuran	ug/L	L1	1200	2.5	1.20E-03	PASS	1.02E-12	PASS	0[4]	PASS
Thallium, total	ug/L	L1	4.5	5	4.50E-06	PASS	3.84E-15	PASS	0.0144675	PASS
Tin, total	ug/L	L1	270	na	-	-	-	-	-	-
Toluene	ug/L	L1	110	2.5	1.10E-04	PASS	9.39E-14	PASS	0.35365	PASS
Total Dissolved Solids	mg/L	L1	34000	2237.9	-	-	-	-	-	-
Total Organic Carbon	mg/L	L1	1800	10.27	-	-	-	-	-	-
Total Suspended Solids	mg/L	L1	390	na	-	-	-	-	-	-
Toxaphene	ug/L	L1	10	1	1.00E-05	PASS	8.54E-15	PASS	0.03215	PASS
trans-1,2-Dichloroethene	ug/L	L1	200	2.5	2.00E-04	PASS	1.71E-13	PASS	0.643	PASS
trans-1,3-Dichloropropene	ug/L	L1	50	5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
trans-1,4-Dichloro-2-Butene	ug/L	L1	50	1	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Trichloroethene	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Trichlorofluoromethane	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Vinyl Acetate	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Vinyl Chloride	ug/L	L1	50	2.5	5.00E-05	PASS	4.27E-14	PASS	0.16075	PASS
Xylenes (Total)	ug/L	L1	150	2.5	1.50E-04	PASS	1.28E-13	PASS	0.48225	PASS
Zinc, total	ug/L	L1	2400	297.8	2.40E-03	PASS	2.05E-12	PASS	7.716	PASS

NOTES:

1 - Surrogate 1, MPF = 1.103e-6
2 - Surrogate 2, MPF = 0
3 - Surrogate 3, MPF = 1.754e-26
4 - Surrogate 4, MPF = 0
5 - Surrogate 5, MPF = 0
6 - Surrogate 6, MPF = 0

Table 6: Existing and South Unit AGQS and MAPC Values

Parameter	Units	AGQS	MAPC
1,1,1,2-Tetrachloroethane	ug/L	2.5	2.5
1,1,1-Trichloroethane	ug/L	2.5	2.5
1,1,2,2-Tetrachloroethane	ug/L	2.5	2.5
1,1,2-Trichloroethane	ug/L	2.5	2.5
1,1-Dichloroethane	ug/L	2.5	2.5
1,1-Dichloroethene	ug/L	2.5	2.5
1,1-Dichloropropene	ug/L	2.5	2.5
1,2,3-Trichlorobenzene	ug/L	2.5	2.5
1,2,3-Trichloropropane	ug/L	2.5	2.5
1,2,4-Trichlorobenzene	ug/L	2.5	2.5
1,2,4-Trimethylbenzene	ug/L	2.5	2.5
1,2-Dibromo-3-chloropropane	ug/L	2.5	2.5
1,2-Dibromoethane	ug/L	0.05	0.05
1,2-Dichlorobenzene	ug/L	2.5	2.5
1,2-Dichloroethane	ug/L	2.5	2.5
1,2-Dichloropropane	ug/L	2.5	2.5
1,3,5-Trimethylbenzene	ug/L	2.5	2.5
1,3-Dichlorobenzene	ug/L	2.5	2.5
1,3-Dichloropropane	ug/L	2.5	2.5
1,3-Dichloropropene	ug/L	2.5	2.5
1,4-Dichlorobenzene	ug/L	2.5	2.5
1-Propanol	ug/L	na	na
2,2-Dichloropropane	ug/L	2.5	2.5
2,4,5-TP (Silvex)	ug/L	1	1
2,4,6-Trichlorophenol	ug/L	na	na
2,4-D	ug/L	5	5
2,4-Dichlorophenol	ug/L	na	na
2,4-Dimethylphenol	ug/L	na	na
2,4-Dinitrophenol	ug/L	na	na
2,4-Dinitrotoluene	ug/L	na	na
2,6-Dinitrotoluene	ug/L	na	na
2-Butanone (MEK)	ug/L	5	5
2-Chloroethyl vinyl ether	ug/L	na	na
2-Chloronaphthalene	ug/L	na	na
2-Chlorophenol	ug/L	na	na
2-Chlorotoluene	ug/L	2.5	2.5
2-Hexanone (MBK)	ug/L	5	5
2-Nitrophenol	ug/L	na	na
2-Propanol	ug/L	na	na
3,3'-Dichlorobenzidine	ug/L	na	na
4,4'-DDD	ug/L	na	na
4,4'-DDE	ug/L	na	na
4,6-Dinitro-2-methylphenol	ug/L	na	na
4-Bromophenyl-phenylether	ug/L	na	na
4-Chlorophenyl-phenylether	ug/L	na	na
4-Chlorotoluene	ug/L	2.5	2.5
4-Methyl-2-pentanone (MIBK)	ug/L	5	5
4-Methylphenol	ug/L	5	5
4-Nitrophenol	ug/L	na	na
Acenaphthene	ug/L	1	1
Acetone	ug/L	5	5
Alachlor	ug/L	0.0445	0.0445
Aldicarb	ug/L	1.725	1.725
Aldrin	ug/L	0.025	0.025
Alkalinity, bicarbonate	mg/L	na	na
alpha-BHC	ug/L	0.05	0.05
Aluminum, total	ug/L	968966	968966
Ammonia as N, total	mg/L	0.346	0.346
Anthracene	ug/L	1	1
Antimony, total	ug/L	30	30
Arsenic, total	ug/L	7.1	7.1
Atrazine	ug/L	0.151	0.151
Barium, total	ug/L	222	222
Benzene	ug/L	2.5	2.5
Benzo(a)anthracene	ug/L	0.13	0.13
Benzo(a)pyrene	ug/L	5	5

Table 6: Existing and South Unit AGQS and MAPC Values

Parameter	Units	AGQS	MAPC
Benzo(b)fluoranthene	ug/L	0.18	0.18
Benzo(g,h,i)perylene	ug/L	na	na
Benzo(k)fluoranthene	ug/L	0.17	0.17
Beryllium, total	ug/L	5	5
beta-BHC	ug/L	na	na
Biochemical Oxygen Demand	mg/L	6.5	6.5
bis(2-chloroethoxy)methane	ug/L	na	na
bis(2-chloroethyl)ether	ug/L	na	na
bis(2-chloroisopropyl)ether	ug/L	na	na
bis(2-ethylhexyl)phthalate	ug/L	1	1
bis(chloromethyl)ether	ug/L	na	na
Boron, total	ug/L	504	504
Bromobenzene	ug/L	2.5	2.5
Bromochloromethane	ug/L	2.5	2.5
Bromodichloromethane	ug/L	2.5	2.5
Bromoform	ug/L	2.5	2.5
Bromomethane	ug/L	2.5	2.5
Butanol	ug/L	na	na
Butylbenzylphthalate	ug/L	na	na
Cadmium, total	ug/L	3.1	3.1
Calcium, total	mg/L	295.81	295.81
Carbofuran	ug/L	2.03	2.03
Carbon Disulfide	ug/L	5	5
Carbon Tetrachloride	ug/L	2.5	2.5
Chemical Oxygen Demand	mg/L	28	28
Chlordane	ug/L	0.05	0.05
Chloride, total	mg/L	211.53	211.53
Chlorobenzene	ug/L	2.5	2.5
Chloroethane	ug/L	2.5	2.5
Chloroform	ug/L	2.5	2.5
Chloromethane	ug/L	5	5
Chromium, total	ug/L	64.5	64.5
Chrysene	ug/L	1	1
cis-1,2-Dichloroethene	ug/L	2.5	2.5
Cobalt, total	ug/L	48.1	48.1
Copper, total	ug/L	97.5	97.5
Cyanide, total	mg/L	0.0066	0.0066
DDT	ug/L	0.05	0.05
delta-BHC	ug/L	na	na
Dibenzo(a,h)anthracene	ug/L	0.3	0.3
Dibromochloromethane	ug/L	5	5
Dibromomethane	ug/L	5	5
Dichlorodifluoromethane	ug/L	2.5	2.5
Dieldrin	ug/L	0.025	0.025
Diethylphthalate	ug/L	5	5
Dimethylphthalate	ug/L	5	5
Di-n-butylphthalate	ug/L	5	5
Di-n-octylphthalate	ug/L	na	na
Endosulfan I	ug/L	na	na
Endosulfan II	ug/L	na	na
Endosulfan Sulfate	ug/L	na	na
Endrin	ug/L	0.05	0.05
Endrin Aldehyde	ug/L	na	na
Ethyl Acetate	ug/L	na	na
Ethylbenzene	ug/L	2.5	2.5
Fecal Coliform Bacteria	/100 mL	na	na
Fluoranthene	ug/L	1	1
Fluorene	ug/L	1	1
Fluoride, total	mg/L	0.4485	0.4485
gamma-BHC (Lindane)	ug/L	0.025	0.025
Heptachlor	ug/L	0.025	0.025
Heptachlor Epoxide	ug/L	0.5	0.5
Hexachlorobenzene	ug/L	na	na
Hexachlorobutadiene	ug/L	2.5	2.5
Hexachlorocyclopentadiene	ug/L	0.5	0.5
Hexachloroethane	ug/L	na	na

Table 6: Existing and South Unit AGQS and MAPC Values

Parameter	Units	AGQS	MAPC
Indeno(1,2,3-cd)pyrene	ug/L	0.4	0.4
Iodomethane	ug/L	5	5
Iron, total	ug/L	29727.6	29727.6
Isopropylbenzene	ug/L	2.5	2.5
Lead, total	ug/L	31	31
m&p-Xylene	ug/L	2.5	2.5
Magnesium, total	mg/L	204.58	204.58
Manganese, total	ug/L	4849	4849
Mercury, total	ug/L	0.1	0.1
Methoxychlor	ug/L	1	1
Methylene Chloride	ug/L	2.5	2.5
Naphthalene	ug/L	5	5
n-Butylbenzene	ug/L	2.5	2.5
Nickel, total	ug/L	41.5	41.5
Nitrate as N, total	mg/L	4.474	4.474
Nitrobenzene	ug/L	na	na
N-Nitrosodimethylamine	ug/L	na	na
N-Nitroso-di-n-propylamine	ug/L	na	na
N-Nitrosodiphenylamine	ug/L	na	na
n-Propylbenzene	ug/L	2.5	2.5
Oil (Hexane Soluble)	mg/L	5	5
o-Xylene	ug/L	2.5	2.5
Parathion	ug/L	5	5
Pentachlorophenol	ug/L	25	25
pH (field)	s.u.	6.39 - 7.87	6.39 - 7.87
Phenanthrene	ug/L	na	na
Phenolics	ug/L	12.2	12.2
Phosphorus, total	mg/L	na	na
p-Isopropyltoluene	ug/L	2.5	2.5
Polychlorinated Biphenyls(PCBs)	ug/L	25	25
Potassium, total	mg/L	5.796	5.796
Pyrene	ug/L	1	1
sec-Butylbenzene	ug/L	2.5	2.5
Selenium, total	ug/L	2.7	2.7
Silver, total	ug/L	5	5
Sodium, total	mg/L	212.69	212.69
Specific Conductance (field)	umhos/cm	5600	5600
Styrene	ug/L	2.5	2.5
Sulfate, total	mg/L	720.25	720.25
tert-Butylbenzene	ug/L	2.5	2.5
Tetrachlorodibenzo-p-Dioxins	ug/L	na	na
Tetrachloroethene	ug/L	2.5	2.5
Tetrahydrofuran	ug/L	2.5	2.5
Thallium, total	ug/L	5	5
Tin, total	ug/L	na	na
Toluene	ug/L	2.5	2.5
Total Dissolved Solids	mg/L	2237.9	2237.9
Total Organic Carbon	mg/L	10.27	10.27
Total Suspended Solids	mg/L	na	na
Toxaphene	ug/L	1	1
trans-1,2-Dichloroethene	ug/L	2.5	2.5
trans-1,3-Dichloropropene	ug/L	5	5
trans-1,4-Dichloro-2-Butene	ug/L	1	1
Trichloroethene	ug/L	2.5	2.5
Trichlorofluoromethane	ug/L	2.5	2.5
Vinyl Acetate	ug/L	2.5	2.5
Vinyl Chloride	ug/L	2.5	2.5
Xylenes (Total)	ug/L	2.5	2.5
Zinc, total	ug/L	297.8	297.8

Table 7: Northwest Unit AGQS and MAPC Values

Parameter	Units	AGQS	MAPC
1,1,1,2-Tetrachloroethane	ug/L	2.5	2.93
1,1,1-Trichloroethane	ug/L	2.5	2.93
1,1,2,2-Tetrachloroethane	ug/L	2.5	2.93
1,1,2-Trichloroethane	ug/L	2.5	2.93
1,1-Dichloroethane	ug/L	2.5	2.93
1,1-Dichloroethene	ug/L	2.5	2.93
1,1-Dichloropropene	ug/L	2.5	2.93
1,2,3-Trichlorobenzene	ug/L	2.5	2.93
1,2,3-Trichloropropane	ug/L	2.5	2.93
1,2,4-Trichlorobenzene	ug/L	2.5	2.93
1,2,4-Trimethylbenzene	ug/L	2.5	2.93
1,2-Dibromo-3-chloropropane	ug/L	2.5	2.93
1,2-Dibromoethane	ug/L	0.05	0.59[2]
1,2-Dichlorobenzene	ug/L	2.5	2.93
1,2-Dichloroethane	ug/L	2.5	2.93
1,2-Dichloropropane	ug/L	2.5	2.93
1,3,5-Trimethylbenzene	ug/L	2.5	2.93
1,3-Dichlorobenzene	ug/L	2.5	2.93
1,3-Dichloropropane	ug/L	2.5	2.93
1,3-Dichloropropene	ug/L	2.5	2.93
1,4-Dichlorobenzene	ug/L	2.5	2.93
1-Propanol	ug/L	na	na
2,2-Dichloropropane	ug/L	2.5	2.93
2,4,5-TP (Silvex)	ug/L	1	1.17
2,4,6-Trichlorophenol	ug/L	na	na
2,4-D	ug/L	5	5.85
2,4-Dichlorophenol	ug/L	na	na
2,4-Dimethylphenol	ug/L	na	na
2,4-Dinitrophenol	ug/L	na	na
2,4-Dinitrotoluene	ug/L	na	na
2,6-Dinitrotoluene	ug/L	na	na
2-Butanone (MEK)	ug/L	5	5[3]
2-Chloroethyl vinyl ether	ug/L	na	na
2-Chloronaphthalene	ug/L	na	na
2-Chlorophenol	ug/L	na	na
2-Chlorotoluene	ug/L	2.5	2.93
2-Hexanone (MBK)	ug/L	5	5.85
2-Nitrophenol	ug/L	na	na
2-Propanol	ug/L	na	na
3,3'-Dichlorobenzidine	ug/L	na	na
4,4'-DDD	ug/L	na	na
4,4'-DDE	ug/L	na	na
4,6-Dinitro-2-methylphenol	ug/L	na	na
4-Bromophenyl-phenylether	ug/L	na	na
4-Chlorophenyl-phenylether	ug/L	na	na
4-Chlorotoluene	ug/L	2.5	2.93
4-Methyl-2-pentanone (MIBK)	ug/L	5	5.85
4-Methylphenol	ug/L	5	5.85
4-Nitrophenol	ug/L	na	na
Acenaphthene	ug/L	1	1.17
Acetone	ug/L	5	5[3]
Alachlor	ug/L	0.0445	0.0521
Aldicarb	ug/L	1.725	2.02
Aldrin	ug/L	0.025	0.0293
Alkalinity, bicarbonate	mg/L	na	na
alpha-BHC	ug/L	0.05	0.0585
Aluminum, total	ug/L	968966	1133690
Ammonia as N, total	mg/L	0.346	0.391[1]
Anthracene	ug/L	1	1.17
Antimony, total	ug/L	30	35.1
Arsenic, total	ug/L	7.1	8.31
Atrazine	ug/L	0.151	0.177
Barium, total	ug/L	222	260
Benzene	ug/L	2.5	2.93
Benzo(a)anthracene	ug/L	0.13	0.13[3]
Benzo(a)pyrene	ug/L	5	5.85
Benzo(b)fluoranthene	ug/L	0.18	0.18[3]

Table 7: Northwest Unit AGQS and MAPC Values

Parameter	Units	AGQS	MAPC
Benzo(g,h,i)perylene	ug/L	na	na
Benzo(k)fluoranthene	ug/L	0.17	0.17^3
Beryllium, total	ug/L	5	5.85
beta-BHC	ug/L	na	na
Biochemical Oxygen Demand	mg/L	6.5	6.5^4
bis(2-chloroethoxy)methane	ug/L	na	na
bis(2-chloroethyl)ether	ug/L	na	na
bis(2-chloroisopropyl)ether	ug/L	na	na
bis(2-ethylhexyl)phthalate	ug/L	1	1.17
bis(chloromethyl)ether	ug/L	na	na
Boron, total	ug/L	504	590
Bromobenzene	ug/L	2.5	2.93
Bromochloromethane	ug/L	2.5	2.93
Bromodichloromethane	ug/L	2.5	2.93
Bromoform	ug/L	2.5	2.93
Bromomethane	ug/L	2.5	2.93
Butanol	ug/L	na	na
Butylbenzylphthalate	ug/L	na	na
Cadmium, total	ug/L	3.1	3.63
Calcium, total	mg/L	295.81	346
Carbofuran	ug/L	2.03	2.38
Carbon Disulfide	ug/L	5	5.85
Carbon Tetrachloride	ug/L	2.5	2.93
Chemical Oxygen Demand	mg/L	28	28^4
Chlordane	ug/L	0.05	0.0585
Chloride, total	mg/L	211.53	247
Chlorobenzene	ug/L	2.5	2.93
Chloroethane	ug/L	2.5	2.93
Chloroform	ug/L	2.5	2.93
Chloromethane	ug/L	5	5.85
Chromium, total	ug/L	64.5	75.5
Chrysene	ug/L	1	1.17
cis-1,2-Dichloroethene	ug/L	2.5	2.93
Cobalt, total	ug/L	48.1	56.3
Copper, total	ug/L	97.5	114
Cyanide, total	mg/L	0.0066	0.00772
DDT	ug/L	0.05	0.0585
delta-BHC	ug/L	na	na
Dibenzo(a,h)anthracene	ug/L	0.3	0.3^3
Dibromochloromethane	ug/L	5	5.85
Dibromomethane	ug/L	5	5.85
Dichlorodifluoromethane	ug/L	2.5	2.93
Dieldrin	ug/L	0.025	0.0293
Diethylphthalate	ug/L	5	5.85
Dimethylphthalate	ug/L	5	5.85
Di-n-butylphthalate	ug/L	5	5.85
Di-n-octylphthalate	ug/L	na	na
Endosulfan I	ug/L	na	na
Endosulfan II	ug/L	na	na
Endosulfan Sulfate	ug/L	na	na
Endrin	ug/L	0.05	0.0585
Endrin Aldehyde	ug/L	na	na
Ethyl Acetate	ug/L	na	na
Ethylbenzene	ug/L	2.5	2.93
Fecal Coliform Bacteria	/100 mL	na	na
Fluoranthene	ug/L	1	1.17
Fluorene	ug/L	1	1.17
Fluoride, total	mg/L	0.4485	0.525
gamma-BHC (Lindane)	ug/L	0.025	0.0293
Heptachlor	ug/L	0.025	0.0293
Heptachlor Epoxide	ug/L	0.5	0.585
Hexachlorobenzene	ug/L	na	na
Hexachlorobutadiene	ug/L	2.5	2.93
Hexachlorocyclopentadiene	ug/L	0.5	0.585
Hexachloroethane	ug/L	na	na
Indeno(1,2,3-cd)pyrene	ug/L	0.4	0.468
Iodomethane	ug/L	5	5.85

Table 7: Northwest Unit AGQS and MAPC Values

Parameter	Units	AGQS	MAPC
Iron, total	ug/L	29727.6	34781
Isopropylbenzene	ug/L	2.5	2.93
Lead, total	ug/L	31	36.3
m&p-Xylene	ug/L	2.5	2.93
Magnesium, total	mg/L	204.58	239
Manganese, total	ug/L	4849	5,673
Mercury, total	ug/L	0.1	0.117
Methoxychlor	ug/L	1	1.17
Methylene Chloride	ug/L	2.5	2.95[2]
Naphthalene	ug/L	5	5.85
n-Butylbenzene	ug/L	2.5	2.93
Nickel, total	ug/L	41.5	48.6
Nitrate as N, total	mg/L	4.474	5.23
Nitrobenzene	ug/L	na	na
N-Nitrosodimethylamine	ug/L	na	na
N-Nitroso-di-n-propylamine	ug/L	na	na
N-Nitrosodiphenylamine	ug/L	na	na
n-Propylbenzene	ug/L	2.5	2.93
Oil (Hexane Soluble)	mg/L	5	5[4]
o-Xylene	ug/L	2.5	2.93
Parathion	ug/L	5	5.85
Pentachlorophenol	ug/L	25	29.3
pH (field)	s.u.	6.39 - 7.87	6.39 - 7.87[4]
Phenanthrene	ug/L	na	na
Phenolics	ug/L	12.2	12.2[3]
Phosphorus, total	mg/L	na	na
p-Isopropyltoluene	ug/L	2.5	2.93
Polychlorinated Biphenyls(PCBs)	ug/L	25	29.3
Potassium, total	mg/L	5.796	6.78
Pyrene	ug/L	1	1.17
sec-Butylbenzene	ug/L	2.5	2.93
Selenium, total	ug/L	2.7	3.16
Silver, total	ug/L	5	5.85
Sodium, total	mg/L	212.69	249
Specific Conductance (field)	umhos/cm	5600	5600[4]
Styrene	ug/L	2.5	2.93
Sulfate, total	mg/L	720.25	843
tert-Butylbenzene	ug/L	2.5	2.93
Tetrachlorodibenzo-p-Dioxins	ug/L	na	na
Tetrachloroethene	ug/L	2.5	2.93
Tetrahydrofuran	ug/L	2.5	2.5[3]
Thallium, total	ug/L	5	5.85
Tin, total	ug/L	na	na
Toluene	ug/L	2.5	2.93
Total Dissolved Solids	mg/L	2237.9	2237.9[4]
Total Organic Carbon	mg/L	10.27	10.27[4]
Total Suspended Solids	mg/L	na	na
Toxaphene	ug/L	1	1.17
trans-1,2-Dichloroethene	ug/L	2.5	2.93
trans-1,3-Dichloropropene	ug/L	5	5.85
trans-1,4-Dichloro-2-Butene	ug/L	1	1.17
Trichloroethene	ug/L	2.5	2.93
Trichlorofluoromethane	ug/L	2.5	2.93
Vinyl Acetate	ug/L	2.5	2.93
Vinyl Chloride	ug/L	2.5	2.93
Xylenes (Total)	ug/L	2.5	2.93
Zinc, total	ug/L	297.8	348

NOTES:

BASELINE WPF = 1.17

1 - Surrogate 1 WPF = 1.13

2 - Surrogate 3 WPF = 1.18

3 - Surrogates 2, 4, 5 and 6 WPF = 1

4 - Non-Fickian Parameter WPF = 1