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FINAL

FATE & TRANSPORT MODELING FOR DETERMINATION OF SOIL CLEANUP GOALS PROTECTIVE OF GROUNDWATER

VOLUME I

GREENWOOD CHEMICAL SITE
ALBEMARLE COUNTY, VIRGINIA

EPA WORK ASSIGNMENT NUMBER 37-17-39P5
CONTRACT NUMBER 68-W8-0037

HALLIBURTON NUS PROJECT NUMBER 2752

FEBRUARY 1993

HALLIBURTON NUS
Environmental Corporation

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This report summarizes the unsaturated zone soil cleanup goals for the leaching to groundwater pathway at the Greenwood Chemical Site in Albemarle County, Virginia. Other exposure pathways were not considered in this study. The chemicals of concern included the 12 chemicals described in the Record of Decision (ROD) dated December 29, 1989 for Operable Unit 1, along with seven additional chemicals that were determined to be of concern as a result of this study. The cleanup goals represent the estimated maximum soil concentrations that can remain at the site and permit Safe Drinking Water Act Maximum Contaminant Levels (MCLs) or other health-based standards to be attained in the groundwater. Because of the existing contamination in the saturated zone soils, groundwater containment will be required for a period of time prior to attainment of the drinking water standards. Cleanup of the unsaturated zone soils to the estimated concentration levels prescribed herein along with groundwater containment for the period indicated will result in attainment of the required standards.

The site was divided into three geographic sections for cleanup goal determination: Area 1A, the Main Source, defined as the area south of the chemical manufacturing buildings and north of Lagoon 4; Area 1B, Northern Warehouse Area and areas sampled east of the warehouse; and Area 2, the Drum Disposal Area, west of Lagoon 4 between the access roadway and the western property boundary.

The cleanup goals were determined for each Area using contaminant transport computer models, namely the EPA Hydraulic Evaluation of Landfill Performance (HELP) model for percolation of precipitation to determine the net inflow of moisture to the soils, and the Halliburton NUS one-dimensional spreadsheet based model to determine the resulting groundwater concentrations at the point of compliance. The point of compliance was determined to be the groundwater directly beneath the area of contamination. Thus downgradient transport, mixing, dispersion, and dilution were not considered.

Soil and groundwater chemical and characteristic data from the U.S. Army Corps of Engineers Pre-Design Field Investigation and the REM III Remedial Investigation were used as sources of input data for the modeling. Prior to modeling each of the 19 chemicals, a screening procedure was used to remove from further consideration those chemicals that did not pose a significant health concern using simpler, more conservative transport models (the Summer's Model). This screening procedure eliminated a number of chemicals from further cleanup goal consideration.

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The results are summarized in Table ES-1. These chemical concentrations are the cleanup goals if the groundwater containment period indicated is provided. Only those chemicals for which soil remediation is necessary are included in this table. At the direction of the EPA, the concentration given in Table ES-1 is total concentration (Ct), which includes contributions from the chemical sorbed to the soil particles (C_s) and chemical concentration present in the soil pore water (C_w). Results of chemical analysis from various investigations summarized in tables in Section 2, as well as screening and modeling results shown in tables in Section 3 and in appendices are indicated as sorbed concentrations (C_s).

TABLE ES-1

UNSATURATED ZONE - SOIL CLEANUP GOALS
GREENWOOD CHEMICAL SITE

Chemical	Soil Total Concentration (Ct) mg/kg (1)		
	Area 1A Main Source Area 2.5 Yr Containment	Area 1B North Warehouse Area 0.5 Yr Containment	Area 2 Drum Disposal Area 2 Yr Containment
Acetone	1462.1	10.1	NA(3)
Benzene	0.225	NA(3)	0.0224
4-Chloroaniline	565.7	NA(3)	NA(3)
Chlorobenzene	7,708.7	NA(3)	NA(3)
Methylene chloride	2,665.1	NA(3)	>10.83
Toluene	40,917	NA(3)	>101.4
Chloroform	0.219	NA(3)	0.3262
1,2-Dichloroethane	0.124	NA(3)	NA(3)
Tetrachloroethene	NA(3)	NA(3)	0.2364
Trichloroethene	NA(3)	NA(3)	0.0974
Naphthaleneacetic acid(2)	NA(3)	NA(3)	158.6
Tetrahydrofuran	97,269	NA(3)	0(4)

(1) Cleanup goal as total concentration for groundwater containment period indicated. Total concentration is the sum of the chemical concentration sorbed to the soil particles (C_s) as well as the concentration present in the pore water entrapped in the soil matrix (C_w).

(2) Total semi-volatile tentatively identified compounds (TICs) used as representative as Naphthaleneacetic Acid (NAA).

(3) NA = No cleanup required for this chemical in this area.

(4) Tetrahydrofuran not present in unsaturated soils in this area; however, unsaturated or groundwater concentration requires 0.25 year containment before groundwater attains drinking or health-based standards.

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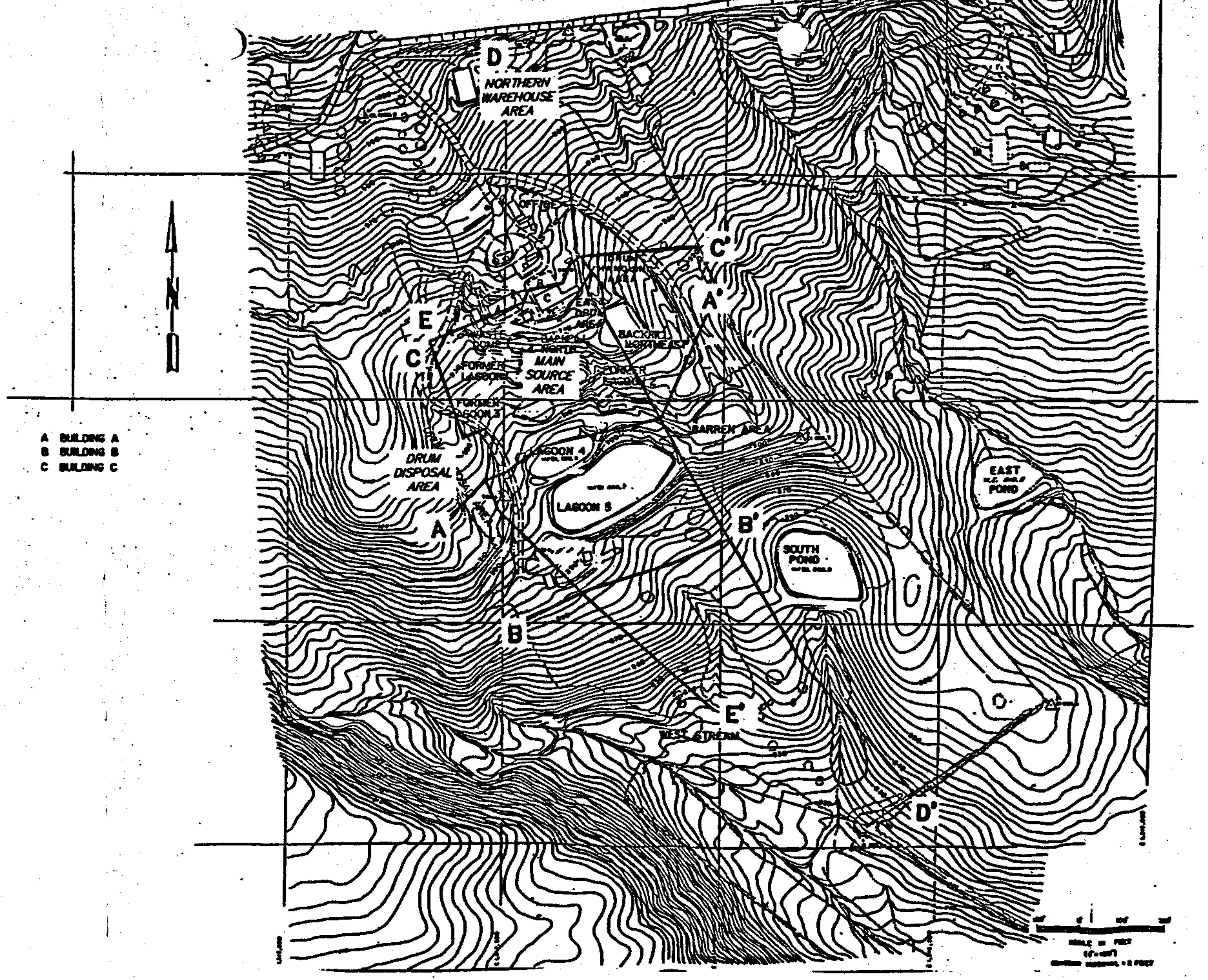

FIGURE 2–1

CROSS–SECTION LOCATION MAP
GREENWOOD CHEMICAL SITE, ALBEMARLE COUNTY, VIRGINIA

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2.3.2 REM III NAA and THF Data

The 1989 Record of Decision (ROD) document reported that the concentrations of volatile and semivolatile Tentatively Identified Compounds (TICs) were sufficiently high enough to warrant consideration as cleanup goals. Two compounds were selected as representative of these TICs: naphthaleneacetic acid (NAA) was selected as representative of the total semivolatile TICs and tetrahydrofuran (THF) was selected to represent the total volatile TICs. USACE THF data was available and was used for the THF data. Because the Army Corps of Engineers' data did not report NAA or semivolatile TIC data, it was necessary to use the TIC data from the August 1990 RI Report. This data is included in Appendix D. The semivolatile TIC data was adjusted to compensate for semivolatile TICs found present in background locations by subtracting out the average background semivolatile TIC data prior to using the data to establish the extent of contamination and the median concentrations.

2.3.3 REM III Data for Drum Disposal Area

For the Drum Disposal Area (Area 2; see Area descriptions, Section 2.5) insufficient Army Corps data was available to determine the saturated zone concentrations. It became necessary to use the actual groundwater concentrations from monitoring wells sampled during the REM III RI in February and March of 1989 (reported in RI Report, August 1990). Only the REM III soils data collected during the same time frame as the monitoring well data was used to determine the cleanup goals in the groundwater modeling effort.

2.4 HYDROGEOLOGICAL AND GEOTECHNICAL PARAMETERS

A brief description of the lithologic units is included in the section. Information specific to the data required to perform the modeling is emphasized.

2.4.1 Geology

A total of three lithologic units were identified and evaluated for the purposes of this report. Those units are termed as: the unconsolidated layer, the saprolite, and the bedrock. Five geologic cross sections were developed for the site area and are shown on Drawings 1 and 2 in the back of this report. A cross section location map is included as Figure 2-1. A discussion of these lithologic units, from the shallowest to the deepest unit, is included in the following paragraphs.

The unconsolidated layer consists primarily of colluvial deposits comprised of clays, silts, sands, and gravel with local variations. The local variations exist in areas where the unconsolidated layer has been reworked and/or replaced by man made fill. The unconsolidated layer extends from the ground

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1.0 INTRODUCTION

In response to a request from Darius Ostrauskas, former EPA Remedial Project Manager for the Greenwood Chemical Site in Albemarle County, Virginia, HALLIBURTON NUS has prepared this report summarizing the results of groundwater modeling performed to determine revised soil cleanup goals based on attaining Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs), SDWA Proposed Maximum Contaminant Levels (PMCLs) and/or protective levels based on reference dose concentrations in the aquifer(s) underlying contaminant source(s) at the site.

1.1 BACKGROUND

A Remedial Design for Operable Unit One (OU-1) is currently being prepared by the U.S. Army Corps of Engineers (USACE) to address contaminated soils associated with the site. The remedy of concern was selected in a Record of Decision (ROD) dated December 29, 1989 and include the excavation and offsite incineration, stabilization and/or disposal of soils exceeding cleanup levels protective of human health and the environment. Contaminants of concern in OU-1 soils include arsenic, benzene, chlorobenzene, cyanide, methylene chloride, semivolatile tentatively identified compounds (TICs), PCE, TCE and tetrahydrofuran (a volatile TIC). The ROD for OU-1 included soil cleanup levels protective of potable groundwater. Based on the results of sampling conducted during the RD, as well as new MCLs and PMCLs, it was determined that soil cleanup levels protective of groundwater should be re-evaluated.

In response, additional fate and transport modeling has been conducted to develop revised soil cleanup goals for site-related contaminants. In addition to soils of concern identified in the ROD for OU-1, this modeling effort addresses all other contaminated soils at the site.

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2.0 GROUNDWATER TRANSPORT MODELING INPUTS

The mechanism for exposure involves incident precipitation and surface water runoff infiltrating into areas containing chemicals of concern, and the formation of leachate containing these chemicals discharging into the aquifer, which may be used as a potable water source by residents downgradient of the site. The recently finalized Multimed model (developed under the auspices of EPA) was initially expected to be used to determine soil cleanup levels based on attainment of health-based criteria in aquifer(s) underlying the site. However, EPA determined that a one-dimensional spreadsheet-based contaminant flow and transport model developed by Halliburton NUS could better simulate site-specific conditions. The model utilized in this case is described in Appendix A. The model analysis was conducted by EPA Region III and Halliburton NUS for 19 chemicals determined to be of toxicological concern.

This document summarizes the inputs to the model and the results of the modeling effort. Many of the input parameters are required for both the Multimed and Halliburton NUS models. The input parameters have been separated into three areas, including chemical-specific parameters, hydrogeologic and geotechnical parameters, and source parameters.

2.1 CHEMICALS OF CONCERN

The chemicals of concern were established following a review of the cleanup goals established in the ROD for OU-1 (EPA, December, 1989), and the results of ACE pre-design soil sampling conducted in 1991. The 1989 ROD established soil cleanup goals for 12 chemicals, including arsenic, cyanide, benzene, 4-chloroaniline, chlorobenzene, methylene chloride, tetrachloroethene (PCE), trichloroethylene (TCE) toluene, naphthalene, naphthalene acetic acid, and tetrahydrofuran, as determined by the REM III contractor. Based on further review of the ACE data, Halliburton NUS recommended the addition of seven chemicals to the list, including acetone, 1,2-dichloroethane (1,2-DCA), di-n-butylphthalate, bis(2-ethylhexyl)phthalate, 2,4,6-trichlorophenol, chloroform, and xylenes.

2.1.1 Groundwater ARARs or Health-Based Criteria

Table 2-1 identifies groundwater concentrations of site-related contaminants which are protective for drinking water purposes. This table identifies former criteria (utilized to calculate soil cleanup levels identified in the ROD) and new criteria developed in response to new SDWA MCLs and PMCLs.

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TABLE 2-1

SUMMARY OF GROUNDWATER ARARs OR HEALTH-BASED CRITERIA
GREENWOOD CHEMICAL SITE

Chemical	Former ARARs/ Criteria (µg/L)(1)(2)	New ARARs/Criteria (µg/L)(7)
Arsenic	50 (MCL)	50 (MCL)
Cyanide	5.2 (WQC)	200 (PMCL)
Acetone	--	3,500 (RFD)
Benzene	5 (MCL)	5 (MCL)
4-Chloroaniline	TT	140 (RFD)
Chlorobenzene	488 (WQC)	100 (MCL)
Methylene chloride	10^{-5} ca. risk	5 (MCL)
Tetrachloroethene	0.8 (WQC)	5 (MCL)
Trichloroethene	5 (MCL)	5 (MCL)
Toluene	2,000 (PMCLG)	1,000 (MCL)
Naphthalene	TT	140 (RFD)
Naphthaleneacetic acid(5)	TT(3)	305(RFD)(6)
Tetrahydrofuran	TT	73 (RFD)(4)
Bis(2-ethylhexyl)phthalate	--	4 (PMCL)
Chloroform	--	100 (MCL)
1,2-Dichloroethane	--	5 (MCL)
Di-n-butyl phthalate	--	3,500 (RFD)
Xylene	--	10,000 (MCL)
2,4,6-Trichlorophenol	--	3.2 (10^{-5} ca. risk)

(1) These values are consistent with the Record of Decision (ROD) dated Dec. 31, 1989.

(2) Basis for guideline in parentheses:
MCL = SDWA Maximum Contaminant Level
WQC = Water Quality Criteria
PMCLG = SDWA Proposed MCL Goal
PMCL = SDWA Proposed MCL
RFD = Risk Reference Dose
TT = Threshold Toxicity

(3) Identified as representative of semi-volatile TICs in December 31, 1989 ROD.

(4) Per draft document entitled "Selecting Exposure Routes and Contaminants of Concern by Risk-Based Screening," dated March 17, 1992, EPA Region III Hazardous Waste Management Division, Contact: Dr. Roy L. Smith.

(5) As noted in the ROD, the toxicity of total semivolatile TICs is assumed equivalent to naphthalene acetic acid (NAA). As a result, health-based criteria for NAA in groundwater is also considered to be the health-based criteria for total semivolatile TICs in groundwater.

(6) EPA memorandum from R. Brunker and D. Ostrauskas, February 5, 1992.

(7) These ARARs/criteria used as standards for the groundwater modeling in this report.

In addition, certain criteria have been revised to reflect consistency with existing MCLs (i.e., if an MCL is available, this is identified as the new criteria. The objective of the modeling effort is to predict estimated contaminant concentrations in soil (i.e., soil cleanup levels) that will facilitate meeting these groundwater criteria.

2.2 CHEMICAL-SPECIFIC PARAMETERS

The following is a description of the methods used to develop three tables of chemical-specific properties for the 19 chemicals for which the soil cleanup goals were derived. Details concerning special calculations and derivations and a list of sources follow the tables. The parameters were developed based on the requirements for the Multimed model; however, many of the parameters were used for the Halliburton NUS model.

- Chemical-specific parameters are summarized in Table 2-2, and include Koc, air diffusion coefficient, molecular weight, Henry's Law constant and vapor pressure constants.

- Decay Constants, are summarized in Table 2-3 and 2-4, and include values determined for biodegradation and hydrolysis rate constants, respectively.

- Calculated Values (Table 2-5) includes the results of calculation of the distribution coefficient K_D and mass fraction of solute.

2.2.1 Biodegradation Coefficient

For each compound, the biodegradation rate constant is used as the biodegradation coefficient (1/yr, saturated zone). Biodegradation rate constants were derived using equations found in Dragun, 1988:

$$t(1/2) = 0.693/k$$
$$k = (2.303/t) \log [a/(a-x)]$$

where:
k = rate constant
t = time
$t(1/2)$ = half-life
a = initial concentration
x = amount degraded in time t

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TABLE 2-2

CHEMICAL-SPECIFIC PARAMETERS
GREENWOOD CHEMICAL SITE

Chemical	Koc (ml/g)	Air diff. coeff. $^{(1)}$ (cm^2/s)	Ref. temp. ADC$^{(1)}$ (C)	Mol. wt. (g/mol)$^{(2)}$	Solute vap. pressure (mmHg)$^{(2)}$	Henry's Law K$^{(2)}$ (atm m^3/mol)
Arsenic	-	-	-	74.92	1(372 C)$^{(3)}$	NA
Cyanide	-	-	-	26.018$^{(3)}$	NA	NA
Acetone	9.2$^{(2)}$	0.09699 0.10930 0.12223	10 30 50	58.08	270(30C)$^{(4)}$ 270(20C)	3.43E-5
Benzene	83$^{(5,6)}$	0.08195 0.088$^{(6)}$ 0.09234 0.10327	10 25$^{(6)}$ 30 50	78.12	95.2(20C)	5.5E-3
4-Chloroaniline	52$^{(2)}$	-	-	127.6	1.5E-2(20C)	1.07E-5
Chlorobenzene	330$^{(5)}$	0.06769 0.07627 0.08530	10 30 50	112.56	11.7(20C)	3.58E-3
Methylene chloride	8.8$^{(5)}$	0.101$^{(7)}$	25$^{(7)}$	84.94	362(20C)	2.03E-3
Tetrachloroethene	364$^{(5)}$	0.06968 0.07852 0.08781	10 30 50	165.83	14(20C)	1.53E-2
Trichloroethene	126$^{(5)}$	0.07638 0.08606 0.09625	10 30 50	131.39	57.9(20C)	9.1E-3
Toluene	300$^{(5)}$	0.07367 0.08301 0.09283	10 30 50	92.13	28(25C)$^{(8)}$ 28.7(20C)	6.66E-3
Naphthalene	940$^{(2)}$ 1300$^{(6)}$	-	-	128.2	8.7E-3(25C)	4.6E-4

TABLE 2-2
CHEMICAL-SPECIFIC PARAMETERS
GREENWOOD CHEMICAL SITE
PAGE TWO

Chemical	Koc (ml/g)	Air diff. coeff. [1] (cm^2/s)	Ref. temp. ADC[1] (C)	Mol. wt. (g/mol)[2]	Solute vap. pressure (mmHg)[2]	Henry's Law K[2] (atm m^3/mol)
Naphthaleneacetic Acid	160-610[9]	-	-	186.21	2.01E-6(25C)[9]	1.2E-9[c]
Tetrahydrofuran	42.39[a][10,14]	0.098[7]	25[7]	72.11	133(20C) 162(25C)[8]	1.1E-4[12]
Bis(2-ethylhexyl) Phthalate	2E9[2]	-	-	390.62	2E-7(20C)	3E-7
Chloroform	44[2]	0.08345 0.09404 0.10517	10 30 50	119.38	150(20)	2.88E-3
1,2-Dichloroethane	14[2]	0.08557 0.09404 0.10517	10 30 50	98.96	61(20C)	9.14E-4
Di-n-butyl Phthalate	1.7E5[2]	-	-	278.3	1E-5(25C)	2.8E-7
Xylenes	248[2]	0.06742 0.07597 0.08495	10 30 50	106.16	6.5(20C) (p-)	4.33E-3
2,4,6-Trichlorophenol	3020[b][11,13]	-	-	197.45	1(76.5C)[15]	4E-6

(a)(b) See calculation of Koc for tetrahydrofuran and trichlorophenol in Appendix C.

(1) USEPA, April 1988. Superfund Exposure Assessment Manual. Office of Remedial Response, Washington, D.C. EPA/540/1-88/001.
(2) USEPA, December 1982. Aquatic Fate Process Data for Organic Priority Pollutants. EPA 440/4-81-014.
(3) CRC Press, Inc. CRC Handbook of Chemistry and Physics. 60th Edition. Boca Raton, Florida.
(4) Verschueren, K., 1983. Handbook of Environmental Data on Organic Chemicals. Second Edition. Van Nostrand Reinhold Company, New York.
(5) USEPA, 1986. Superfund Public Health Evaluation Manual. Office of Emergency and Remedial Response. EPA 540/1-86/060.
(6) Dragun, J., 1988. The Soil Chemistry of Hazardous Materials. Hazardous Materials Control Research Institute, Silver Spring, Maryland.

TABLE 2-2
CHEMICAL-SPECIFIC PARAMETERS
GREENWOOD CHEMICAL SITE
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(7) USEPA. Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) - Air Emission Models.

(8) Dean, J. A., 1985. Lange's Handbook of Chemistry, Thirteenth Edition. McGraw-Hill Book Company, Inc., New York.

(9) National Library of Medicine. Hazardous Substances Data Bank (HSDB). Record for 1-naphthaleneacetic acid, August 5, 1991.

(10) Treiner, C. and A. K. Chattopadhyay, January 1986. "Correlation of Partition Coefficients for Polar Aromatic and Aliphatic Molecules between Trimethyldodecylammonium Bromide Micelles + Water and Octanol + Water Systems at 298.15 K". Journal of Colloid and Interface Science, Vol. 109, No. 1, pp. 101-108.

(11) Karickhoff, S. W. and D. S. Brown, 1978. "Paraquat Sorption as a Function of Particle Size in Natural Sediments." Journal of Environmental Quality, Vol. 7, pp. 246-252.

(12) Volskai, V. T. Jr. and C.P.L. Grady, Jr., October 1988. "Toxicity of Selected RCRA Compounds to Activated Sludge Microorganisms." Journal of WPCF, Vol. 60, No. 10, pp. 1850-1856.

(13) Leo, A., C., Hansch, and D. Elkins, December 1971. "Partition Coefficients and Their Uses." Critical Reviews, Vol. 71, No. 6, pp. 525-616.

(14) Kenaga, E. E. and C. A. I. Goring. "Relationship between Water Solubility, Soil-Sorption, Octanol-Water Partitioning, and Bioconcentration of Chemicals in Biota," prepublication copy of paper dated October 13, 1978, given at the American Society for Testing and Materials, 3rd Aquatic Toxicology Symposium, October 17-18, 1978, New Orleans, Louisiana.

(15) Callahan, M. A., M. W. Slimak, et. al., for USEPA, 1977. Water-related Environmental Fate of 129 Priority Pollutants, Vol. II, EPA Report No. EPA 440/4-79-029b.

TABLE 2-3

SATURATED ZONE BIODEGRADATION COEFFICIENTS GREENWOOD CHEMICAL SITE

Chemical	Data from Literature	Value (1/year)
Arsenic	N/A	0
Cyanide	calcium cyanide-N/A, barium cyanide-N/A, sodium cyanide-N/A, potassium cyanide-N/A, hydrogen cyanide-NQ, benzonitrile-N/A	0
Acetone	0.016 (1/hr) + 20 hr lag, activated sludge, (assumed t(1/2) = 51.25 hr) (HSDB) 100% degrad. in 4 d + 5 d lag, anaerobic, (assumed t = 9 d) (HSDB)	activ. 115.6 anaer. 40
Benzene	t(1/2) = 110 d, sgw, fo (Dragun) t(1/2) = 68 d, sgw, fo (Dragun)	2.3 3.7
4-Chloroaniline	46% degrad. in 8 d, innoculum (HSDB)	28
Chlorobenzene	t(1/2) = 37 d, sgw, fo (Dragun)	6.8
Methylene chloride	100% degrad. in 7 d, scf, sdw (Dragun)	52
Tetrachloroethene	t(1/2) = 300 d, sgw, fo (Dragun)	0.84
Trichloroethene	t(1/2) = 300 d, sgw, fo (Dragun)	0.84
Toluene	t(1/2) = 37 d, sgw, fo (Dragun) t(1/2) = 39 d, sgw, fo (Dragun)	6.8 6.5
Naphthalene	t(1/2) = 110 d, sgw, fo (Dragun)	2.3
Naphthaleneacetic acid	N/A	2.3(1)
Tetrahydrofuran	N/A	6.8/6.5(2)
Bis(2-ethylhexyl) phthalate	0% degrad. in 7 d, scf, sdw (Dragun)	0
Chloroform	49% degrad. in 7 d, aerobic (HSDB) 0% degrad. in 27 wk, anaerobic aquifer (HSDB)	aer. 36 anaer. 0
1,2-Dichloroethane	23% degrad. in 7 d, scf, sdw (Dragun)	13.6
Di-n-butyl phthalate	100% degrad. in 7 d, scf, sdw (Dragun)	52
Xylenes	t(1/2) = 37 d, sgw, fo (Dragun) t(1/2) = 15 d, sgw, fo (Dragun) t(1/2) = 11 d, sgw, fo (Dragun) t(1/2) = 32 d, sgw, fo (Dragun) t(1/2) = 37 d, sgw, fo (Dragun) t(1/2) = 17 d, sgw, fo (Dragun)	6.8 16.9 23 7.9 6.8 14.9

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TABLE 2-3
SATURATED ZONE BIODEGRADATION COEFFICIENTS
GREENWOOD CHEMICAL SITE
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Chemical	Data from Literature	Value (1/year)
2,4,6-Trichlorophenol	95% degrad. in 3 d, aerobic, clay loam (HSDB) 28% degrad. in 80 d, anaerobic, clay loam (HSDB)	aer. 360.9 anaer. 1.5

Those chemicals with multiple coefficients can be treated in the following ways: (1) use the most conservative (lowest) coefficient, (2) use the least conservative (highest) coefficient, or (3) use the arithmetic mean of the coefficients. It is recommended that (3) be used because the coefficients are not dissimilar. This is not recommened for coefficients for which both anaerobic and aerobic coefficients have been derived.

Example calculations and derivations are included in Appendix B.

Abbreviations:

HSDB = Hazardous Substances Data Bank
Calc. = calculated
N/A = not applicable
NQ = not quantitated
d = days
sgw = soil-groundwater system
fo = field observation
hr = hours
degrad. = degradation
scf = static-culture flask biodegradation test, original culture
sdw = settled domestic wastewater used as microbial innoculum
wk = weeks
activ. = activated
anaer. = anaerobic
aer. = aerobic

Dragun, J., 1988. The Soil Chemistry of Hazardous Materials. Hazardous Materials Control Research Institute, Silver Springs, Maryland.

National Library of Medicine. Hazardous Substances Data Bank (HSDB). Records for calcium cyanide, barium cyanide, sodium cyanide, potassium cyanide, hydrogen cyanide, benzonitrile, acetone, 4-chloroaniline, tetrahydrofuran, chloroform, and 2,4,6-trichlorophenol, August 5, 1991.

Ebasco Services, Inc. for USEPA, August 1989. Final Focused Feasibility Study Report - Operable Unit 1. Appendix B - Clean Up Goals for Greenwood Chemical Site.

Ebasco Services, Inc. for USEPA, August 1990. Final Remedial Investigation Report: Greenwood Chemical Site, Albemarle County, Virginia.

(1) No data available for NAA. Assumed to be equal to value for naphthalene.
(2) No data available, assumed to be equal to value for toluene.

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TABLE 2-4

HYDROLYSIS RATE CONSTANTS
GREENWOOD CHEMICAL SITE

Chemical	Neutral (yr^{-1})	Base-Catalyzed* (L/M-yr)	Acid-Catalyzed (L/M-yr)	Reference Temperature (C)
Arsenic	NS	NS	NS	-
Cyanide	-	-	-	-
Acetone	NS	NS	NS	-
Benzene	NS	NS	NS	-
4-Chloroaniline	NS	NS	NS	-
Chlorobenzene	NS	NS	NS	-
Methylene chloride	0	NR	0	25
Tetrachloroethene	0	0	0	-
Trichloroethene	0	0	0	-
Toluene	NS	NS	NS	-
Naphthalene	NS	NS	NS	-
Naphthaleneacetic acid	NS	NS	NS	-
Tetrahydrofuran	NS	NS	NS	-
Bis(2-ethylhexyl)phthalate	3.5E-1	3504	0	30
Chloroform	0	2E3	2.19E-5	25
1,2-Dichloroethane	0	NR	1.58E-5	25
Di-n-butyl phthalate	69.4	6.9E5	0	30
Xylene	NS	NS	NS	-
2,4,6-Trichlorophenol	NS	NS	NS	-

* for alkyl halides, pH > 11

Abbreviations

NS = not significant
NR = not reported

Mabey, W. R., J. H. Smith, R. T. Podoll, H. L. Johnson, T. Mill, T. W. Chou, J. Gates, I. Wright Partridge, J. Jaber, and D. Vandenberg, 1982. "Aquatic Fate Process Data for Organic Priority Pollutants." Office of Water Regulations and Standards, Washington, D.C. EPA 440/4-81-014.

TABLE 2-5

DISTRIBUTION COEFFICIENT AND MASS FRACTION OF SOLUTE GREENWOOD CHEMICAL SITE

Chemical	Unsaturated Zone			Saturated Zone			
	Kd (min)	Kd (max)	Kd (mean)	Kd (min)	Kd (max)	Kd (mean)	Mass Fraction (geo. mean)
Arsenic	--	--	924	--	--	924	3.1 E-6
Cyanide	--	--	1,700	--	--	1,700	3.1 E-7
Acetone	0.00368	0.2392	0.04416	0.0046	0.04324	0.0138	7.4 E-6
Benzene	0.0332	2.158	0.3984	0.0415	0.3901	0.1245	5.7 E-9
4-Chloroaniline	0.0208	1.352	0.2496	0.026	0.2444	0.078	1.5 E-6
Chlorobenzene	0.132	8.58	1.584	0.165	1.551	0.495	9.1 E-9
Methylene chloride	0.00352	0.2288	0.04224	0.0044	0.04136	0.0132	5.3 E-9
Tetrachloroethene	0.1456	9.464	1.7472	0.182	1.7108	0.546	2.3 E-9
Trichloroethene	0.0504	3.276	0.6048	0.063	0.5922	0.189	2.3 E-9
Toluene	0.12	7.8	1.44	0.15	1.41	0.45	2.5 E-7
Naphthalene[a]	0.376	24.44	4.512	0.47	4.418	1.41	3.6 E-7
Naphthalene[b]	0.52	23.6	6.24	0.65	6.11	1.95	3.6 E-7
Naphthalene AA[c]	0.064	4.16	0.768	0.08	0.752	0.24	--
Tetrahydrofuran	0.016956	1.10214	0.2035	0.21195	0.199233	0.06358	1.1 E-6
DEHP	8E5	5.2E7	9.6E6	1E6	9.4E6	3.0E6	3 E-7
Chloroform	0.0176	1.144	0.2112	0.022	0.2068	0.066	4 E-9
1,2-Dichloroethane	0.056	0.364	0.0672	0.007	0.0658	0.021	4.6 E-9
Di-n-butyl phthalate	68	4,420	816	85	799	255	3.2 E-7
Xylene	0.0992	6.448	1.1904	0.124	1.1656	0.372	1.8 E-8
2,4,6-Trichlorophenol	1.208	78.52	14.496	1.51	14.194	4.53	4.9 E-7

(a) Based on Koc = 940.
(b) Based on Koc = 1,300.
(c) Based on Koc = 160.

Abbreviations:

Kd = Distribution coefficient
Min = Minimum
Max = Maximum
Naphthalene AA = naphthalene acetic acid (represents total semivolatile Tentatively Identified Compounds, TICs)
DEHP = bis(2-ethylhexyl)phthalate
Koc = Organic carbon partition coefficient

The rate constants were then adjusted to the units of (1/yr). Sample calculations and derivations of the half-life are included in Appendix B.

The sources of the half-lives or times and concentrations were Dragun, 1988, and Hazardous Substances Data Bank (HSDB), August 5, 1991. Preferentially, soil-groundwater field observations were used. In absence of such data, laboratory systems data were used, with preference given to systems using groundwater, soil, and natural microbial flora.

When x = 100 percent in time t, it was assumed that time was required for all degradation, and the number of time periods of length t in a year were used for the rate constant, since the equations will not accept $a - x = 0$.

2.2.2 Solid and Liquid Phase Decay Coefficients

These will be derived by the code; input required (e.g., hydrolysis constants) are supplied.

2.2.3 Calculated Inputs

Mole Fraction of Solute (mol/mol)

For this input, mass fraction was used instead of mole fraction. This method is believed to result in a better estimation than mole fraction because when using mole fraction, a molecular formula for soil would have to be estimated. Using silicon dioxide (sand, SiO_2) would not be appropriate based on the soil types at this site, with the potential for underestimating mole fraction. The use of mass fraction (g/g) eliminates the necessity for deriving a molecular formula for the soil.

The distribution coefficient, K_D, was calculated from the following:

$$K_D = Koc \times FOC$$

where: Koc = organic carbon partition coefficient
FOC = fraction organic carbon

Koc values were obtained from the literature. In two cases, Koc was calculated from Kow (see Table 2-2 and its support documentation in Appendix B). FOC was determined from TOC (total organic carbon), which was obtained from Army Corps of Engineers field data. FOC was determined for the saturated and unsaturated zones; the minimum, maximum, geometric means were determined (see Appendix C). The K_D values are listed in Table 2-5.

It was intended that K_D values for arsenic would be obtained through mass balance calculations using the ACE analytical results of constituent and TC leaching procedure samples. Results (see Appendix C) of calculations of the K_D values for arsenic using the saturated zone soil and leachate data indicated the geometric mean K_D value was 8,258, while use of the unsaturated zone data resulted in a geometric mean K_D of 3,242. The arsenic K_D value calculated by Ebasco and reported in the Focused Feasibility Study report for Operable Unit 1 using ASTM shake test and constituent analysis results indicated a value of 924. Because the use of the lower value would be more conservative (i.e., would result in higher aqueous phase arsenic concentration), the Ebasco value was used. the K_D calculated by Ebasco for cyanide (1,700) was also used in the modeling effort.

Average soil concentrations in the saturated zone were converted to mass fraction by dividing the soil concentration (mg/kg) by 1×10^6. Geometric means from saturated soil analytical results were used as soil concentrations. The mass fractions are summarized in Table 2-5.

2.2.4 Modeling Considerations for Chemical Data

Due to uncertainties in the degradation coefficients described in Table 2-3 for modeling purposes, a factor of safety was used with the data. The degradation half-lives were multiplied by 2 and the product was used as the decay coefficient in the model for values derived from soil groundwater environment. For values derived aerobic environments, such as from wastewater treatment plants, or laboratory studies, the values were multiplied by 10 and the product used as the decay coefficient.

Generally, the distribution coefficient K_D was calculated by the Halliburton NUS model internally using the Koc and mean Foc values. The Foc values were calculated using ACE data collected from onsite soils during the pre-design investigation. Separate geometric means were calculated for the saturated and unsaturated soil zones. K_D values for arsenic and cyanide were used directly in the model.

2.3 DATA HANDLING

This section describes the methods used in handling blank contamination and below detectable limit analytical results in the calculation of statistical values for the analytical results. Table 2-6 summarizes the results of saturated zone analytical data for soil samples collected by the ACE.

TABLE 2-6

SATURATED ZONE SOILS ANALYTICAL DATA
GREENWOOD CHEMICAL SITE

<---------------------------------- all results expressed as mg/kg ---------------------------------->

SAMPLE NUMBER	SAMPLE DEPTH	ACETONE	BENZENE	CHLORO-BENZENE	CHLOROFORM	METHYLENE CHLORIDE	TOLUENE	XYLENE	1,2-DCA (1)	PCE (2)	TCE (3)
BN8	30	2.187 *	0.00844 #	0.00844 #	0.00844 #	0.01689 #	0.05876	0.359	0.00844 #	0.00844 #	0.00844 #
BN8	35	56.096 *	0.00791 #	0.00791 #	0.00791 #	0.01582 #	0.212	0.594	0.251	0.00791 #	0.00791 #
BN8	40	17.279 *	0.128	0.04867	0.0055 #	0.01111 #	3.401	3.957	0.944	0.0055 #	0.0055 #
BN3	30	12.916 *	0.00534 #	0.477	0.00534 #	0.01068 #	0.37436	0.59679	0.018	0.00534 #	0.00534 #
BN3	35	21.606 *	0.001645 #	0.001645 #	0.001645 #	0.00329 #	0.001645 #	0.16428	0.001645 #	0.001645 #	0.001645 #
BN1	30	5.153 *	0.01785	0.00185 #	0.00185 #	0.00741 #	1.01	0.00185 #	0.00185 #	0.00185 #	0.00185 #
BN1	35	0.658 *	0.03816	0.001905 #	0.001905 #	0.00381 #	1.378	0.001905 #	0.001905 #	0.001905 #	0.001905 #
L302	15	7.108 *	0.001565 #	0.001565	0.001565 #	0.003125 #	0.0076	0.001565 #	0.001565 #	0.001565 #	0.001565 #
L102	25	8.664 *	0.00169 #	0.00169	0.00169 #	0.00338 #	0.00169 #	0.00169 #	0.00169 #	0.00169 #	0.00169 #
L102	30	8.712 *	0.001785 #	0.001785	0.001785 #	0.00357 #	0.001785 #	0.001785 #	0.001785 #	0.001785 #	0.001785 #
BN4	30	8.691 *	0.00548 #	0.00548 #	0.00548 #	0.01096 #	0.00548 #	0.00548 #	0.00548 #	0.00548 #	0.00548 #
BN4	35	2.766 *	0.00149 #	0.00149 #	0.00149 #	0.00298 #	0.00149 #	0.00149 #	0.00149 #	0.00149 #	0.00149 #
DD2	20	1.991 *	0.00176 #	0.00176 #	0.00176 #	0.00352 #	0.00176 #	0.00176 #	0.00176 #	0.00176 #	0.00176 #
DD2	25	2.869 *	0.001625 #	0.001625 #	0.001625 #	0.00325 #	0.001625 #	0.027 *	0.001625 #	0.001625 #	0.001625 #
DD2	30	2.208 *	0.001625 #	0.001625 #	0.001625 #	0.00325 #	0.001625 #	0.001625 #	0.001625 #	0.001625 #	0.001625 #
L101	25	74.781 *	0.001645 #	0.001645 #	0.001645 #	0.00329 #	0.001645 #	0.001645 #	0.001645 #	0.001645 #	0.001645 #
L203	25	0.863 *	0.00169 #	0.00169 #	0.00169 #	0.00338 #	0.00169 #	0.00169 #	0.00169 #	0.00169 #	0.00169 #
A101	25	0.00333 #	0.001665 #	0.001665 #	0.001665 #	0.00333 #	0.001665 #	0.001665 #	0.001665 #	0.001665 #	0.001665 #
A101	30	0.00325 #	0.001625 #	0.001625 #	0.001625 #	0.00325 #	0.001625 #	0.001625 #	0.001625 #	0.001625 #	0.001625 #
A101	35	0.00313 #	0.001565 #	0.001565 #	0.001565 #	0.00313 #	0.001565 #	0.001565 #	0.001565 #	0.001565 #	0.001565 #
A204	30	3.393 *	0.00171 #	0.25069	0.00171 #	0.00342 #	20.618 *	0.26205	0.00171 #	0.00171 #	0.00171 #
A204	35	1.302 *	0.00169 #	0.00169 #	0.00169 #	0.00338 #	1.969 *	0.00169 #	0.00169 #	0.00169 #	0.00169 #
DHA1	30	8.479 *	0.00147 #	0.00147 #	0.00147 #	0.00294 #	0.00147 #	0.00147 #	0.00147 #	0.00147 #	0.00147 #
DHA1	35	5.867 *	0.001645 #	0.01388	0.01941	0.00329 #	0.131 *	0.001645 #	0.001645 #	0.001645 #	0.001645 #
DHA2	30	2.361 *	0.0953	0.0617	0.0380	0.0033 #	1.733 *	0.00165 #	0.00165 #	0.00165 #	0.00165 #
DHA2	35	1.3 *	0.07367	0.0536	0.02033	0.00333 #	4.47 *	0.00166 #	0.00166 #	0.00166 #	0.00166 #
DHA2	40	0.03280 #	0.0164 #	0.0164 #	0.0164 #	0.03280 #	1.44 *	0.0164 #	0.0164 #	0.0164 #	0.0164 #
DHA3	30	1.4685 *	0.001715 #	0.001715 #	0.001715 #	0.0343 #	0.031 *	0.001715 #	0.001715 #	0.001715 #	0.001715 #
DHA3	35	0.00313 #	0.02031	0.03394	0.06306	0.00313 #	0.421 *	0.001565 #	0.001565 #	0.001565 #	0.001565 #
DHA4	30	0.404 *	0.001645 #	0.03678	0.001645 #	0.00329 #	0.162 *	0.001645 #	0.001645 #	0.001645 #	0.001645 #
NW1	30	1.463 *	0.001565 #	0.001565 #	0.001565 #	0.00313 #	0.001565 #	0.001565 #	0.001565 #	0.001565 #	0.001565 #
NW1	35	0.00298 #	0.00149 #	0.00149 #	0.00149 #	0.00298 #	0.00149 #	0.00149 #	0.00149 #	0.00149 #	0.00149 #
SA3	35	12.221	0.00156 #	0.00156 #	0.00155 #	0.00313 #	0.04572 *	0.00156 #	0.00156 #	0.00156 #	0.00156 #

ORIGINAL
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TABLE 2-6
SATURATED ZONE SOILS ANALYTICAL DATA
GREENWOOD CHEMICAL SITE
PAGE TWO

<------------------------- all results expressed as mg/kg ------------------------->

SAMPLE NUMBER	SAMPLE DEPTH	THF (4)	DEHP (6)	DBP (7)	ARSENIC	CYANIDE	2,4,6-TCP (8)	4-CA (9)	NAP (10)	NAA (5)
BN8	30	ND	0.205 #	0.2 *@	13.5	0.57	0.675 #	2.025 #	10.58	ND
BN8	35	ND	0.19 #	0.77 *	2.49	0.125 #	0.635 #	1.9 #	5.93	ND
BN8	40	ND	0.2 #	0.43 *	1.6	0.125 #	0.665 #	2 #	2.01	ND
BN3	30	ND	0.19 #	0.22 *	2.8	0.125 #	0.64 #	1.925 #	0.13	ND
BN3	35	ND	0.195 #	0.38 *	2.6	0.125 #	0.66 #	1.975 #	0.4	ND
BN1	30	ND	0.205 #	0.2 *@	1.7	0.125 #	0.675 #	2.025 #	0.12	ND
BN1	35	ND	0.89	0.09 *	2.06	0.125 #	0.685 #	2.055 #	1.38	ND
L302	15	ND	0.69	0.2 *@	6.2	0.125 #	0.625 #	1.875 #	0.19 #	ND
L102	25	ND	0.2025 #	0.27 *	4.65	0.125 #	0.67 #	2.0125 #	0.2025 #	ND
L102	30	ND	0.215 #	0.02 *	6.64	0.125 #	0.665 #	2 #	0.2 #	ND
BN4	30	ND	0.26	0.21 *	1.8	0.125 #	0.66 #	1.975 #	1.7	ND
BN4	35	ND	6.15	0.65 *	1.9	0.125 #	0.595 #	1.785 #	0.38	ND
DD2	20	ND	0.54	1.23 *	2.6	0.125 #	0.705 #	2.115 #	0.12	ND
DD2	25	0.66	0.61	0.17 *	1.9	0.125 #	0.65 #	1.95 #	0.08	ND
DD2	30	ND	0.15	0.32 *	1.5	0.125 #	0.65 #	1.95 #	0.195 #	ND
L101	25	ND	0.195 #	0.48 *	1.8	1.08	0.66 #	1.975 #	3.79	ND
L203	25	0.83	0.28	0.75 *	3.1	0.125 #	0.675 #	2.025 #	0.205 #	ND
A101	25	ND	0.2 *@	2.2995 *	2.9	0.8425 #	0.6665 #	2 #	0.1675	ND
A101	30	ND	0.2 *@	0.978 *	2.3	0.125 #	0.6495 #	1.948 #	0.261	ND
A101	35	ND	0.2 *@	1.708 *	2.7	0.125 #	0.625 #	1.875 #	0.1875 #	ND
A204	30	ND	0.2 *@	0.224 *	12.3	0.125 #	0.685 #	2.055 #	0.247	ND
A204	35	ND	0.2 *@	0.267 *	5.4	0.125 #	0.6755 #	2.027 #	0.251	ND
DHA1	30	0.519	0.577 *	0.059 #	0.98	0.125 #	0.196 #	0.588 #	0.059 #	ND
DHA1	35	0.305	0.189 *	0.066 #	2.2	0.125 #	0.2196 #	0.658 #	0.066 #	ND
DHA2	30	ND	0.0665 *@	0.0665 #	2.5	1.57	0.222 #	0.6665 #	0.014	ND
DHA2	35	ND	0.0666 #	0.0665 #	2.2	1.17	0.222 #	0.6665 #	0.0665 #	ND
DHA2	40	ND	0.066 *@	0.066 *@	2	1.67	0.2195 #	0.658 #	0.066 #	ND
DHA3	30	7.7606	8.41 *	4.324 *	1.3	0.125 #	0.6495 #	1.948 #	0.195 #	ND
DHA3	35	3.438	0.0625 *@	0.0625 *@	1.6	0.125 #	0.2085 #	0.625 #	0.0625 #	ND
DHA4	30	ND	0.532 *	0.066 *@	2.4	0.125 #	0.2196 #	0.659 #	0.066 #	ND
NW1	30	ND	1.76625 *	0.0626 #	2	1.4425 #	0.2085 #	0.625 #	0.0625 #	
NW1	35	ND	0.0695 #	0.0695 #	16.2	8.15	0.1985 #	0.595 #	0.0695 #	ND
SA3	35	ND	0.0625 *@	0.0625 #	4.1	0.29	0.2025 #	0.183	0.165	ND

TABLE 2-6
SATURATED ZONE SOILS ANALYTICAL DATA
GREENWOOD CHEMICAL SITE
PAGE THREE

<-- all results expressed as mg/kg -->

SAMPLE NUMBER	SAMPLE DEPTH	ACETONE	BENZENE	CHLORO-BENZENE	CHLOROFORM	METHYLENE CHLORIDE	TOLUENE	XYLENE	1.2-DCA (1)	PCE (2)	TCE (3)
No. of data		33	33	33	33	33	33	33	33	33	33
Algebraic Mean value		8.2	0.0137	0.0324	0.0069	0.0067	1.14	0.1669	0.0390	0.0028	0.0028
Alg Standard deviation		16.86	0.0268	0.0908	0.0128	0.0078	3.59	0.6877	0.1668	0.0030	0.0030
Maximum value		74.781	0.1260	0.4770	0.0631	0.0343	20.62	3.9570	0.9440	0.0164	0.0164
Minimum value		0.00298	0.00147	0.00147	0.00147	0.00294	0.00147	0.00147	0.00147	0.00147	0.00147
Mean of log data		1.2230	0.0038	0.0050	0.0031	0.0047	0.0302	0.0058	0.0029	0.0022	0.0022
Stand dev of log data		17.86	3.90	5.28	2.69	2.03	22.69	8.93	4.29	1.84	1.84
Geometric Mean value		7.4328	0.0057	0.0091	0.0040	0.0063	0.2511	0.0181	0.0046	0.0023	0.0023
Geom. Standard deviation		44.53	0.00637	0.01362	0.00315	0.00261	2.06660	0.05366	0.00569	0.00099	0.00099

ORIGINAL
(Red)

TABLE 2-6
SATURATED ZONE SOILS ANALYTICAL DATA
GREENWOOD CHEMICAL SITE
PAGE FOUR

SAMPLE NUMBER	SAMPLE DEPTH	THF (4)	DEHP (6)	DBP (7)	ARSENIC	all results expressed as mg/kg CYANIDE	2,4,6–TCP (8)	4–CA (9)	NAP (10)	NAA (5)
No. of data		33	33	33	33	33	33	33	33	32
Algebraic Mean value		0.4122	0.5523	0.5225	3.7006	0.648	0.5231	1.556	0.897	0.0
Alg Standard deviation		1.4354	1.4264	0.8418	3.5487	1.5848	0.206	0.643	2.09	0.00
Maximum value		7.7605	8.41	4.324	16.2	9.16	0.705	2.115	10.66	0
Minimum value		0	0.0595	0.02	0.98	0.126	0.198	0.183	0.014	0
Mean of log data		1.0338	0.2391	0.2267	2.8197	0.2359	0.4668	1.3491	0.2262	0.0000
Stand dev of log data		1.59	2.76	3.52	1.93	3.12	1.68	1.85	4.26	0.00
Geometric Mean value		1.0838	0.2969	0.3198	3.0960	0.3123	0.4952	1.4641	0.3569	0.0000
Geom. Standard deviation		0.34144	0.22430	0.31817	1.40371	0.27090	0.17544	0.61731	0.43570	0.00000

FOOTNOTES FOR ANALYSIS RESULTS TABLE:

(1) 1,2–DCA = 1,2–DICHLOROETHANE
(2) PCE = TETRACHLOROETHENE
(3) TCE = TRICHLOROETHENE
(4) THF = TETRAHYDROFURAN
(5) NAA = NAPHTHALENE ACETIC ACID
(6) DEHP = DI (ETHYL HEXYL) PHTHALATE
(7) DBP = DI–N–BUTYLPHTHALATE
(8) 2,4,6–TCP = 2,4,6–TRICHLOROPHENOL
(9) 4–CA = 4–CHLOROANILINE
(10) NAP = NAPHTHALENE
\# Analysis result was non–detect; indicates value shown is 1/2 of the detection limit.
@ Indicates result was corrected by subtracting out average blank concentration. Resulting value was less than zero. Therefore, the value used is 1/2 the detection limit.
* Indicates result was corrected by subtracting out average blank concentration.

2.3.1 Army Corps of Engineers Data Handling

- Raw data obtained by Halliburton NUS on or before August 27, 1991 were used.
  - The arithmetic mean of duplicates was used where duplicate or split samples were taken.
  - For each stage, blanks were averaged. When averaging blanks, the arithmetic mean was used, using one-half the detection limit for non-detects for chemicals for which both positive results and non-detects were found. This average concentration was subtracted from every positive sample of the same stage. The result of this subtraction was then substituted for the positive result. If the result was a negative number, then the result was treated as a non-detect. As of August 27, 1991, cyanide blanks were not provided for Stages 1 and 2. The Stage 1 BNA blank also applied to Stage 2. Because of time constraints, blank adjustment of data was applied only to the saturated zone data.
  - For non-detects, one-half the detection limit was used. CRDLs were not used because they apply to CLP data; these data were not produced under the CLP. This was applied to saturated zone data so that average chemical concentrations in the saturated zone could be calculated. Because of time constraints, this adjustment was only applied to the saturated zone data.
- Arsenic, arsenic concentrations were compared to reported background concentrations. The source of the background concentrations was Ebasco Services, Inc. for USEPA, August 1990, p. 6-6. The maximum of the arsenic background concentration range (<2 to 10.9 mg/kg) was used. Any result greater than 10.9 mg/kg was considered to be above background.
- Calculations for blanks:

Stage 1	
Methylene chloride	not positively detected in samples; therefore no effect.
Acetone (ppm)	(0.02548 + 0.0005 + 0.0005)/3 = 0.00883 ppm
Di-n-butyl phthalate (ppm)	(0.51)/1 = 0.51 ppm

Stage 2	
Methylene chloride	not positively detected in samples; therefore no effect
Acetone (ppm)	(0.0005 + 0.0005 + 0.00655 + 0.01056 + 0.01393 + 0.0005 + 0.02702 + 0.0005)/8 = 0.0075
Toluene (ppm)	(0.00025 + 0.00025 + 0.00313 + 0.00298 + 0.00463 + 0.00299 + 0.00568 + 0.00025)/8 = 0.0025 ppm
Xylene (ppm)	(0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00235 + 0.00569)/8 = 0.0012
Di-n-butyl phthalate (ppm)	(0.51)/1 = 0.51 ppm

Stage 3	
Methylene chloride (ppm)	(0.00184 + 0.0072 + 0.00266 + 0.0005 + 0.00442 + 0.02549 + 0.0075 + 0.0005 + 0.0005 + 0.00499 + 0.00498 + 0.0005 + 0.00935 + 0.01509 + 0.0005 + 0.0005 + 0.0005 + 0.00597 + 0.00386 + 0.00522 + 0.00526 + 0.0438 + 0.00445 + 0.0057 + 0.02164 + 0.00714 + 0.01902 + 0.01516 + 0.00324 + 0.0005 + 0.00372)/31 = 0.0062 ppm
Acetone (ppm)	(0.01354 + 0.0091 + 0.02643 + 0.0005 + 0.00372 + 0.03519 + 0.00544 + 0.0005 + 0.00642 + 0.0005 + 0.0005 + 0.0005 + 0.01708 + 0.01258 + 0.0005 + 0.02169 + 0.0005 + 0.00648 + 0.0216 + 0.01347 + 0.0005 + 0.0005 + 0.00547 + 0.0005 + 0.01067 + 0.00614 + 0.02091 + 0.0005 + 0.0005 + 0.0005 + 0.01277)/31 = 0.0082 ppm
Toluene (ppm)	(0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00508 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00106 + 0.00108 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025 + 0.00025)/31 = 0.00046 ppm
Di-n-butyl phthalate (ppm)	(0.56 + 0.664 + 0.866 + 2.076 + 1.434 + 0.377 + 0.632 + 0.344 + 0.437 + 0.686 + 0.659 + 2.7 + 0.05 + 0.05 + 0.05 + 0.05 + 0.027 + 0.018 + 0.05 + 0.05 + 0.05 + 0.05)/22 = 0.54 ppm
Bis(2-ethylhexyl)phthalate (ppm)	(0.15 + 0.366 + 0.413 + 0.196 + 0.226 + 0.272 + 0.15 + 0.15 + 0.15 + 0.15 + 0.15 + 18.524 + 0.15 + 0.05 + 0.05 + 0.05 + 0.05 + 0.05 + 0.191 + 0.05 + 0.05 + 0.05 + 0.05)/22 = 0.979 ppm

surface to a depth greater than 15 feet beneath the main source area of the site and is nonexistent in some isolated locations in the western portion of the site.

The saprolite consists generally of a silty clay that is the by-product of in-situ chemical weathering of the bedrock. The surface of the saprolite can be found at the ground surface in the western portion of the site, where fill is non-existent, to depths greater than 15 feet beneath the ground surface in the north central portion of the site. The saprolite has an overall thickness of greater than 70 feet in the northern portion of the site and thins generally to the south. In isolated southern and western areas of the site, the saprolite is nonexistent and the bedrock comes in direct contact with the unconsolidated layer. A gradational contact exists between the saprolite and the underlying bedrock.

The bedrock consists of a gneiss of the Pedlar formation. Moderate to high degrees of fracturing exist within the upper portion of the bedrock. The depth to the bedrock surface is highly variable ranging from less than 10 feet beneath the ground surface in the western portion of the site, to a depth of greater than 100 feet in the northern portion of the site.

At the request of the EPA, the unconsolidated layer was further subdivided into individual subunits for two areas at the site; the drum disposal area and the main source area. The purpose of the subdivision was to develop more specific input parameters for the modeling activity. The subunits identified are fill, reworked unconsolidated material, and the undisturbed unconsolidated material. The identification of these subunits within a vertical and horizontal profile is highly interpretative due to the limited amount of data that exists within these areas in addition to the relatively similar visual appearance that exists between each subunit. A discussion of the characteristics of each subunit beneath the two areas is included in the following paragraphs.

The fill beneath the main source area consists primarily of a silty sand with some clay and a trace of gravel and construction debris. The fill is nonexistent in sporadic locations and is more infrequent in the northern portion of the main storage area than in the southern portion. The fill extends from the ground surface to an average depth of 1 foot beneath the ground surface.

Reworked unconsolidated material underlies the fill beneath the main storage area and consists of disturbed unconsolidated material mixed with a trace of root material and construction debris. The average thickness of the reworked unconsolidated material is 5 feet.

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The undisturbed unconsolidated material beneath the main source area underlies the reworked unconsolidated material and consists of a heterogeneous mixture of silty clay with some gravel and some sand. The average thickness of this unit is 7 feet.

Only fill comprises the unconsolidated layer beneath the drum disposal area. The fill consists of a silty clay with variable amounts of gravel and a trace of root material and construction debris. The fill extends from the ground surface to an average depth of 7 feet beneath the ground surface.

For the purposes of providing detailed input parameters for the modeling effort at the drum disposal area and the main source area, values of porosity, moisture content, percent composition of materials, Unified Soil Classification System (USCS) designation, and thicknesses were calculated. These values were calculated for the identified units within the unconsolidated layer as well as for the saprolite layer. The results of the calculations are included on Table 2-7 and the calculations are shown in Appendix E.

2.4.2 Hydrogeology

Groundwater exists within the unconsolidated layer, the saprolite and the bedrock. The depth to groundwater varies from less than 5 feet to more than 25 feet below the ground surface. According to the Remedial Investigation (RI) Report, groundwater within these units is hydraulically connected and acts as a single, unconfined to semi-confined aquifer system. The groundwater flow system is reported in the RI report to flow in a south east direction.

As a requirement for the modeling effort, the thickness of the unsaturated zone was determined. This determination was made by developing a potentiometric surface contour map using the maximum elevation observed at any one time for a specific well over a period from May 14, 1987 to October 10, 1989 (see Drawing 3). The maximum elevation of the potentiometric surface was subtracted from the topographic surface elevation to determine the overall average thickness of the unsaturated zone. The potentiometric surface data used was obtained from Table 3-4 of the RI report.

Hydraulic conductivity values were also used as model input data. The data was taken from Table 3-1 of the RI report and is presented here as Table 2-8. Average hydraulic conductivity values were calculated for the unconsolidated layer and saprolite and used in the model.

TABLE 2-7

AVERAGE CHARACTERISTICS OF THE UNCONSOLIDATED AND SAPROLITE LAYERS
GREENWOOD CHEMICAL SITE

Disposal	Thickness(4) (ft)	Porosity	Moisture(3) Content (%)	Classification(2)	Composition (%) (1)				
					Silt	Clay	Sand	Gravel	Construction Debris
Drum Disposal Area									
Fill	7	0.3	25.9	CL	25	30	15	20	10
Saprolite	10	0.3	33.1	CL	30	35	25	10	—
Main Source Area									
Fill	1	0.4	NA	SM	30	30	35	5	—
Reworked Unconsolidated Material	5	0.3	30.5	CL	25	35	30	10	—
Undisturbed Unconsolidated Material	7	0.3	28.6	CL	30	40	25	5	—
Saprolite	13	0.3	33.5	CL	25	30	25	20	—

(1) Composition based on arithmetic average of sieve analyses results (when available) or calculations (see Appendix E for calculations).

(2) Classification based on average composition of layer.

(3) Moisture content based on average of moisture content recorded on the boring logs.

(4) Values derived from Freeze and Cherry, 1979, p. 37.

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TABLE 2-8

HYDRAULIC CONDUCTIVITY SUMMARY
GREENWOOD CHEMICAL SITE

Monitoring Well	Unit	Hydraulic Conductivity cm/sec(1)
MW-1	OB	4.1×10^{-4}
MW-2S	OB	4.8×10^{-4}
MW-2D	OB	2.6×10^{-4}
MW-2D**	OB	7.6×10^{-5}
MW-3	OB	1.4×10^{-4}
MW-4	OB	7.6×10^{-5}
MW-5	OB	7.6×10^{-5}
MW-7S	OB	9.4×10^{-5}
MW-7D	OB	8.5×10^{-5}
MW-10	OB	3.8×10^{-5}
MW-10D	OB	1.9×10^{-5}
MW-11	OB	4.3×10^{-3}
MW-12S	ROCK	2.6×10^{-3}
MW-14S	ROCK	4.1×10^{-4}
MW-14D	ROCK	9.3×10^{-5}
MW-16S	ROCK	3.7×10^{-3}
MW-16D	ROCK	4.3×10^{-4}
MW-17S	OB	4.3×10^{-6}
MW-19*	OB/ROCK	1.9×10^{-5}
MW-20S**	OB	3.8×10^{-5}
Average Overburden		4.08×10^{-4}

OB	*Overburden Well (includes both unconsolidated material and the saprolite).*
ROCK	Bedrock Well.
(1)	Data from Table 3-1 in "Final Remedial Investigation Report," Greenwood Chemical Site, August 1990. Ebasco Services, Inc.
*	Well is screened just below or across the weathered bedrock and overburden contact.
**	Pumping test.
Note:	All results are based on rising head or falling head tests unless otherwise noted.

2.4.3 Modeling Considerations

An infiltration rate was determined using a water budget and infiltration rate program, the Hydraulic Evaluation of Landfill Performance (HELP) Model. The specific soils information required to run the HELP model included thickness, porosity, moisture content, soil classification, and composition. The values used for these parameters in the HELP model are summarized in Table 2-7.

Meteorological data required for the calculation were obtained from Table 3-8 of the RI report. Calculations and the results of the HELP model run are included in Appendix F. The resulting infiltration rates used in the Halliburton NUS modeling were 0.973 feet per year (Main Source Area) and 0.903 feet per year (Drum Storage Area).

The potentiometric surface map (Drawing 3 in the back of this report) was used to discern which samples were collected from the saturated zone and which were collected from the unsaturated zone. Sample locations and the corresponding depth to maximum water table elevation are summarized in Table 2-9.

The average overburden hydraulic conductivity value was determined to be 4×10^{-4} cm/sec. This value was used in Halliburton NUS model to calculate groundwater flow velocity in the aquifer.

2.5 AREAL EXTENT OF CONTAMINATION AND REPRESENTATIVE CONCENTRATIONS

The last information developed for the model input was the areal extent of contamination and the representative concentration. The analytical soil data from the USACE pre-design field investigation was used for this purpose to generate mean values for each chemical at each sampling site. REM III (RI Report, Ebasco Services, Inc., August 1990) soil analysis results were used as required to supplement the mapping procedure where insufficient USACE data was available (in the Drum Disposal Area and total semivolatiles as representative of naphthalene acetic acid). Separate mean value sets were generated for the saturated and unsaturated soil zones. In the Drum Disposal Area, groundwater analysis results from samples collected at the monitoring wells MW01 and MW04 during the REM III RI were used to calculate the saturated zone soil concentrations because soil samples were not collected from the saturated zone. The groundwater concentrations were multiplied by the distribution coefficient (K_D, see Table 2-5) to generate the saturated zone soil concentrations used in the modeling effort. The mean values determined for the saturated and unsaturated soil zones are summarized in Tables 2- 10 and 2-11, respectively. The mean values were plotted on sample location maps, and the median concentration was determined after examining the isoconcentration contours for each chemical in each zone. These maps are included in Volume II of

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TABLE 2-9

MAXIMUM GROUNDWATER TABLE ELEVATIONS FOR ARMY CORPS SAMPLING LOCATIONS GREENWOOD CHEMICAL SITE

Sample Identification	Maximum Groundwater Surface Elevation	Surface Elevation	Elevation Difference	DTS
L101	902	925.6A	23.6	25*
L102	902	925.4 A	23.4	30*
L103	905	926.2 A	21.2	5
L201	903	921.2 A	18.2	NS
L202	898	920.2 A	22.2	20
L203	898	920.2 A	22.2	25
L204	899	920.3 A	21.3	10
SA01	912	943.8 A	31.8	10
SA02	915	945.3 A	30.3	NS
L301	893	909.5	16.5	5
L302	893	905	12	15*
L303	892	907	15	5
L305	898	918	20	5
DD01	904	924	20	10
DD02	901	918	17	30*
DD03	886	911	25	5
DD04	884	907	23	20
DD05	887	903	16	5
BN01	911	938	27	35*
BN02	901	927	26	25*
BN03	912	942	30	35*
BN04	910	940.1 A	30.1	35*
BN05	912	940	28	NS
BN06	913	942	29	15
BN07	910	935	25	15
BN08	913	942	29	40*
L105	906	930	24	2
L106	906	929	23	2
L107	900	920	20	0.5

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TABLE 2-9
MAXIMUM GROUNDWATER TABLE ELEVATIONS FOR ARMY CORPS SAMPLING LOCATIONS
GREENWOOD CHEMICAL SITE
PAGE TWO

Sample Identification	Maximum Groundwater Surface Elevation	Surface Elevation	Elevation Difference	DTS
L108	901	920	19	2
L109	898	920	22	2
L306	899	918	19	0.5
L307	898	917	19	1.5
L308	898	917	19	2
L309	897	914	17	2
L310	896	914	18	0.8
L311	896	913	17	0.8
L312	894	912	18	2
L313	894	911	17	2
L314	892	909	17	1
BNE6	902	927	25	3
BNE7	895	920	25	3
BNE8	890	915	25	3
A401	918	947	29	13
A402	818	947	129	17
A403	919	947	28	10
A404	915	946	31	10
A405	910	947	37	10
A406	918	945	27	5
A407	924	951	27	12
BNE1	907	932.7	25.7	13
ST01	931	957	26	25
ST02	933	958	25	1
ST03	932	957	25	1
NED1	941	962	21	1
NED2	936	958	22	1
NED3	935	955	20	1

TABLE 2-9
MAXIMUM GROUNDWATER TABLE ELEVATIONS FOR ARMY CORPS SAMPLING LOCATIONS
GREENWOOD CHEMICAL SITE
PAGE THREE

Sample Identification	Maximum Groundwater Surface Elevation	Surface Elevation	Elevation Difference	DTS
BNE2	906	932.7	26.7	10
BNE3	905	932.7	27.7	10
BNE4	906	932.7	26.7	10
BNE5	904	932.7	28.7	10
DHA1	913	943	30	35*
DHA2	912	942	30	40*
DHA3	912	941	29	35*
DHA4	908	935	27	30*
A101	907	929	22	35*
A209	908	937	29	10
A208	915	943	28	10
A201	917	942	25	10
A202	914	942	28	15
NW01	942.3	972	29.7	35*
SA03	914	945	31	35*
A204	922	949	27	35*
A205	919	947	28	15
A601	908	938	30	28
L315	892	904	12	2

A	Surface elevation at sample location from Table A.1 in "60% Design Analysis, Greenwood Chemicals," USACE, May 1991.
DTS	Depth to deepest sample collected.
*	Indicates at least one sample collected from saturated zone.
NS	Not sampled during USACE predesign sampling programs.

TABLE 2-10

AVERAGE SATURATED ZONE SOIL CONCENTRATIONS USED FOR AREAL EXTENT DETERMINATION GREENWOOD CHEMICAL SITE

Sample Number	Acetone (mg/kg)	Napthalene (mg/kg)	Di-n-butyl (mg/kg)	Benzene (mg/kg)	Chlorobenzene (mg/kg)	Chloroform (mg/kg)	Toluene (mg/kg)	4-Chloroan (mg/kg)	2,4,6 TCP (mg/kg)	1,2-DCA (mg/kg)	PCE (mg/kg)	TCE (mg/kg)	Methylene Chloride (mg/kg)	Naphthalene Acetic Acid (mg/kg)(2)	Xylenes (mg/kg)	Tetra-hydrofuran (mg/kg)	BEHP (mg/kg)	Arsenic (mg/kg)	Cyanide (mg/kg)
1 A101	ND	0.212	1.661	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.200	2.633	ND
2 A204	2.348	0.25	0.256	ND	0.126	ND	11.303	ND	ND	ND	ND	ND	ND	ND	0.142	ND	0.200	8.850	ND
3 BN01	2.936	0.74	0.145	0.027	ND	ND	1.194	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.455	1.880	ND
4 BN03	17.261	0.265	0.3	ND	0.239	ND	0.188	ND	ND	0.010	ND	ND	ND	ND	0.376	ND	ND	2.700	ND
5 BN04	5.730	1.04	0.53	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.205	1.850	ND
6 BN08	26.055	6.16	0.467	0.048	0.022	ND	1.224	ND	ND	0.401	ND	ND	ND	ND	1.703	ND	ND	5.863	0.273
7 DD02	2.355	0.132	0.573	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.010	0.22	0.433	2.000	ND
8 DHA1	6.173	ND	ND	ND	0.008	0.010	0.066	ND	ND	ND	ND	ND	ND	ND	ND	0.4565	0.383	1.590	ND
9 DHA2	1.231	0.048	0.066	0.062	0.051	0.025	2.548	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.066	2.233	1.470
10 DHA3	0.736	ND	2.193	0.011	0.018	0.032	0.226	ND	ND	ND	ND	ND	ND	ND	ND	5.599	4.236	1.450	ND
11 DHA4	0.404	ND	0.066	ND	0.037	ND	0.162	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.532	2.400	ND
12 L101	74.781	3.79	0.48	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.800	1.680
13 L102	6.688	ND	0.145	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.745	ND
14 L203	0.863	ND	0.75	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.83	0.280	3.100	ND
15 L302	7.106	ND	0.2	ND	ND	ND	0.008	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.690	6.200	ND
16 NW01	0.733	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.913	9.100	5.296
17 SA-3	12.221	0.165	ND	ND	ND	ND	0.046	0.183	ND	ND	ND	ND	ND	ND	ND	ND	0.063	4.100	0.290
18 A-11(1)		ND					10.35												
19 B-9(1)		ND					ND												
20 A-6(1)		ND					0.002												
Maximum	74.781	6.160	2.193	0.062	0.239	0.032	11.303	0.183	0.000	0.401	0.000	0.000	0.000	0.000	1.703	5.599	4.236	9.100	5.296

(1) Data from REM III Remediation Investigation; other data from Army Corps Predesign Field Investigation.
(2) Total semivolatile TICs from REM III RI Report used for isoconcentration map for naphthalene acetic acid (see data, Appendix D).

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TABLE 2-11

AVERAGE UNSATURATED ZONE SO .CENTRATIONS USED FOR AREAL EXTENT DETERMINATION
GREENWOOD CHEMICAL SITE

Sample Number		Acetone (mg/kg)	Napthalene (mg/kg)	Di-n-butyl phthalate (mg/kg)	Benzene (mg/kg)	Chloro-benzene (mg/kg)	Chloroform (mg/kg)	Toluene (mg/kg)	4-Chloro-aniline (mg/kg)	2,4,6-TCP (mg/kg)	1,2-DCA (mg/kg)	PCE (mg/kg)	TCE (mg/kg)	Methylene Chloride (mg/kg)	Naphthalene Acetic Acid (mg/kg)(4)	Xylenes (mg/kg)	Tetra-hydrofuran (mg/kg)	BEHP (mg/kg)	Arsenic (mg/kg)	Cyanide (mg/kg)
1	A101	2.818	3.026	3.227	0.001	0.002	ND	0.046	0.313	ND	ND	ND	ND	ND	ND	ND	0.876	1.153	3.800	2.748
2	A201	0.472	ND	0.468	ND	ND	ND	0.288	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.624	6.033	1.343
3	A202	1.179	0.581	0.799	0.001	0.003	ND	1.018	ND	ND	ND	0.167	ND	ND	ND	ND	0.149	ND	13.240	1.822
4	A204	1.132	1.541	0.112	ND	0.064	ND	22.160	ND	ND	ND	ND	ND	ND	ND	0.313	ND	4.935	4.100	0.370
5	A205	ND	1.396	0.408	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.090	14.075	0.140
6	A207	ND	ND	2.362	ND	ND	ND	0.049	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	499.200	4.103
7	A208	2.287	338.397	2.431	ND	0.050	ND	0.373	ND	ND	ND	ND	ND	ND	ND	11.470	ND	0.999	12.225	0.638
8	A209	53.204	247.238	3.169	ND	0.993	ND	5.294	ND	0.189	ND	ND	ND	ND	ND	2.708	ND	2.841	18.250	5.683
9	A400	NA	ND	ND	NA	NA	NA	NA	ND	ND	NA	NA	NA	NA	ND	NA	ND	ND	12.400	16.000
10	A401	6.917	5.981	0.691	ND	0.051	0.007	4.465	1.577	ND	ND	ND	ND	ND	ND	ND	ND	0.408	2.525	0.065
11	A402	92.899	1.474	1.808	ND	0.010	ND	0.036	0.025	ND	0.009	ND	ND	ND	ND	0.654	0.037	3.214	17.380	3.896
12	A403	2.421	1.354	0.890	ND	0.345	ND	11.682	0.066	ND	ND	ND	ND	ND	ND	ND	ND	4.029	11.267	0.502
13	A404	0.125	ND	0.253	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	10.225	1.693
14	A405	ND	ND	1.190	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.396	10.367	0.280
15	A406	ND	ND	1.079	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.923	2.500	0.355
16	A407	0.927	ND	1.062	ND	0.025	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.446	5.133	0.748
17	A601	2.378	0.150	1.328	ND	0.013	ND	0.213	0.297	ND	ND	ND	ND	ND	ND	ND	ND	ND	519.733	50.368
18	BN01	11.442	0.703	0.449	ND	0.004	ND	1.622	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	54.371	1.826
19	BN02	1.357	ND	1.350	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.043	6.417	0.797
20	BN03	21.198	0.720	0.657	0.004	0.084	ND	1.534	ND	ND	ND	0.143	ND	ND	ND	0.056	ND	0.059	45.443	6.027
21	BN04	62.987	6.383	0.931	ND	1.179	ND	13.788	ND	ND	ND	0.160	ND	ND	4.000	1.540	0.278	1.569	10.129	1.909
22	BN06	18.816	ND	0.733	ND	ND	ND	0.033	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.288	0.740	5.487
23	BN07	9.971	0.022	0.810	0.179	0.133	ND	7.994	ND	ND	ND	0.010	ND	ND	ND	0.260	2.371	0.084	6.046	0.720
24	BN08	14.800	7.940	0.706	ND	0.261	ND	23.153	ND	ND	0.009	0.611	ND	ND	ND	0.676	ND	ND	32.714	11.846
25	BNE1	0.101	ND	0.729	ND	0.003	ND	0.020	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.124	90.020	228.326
26	BNE2	0.340	0.034	1.713	ND	ND	ND	0.077	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.536	112.575	62.603
27	BNE3	12.903	0.165	ND	ND	0.008	ND	0.622	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.437	42.200	32.400
28	BNE4	10.087	ND	ND	ND	ND	ND	0.005	0.029	ND	ND	ND	ND	ND	ND	ND	0.157	3.486	21.500	36.320
29	BNE5	1.131	0.024	ND	ND	0.012	ND	0.012	0.233	ND	ND	ND	ND	ND	ND	ND	ND	28.353	35.400	29.975
30	BNE6	ND	ND	0.740	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.590	18.500	5.725
31	BNE7	ND	ND	0.450	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.950	23.850	5.355
32	BNE8	ND	ND	0.730	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.093	20.567	9.647
33	DD01	10.649	ND	0.408	ND	ND	ND	ND	ND	ND	ND	0.005	ND	ND	ND	ND	ND	0.080	1.900	ND
34	DD02	18,482.3	0.858	0.863	ND	0.048	ND	66.062	0.033	ND	ND	0.037	ND	ND	ND	0.211	ND	0.510	3.575	0.875
35	DD03	1.600	1.530	0.460	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.800	0.860
36	DD04	1.124	5.622	0.277	0.031	ND	ND	1.437	ND	ND	ND	ND	ND	ND	ND	12.848	ND	0.122	5.067	0.143
37	DD05	0.763	0.795	0.335	ND	ND	ND	ND	0.115	ND	ND	ND	ND	ND	ND	ND	ND	0.350	2.900	ND
38	DHA1	16.222	0.826	0.003	ND	ND	ND	0.005	ND	ND	ND	ND	ND	ND	0.058	ND	1.077	2.623	316.714	0.839
39	DHA2	18.752	0.020	0.781	ND	0.002	ND	0.044	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.905	358.371	16.583
40	DHA3	6.026	0.006	0.015	ND	0.002	ND	0.001	ND	ND	ND	ND	ND	ND	ND	ND	1.078	0.041	33.586	0.617
41	DHA4	0.083	ND	0.081	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.931	31.171	0.827

TABLE 2-11
AVERAGE UNSATURATED ZONE SOIL CONCENTRATIONS USED FOR AREAL EXTENT DETERMINATION
GREENWOOD CHEMICAL SITE
PAGE TWO

Sample Number	Acetone (mg/kg)	Napthalene (mg/kg)	Di-n-butyl phthalate (mg/kg)	Benzene (mg/kg)	Chloro-benzene (mg/kg)	Chloroform (mg/kg)	Toluene (mg/kg)	4-Chloro-aniline (mg/kg)	2,4,6-TCP (mg/kg)	1,2-DCA (mg/kg)	PCE (mg/kg)	TCE (mg/kg)	Methylene Chloride (mg/kg)	Naphthalene Acetic Acid (mg/kg)(1)	Xylenes (mg/kg)	Tetra-hydrofuran (mg/kg)	BEHP (mg/kg)	Arsenic (mg/kg)	Cyanide (mg/kg)
42 L101	33 508	5.162	1.057	ND	0.618	ND	1.923	0.008	ND	ND	ND	ND	ND	ND	0.056	1.280	0.327	6.958	10.788
43 L102	5.923	0.150	0.416	ND	0.007	ND	0.030	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.674	33.100	9.124
44 L103	1.943	0.317	1.077	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND	ND	ND	ND	ND	45 733	12.723
45 L105	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	158.000	NA
46 L106	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	125.000	NA
47 L107	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	11.850	NA
48 L108	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	91.400	NA
49 L109	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	5 300	NA
50 L202	1.816	ND	1.478	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0 302	7.480	2.550
51 L203	3.102	0.023	0.743	ND	ND	ND	0.073	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.358	6.480	0.218
52 L204	3.134	0.210	1.490	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.150	64.267	4.017
53 L301	0.949	ND	0.335	ND	ND	ND	0.027	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	45.950	8.180
54 L302	11.018	ND	0.640	ND	0.007	ND	0.010	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.347	8.267	0 860
55 L303	2.211	ND	1.005	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0 065	34.100	2.110
56 L305	9.245	7.927	1.410	ND	ND	ND	ND	0.207	ND	ND	ND	ND	ND	ND	ND	ND	ND	12.033	19.768
57 L306	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	26.100	NA
58 L307	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	79.300	NA
59 L308	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.900	NA
60 L309	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.900	NA
61 L310	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7 200	NA
62 L311	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	8 400	NA
63 L312	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6 600	NA
64 L313	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	42.400	NA
65 L314	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	9.350	NA
66 L315	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	49.600	NA
67 NED1	NA	5.877	ND	NA	NA	NA	NA	ND	NA	NA	NA	NA	NA	ND	NA	NA	ND	33.400	12.800
68 NED2	NA	556.944	ND	NA	NA	NA	NA	ND	NA	NA	NA	NA	NA	ND	NA	NA	ND	26 400	4 020
69 NED3	NA	ND	ND	NA	NA	NA	NA	ND	NA	NA	NA	NA	NA	ND	NA	NA	ND	2.550	ND
70 NW01	4.367	ND	0.406	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.755	0 125
71 SA01	19.036	0.253	1.100	ND	ND	ND	ND	0.440	ND	ND	ND	ND	ND	ND	ND	0.225	0.330	235.500	20 160
72 SA03	30.758	0.355	0.006	ND	0.003	ND	0.387	0.703	ND	ND	ND	ND	ND	ND	ND	0.360	0 078	536.980	92 440
73 ST01	0.205	ND	0.624	ND	ND	ND	ND	ND	ND	ND	0.081	ND	ND	ND	ND	ND	ND	2.733	ND
74 ST02	ND	ND	ND	ND	ND	ND	0.074	ND	ND	ND	20.143	0.024	0.597	ND	ND	ND	ND	11.400	3 560
75 ST03	ND	ND	0.467	ND	ND	ND	ND	ND	ND	ND	0.014	ND	ND	ND	ND	ND	ND	2 500	0.460
MAXIMUM	18,482.32	556.944	3.227	1.179	1.179	0.007	66.062	1.577	0.189	0.009	20.143	0.024	0.597	4.000	12.848	2.371	28.353	536 980	228.326

(1) Total semivolatile TICs from REM III RI Report used for isoconcentration map for naphthalene acetic acid (see data, Appendix D).
ND - Not Detected
NA - Not Analyzed

this report. The maximum soil concentration encountered at any sample depth for each chemical in each zone was also determined for use in the modeling screening procedure described in Section 3.0. These maximum soil concentrations observed are included in Table 2-12.

The areal extent of contamination was also determined from the isoconcentration plots. The zero contour was plotted at the outside edge of the concentration contour, beyond the location of positive detection of the chemicals. The width (in the direction perpendicular to groundwater flow) and length (in the direction parallel to groundwater flow) were determined from the maps using the zero contour as the outer boundary of the contamination. These length and width dimensions were then used as inputs to the model.

Based on the mapping exercise, up to three distinct zones of contamination were identified for each chemical, including:

- Area 1A, Main Source Area, which includes the areas south of the chemical manufacturing buildings and north of Lagoon 4;
- Area 1B, Northern Warehouse Area, which includes samples collected at the Northern Warehouse and the area east of the warehouse ("NW" and "NE" series samples). This area was separated from the Main Source Area determination because of the horizontal distance of separation and the lack of analysis results in the area between Area 1A and 1B. In many cases, only one data point was available for mapping in this area, so that this source area was not analyzed for all chemicals where the results indicated no positive detections.
- Area 2, Drum Disposal Area, the area west of Lagoon 4 between the access road and the western property boundary, where drum removal actions occurred previously.

The areal extent of contamination and the median soil concentrations for each area are summarized *in Table 2-13 (Saturated Zone Soils) and 2-14 (Unsaturated Zone Soils).*

TABLE 2-12

MAXIMUM SOIL CONCENTRATIONS (mg/kg) ENCOUNTERED IN REM III RI OR ACE PRE-DESIGN SAMPLING GREENWOOD CHEMICAL SITE

Chemical	Area 1A		Area 1B		Area 2	
	Unsaturated	Saturated	Unsaturated	Saturated	Unsaturated	Saturated
Arsenic	2,470.0	13.5	33.4	16.2	701	2.6
Cyanide	1,000.0	1.68	12.8	9.2	80.3(1)	20.4(2)
Acetone	201.3	74.8	17,03	1.4	73,910.2	2.8
Benzene	0.16	0.13	ND	ND	230(1)	0.029(2)
4-Chloroaniline	6.31	0.18	ND	ND	0.23	ND
Chlorobenzene	5.12	0.48	ND	ND	0.191	ND
Methylene Chloride	0.597	ND	ND	ND	305.5(1)	0.013(2)
PCE	20.14	ND	ND	ND	0.149	ND
TCE	0.0235	ND	ND	ND	32(1)	0.019(2)
Toluene	125.8	20.6	ND	ND	264.25	10.35(1)
Naphthalene	757.2	10.56	556.9	ND	32.18	0.12
Naphthaleneacetic acid	17.0	ND	ND	ND	3780(1)	2.64(2)
Tetrahydrafuran	9.0	7.76	ND	ND	ND	0.053(2)
Bis(2-ethylhexyl) phthalate	104.4	8.41	ND	1.76	2.04	0.61
Chloroform	0.041	0.063	ND	ND	16(1)	0.038(2)
1,2-DCA	0.0513	0.94	ND	ND	0.026(1)	ND
Di-n-butyl phthalate	9.418	2.29	1.484	ND	1.74	1.23
Xylene	34.02	3.96	ND	ND	64.24	0.027
2,4,6-Trichlorophenol	0.468	ND	ND	ND	ND	ND

Maximum = Highest concentration encountered at any sample location and depth.

(1) REM III RI Report Data

(2) Determined from groundwater concentrations reported in REM III RI Report.

TABLE 2-13

AVERAGE SATURATED ZONE SOIL CONTAMINATION GREENWOOD CHEMICAL SITE

Chemical	Area	Dimensions, Feet W x L	Median Soil Concentration (mg/kg)
Toluene	1A 2	200 x 230 100 x 100	1.0 0.86(1)
4-Chloroaniline	1A 2	50 x 50 0 x 0	0.1 3e^{-4}(1)
Tetrahydrofuran	1A 2	45 x 240 50 x 55	0.5 0.028(1)
Chloroform	1A 2	95 x 70 0 x 0	0.02 0.016(1)
Xylenes	1A 2	100 x 140 45 x 45	0.2 0.01
Benzene	1A 2	200 x 95 0 x 0	0.02 0.016(1)
Chlorobenzene	1A 2	190 x 170 0 x 0	0.05 0.024(1)
Trichloroethene (TCE)	2	0 x 0	0.007(1)
Methylene Chloride	2	0 x 0	0.004(1)
Tetrachloroethene (PCE)	2	0 x 0	0.002(1)
Naphthaleneacetic acid (NAA)	2	0 x 0	0.73(1)
Di-n-butyl phthalate	1A 2	305 x 410 90 x 100	0.1 6,750(1)
Naphthalene	1A 2	285 x 140 65 x 80	0.1 0.064(1)
Bis(2-ethylhexyl)phthalate	1A 1B 2	300 x 420 95 x 100 55 x 60	0.3 0.5 0.3
Arsenic	1A 1B 2	270 x 480 100 x 120 80 x 95	5.0 6.0 4.07(1)
Cyanide	1A 1B 2	200 x 90 60 x 70 0 x 0	0.3 2.0 5.1(1)

TABLE 2-13
AVERAGE SATURATED ZONE SOIL CONTAMINATION
GREENWOOD CHEMICAL SITE
PAGE TWO

Chemical	Area	Dimensions, Feet W x L	Median Soil Concentration mg/kg
1,2-DCA	1A 1B 2	50 x 50 0 x 0 0 x 0	0.2 ND ND
Acetone	1A 1B 2	 50 x 50 0 x 0	 0.3 0.013(1)

(1) Median saturated soil concentration calculated by multiplying the mean groundwater concentration (data from MW01 and MW04 found in the 1990 RI Report) by the distribution coefficient, Kd. Other data from USACE Pre-Design Sampling Work.

TABLE 2-14

AVERAGE UNSATURATED ZONE SOIL CONTAMINATION GREENWOOD CHEMICAL SITE

Chemical	Area(3)	Dimensions, Feet W x L	Median Soil Concentration (mg/kg)
PCE	1A	90 x 280	0.1
	2(1)	76 x 160	1.5
1,2-DCA	1A	165 x 25	0.002
	2(1)	< 10 x < 10	0.004
TCE	1A(1)	45 x 45	0.002
	2(1)	65 x 65	3
Arsenic	1A	460 x 430	15
	1B	245 x 145	2
	2(1)	150 x 270	3
Di-n-butyl phthalate	1A	410 x 420	1
	1B	70 x 70	0.3
	2(1)	80 x 160	0.58
Bis(2-ethylhexyl)phthalate	1A	370 x 420	2
	1B	0 x 0	ND
	2(1)	140 x 220	0.3
Cyanide	1A	380 x 320	8
	1B	220 x 60	0.2
	2(1)	140 x 250	0.2
Acetone	1A	325 x 310	5
	1B	50 x 50	2
	2(1)	160 x 260	2
Xylenes	1A	140 x 220	0.2
	1B	0 x 0	ND
	2(1)	75 x 135	0.3
Naphthalene	1A	290 x 190	5
	1B	90 x 80	10
	2(1)	110 x 260	5
Toluene	1A	270 x 185	0.5
	1B	0 x 0	ND
	2(1)	170 x 260	100
Benzene	1A	40 x 150	0.005
	1B	0 x 0	ND
	2(1)	90 x 235	0.95
Methylene Chloride	2(1)	75 x 135	1

ORIGINAL
(Red)

TABLE 2-14
AVERAGE UNSATURATED ZONE SOIL CONTAMINATION
GREENWOOD CHEMICAL SITE
PAGE TWO

Chemical	Area(3)	Dimensions, Ft W X L	Median Soil Concentration (mg/kg)
4-Chloroaniline	1A	60 x 260	0.1
		60 x 180	0.1
	1B	0 x 0	ND
	2(1)	85 x 160	2
Chlorobenzene	1A	130 x 200	0.01
	1B	0 x 0	ND
	2(1)	75 x 80	2.5
Naphthaleneacetic Acid	1A(4)	325 x 325	500(2)
	1B(4)	110 x 85	20(2)
	2(1)	130 x 250	100(2)
Tetrahydrofuran	1A	120 x 230	0.05
	1B	0 x 0	ND
	2	0 x 0	ND
Chloroform	1A	40 x 40	0.003
	1B	0 x 0	ND
	2(1)	75 x 80	1.5

(1) Median Soil Concentration and Dimensions of Drum Disposal Area estimated from Ebasco Services data (*RI Report, August, 1990*); other data from Army Corps of Engineers.

(2) Assumed to be the sum of semivolatile TICs.

(3) Definitions:
Area 1A = Main Source Area; Area 1B = Northern Warehouse Area
Area 2 = Drum Disposal Area

(4) REM III RI Report semivolatile TICs used to determine contaminant distribution. Areal distribution adjusted by subtracting average background concentration (25 mg/kg) from each data point.

ND = Not Detected.

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3

3.0 GROUNDWATER MODELING

After determination of the inputs required for modeling, a screening procedure was used to minimize the computer runs necessary. This screening procedure included the use of the theoretical distribution of a chemical between the soil and aqueous phases, using the distribution coefficient K_D to determine the theoretical maximum concentration that may be observed, as well as the Summer's leaching model as a conservative estimate of the cleanup goals for comparison with the maximum groundwater concentrations that may occur.

3.1 SCREENING PROCEDURE

The screening procedure used for the cleanup goals determination is shown schematically in Figure 3-1. The procedure includes the steps described in the following sections.

The screening procedure is separated into the procedure used for the Source (1A) and the Northern Warehouse (1B) Areas, and that used for the Drum Disposal Area (2). The first two steps of both sections are designed to evaluate the saturated zone soil concentrations, while the remaining steps are designed to evaluate the unsaturated zone soil concentrations.

3.1.1 Source and Northern Warehouse Areas

The screening procedure used for these areas consists of the following steps:

1. The first step in this procedure is to calculate the maximum theoretical groundwater concentration as a result of the saturated zone soil contamination. These maximum groundwater concentrations were determined by dividing the maximum saturated zone soil concentration by the distribution coefficient. The resulting values were compared to the water criteria (SDWA MCLs or toxicity based values). If the resulting aqueous concentration was less than the criteria, no further analysis of the saturated zone soils was required, because no exceedance would occur even at the maximum saturated soil concentration. The results of this calculation are summarized in Table 3-1, which includes the maximum soil concentrations observed in each area, and the result of the comparison between the theoretical maximum aqueous chemical concentration and the water criteria. A "yes" in the last two columns of the table indicate that further evaluation of the saturated zone soil contamination is necessary.

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FIGURE 3-1

SCHEMATIC OF CLEANUP GOALS SCREENING PROCESS GREENWOOD CHEMICAL SITE

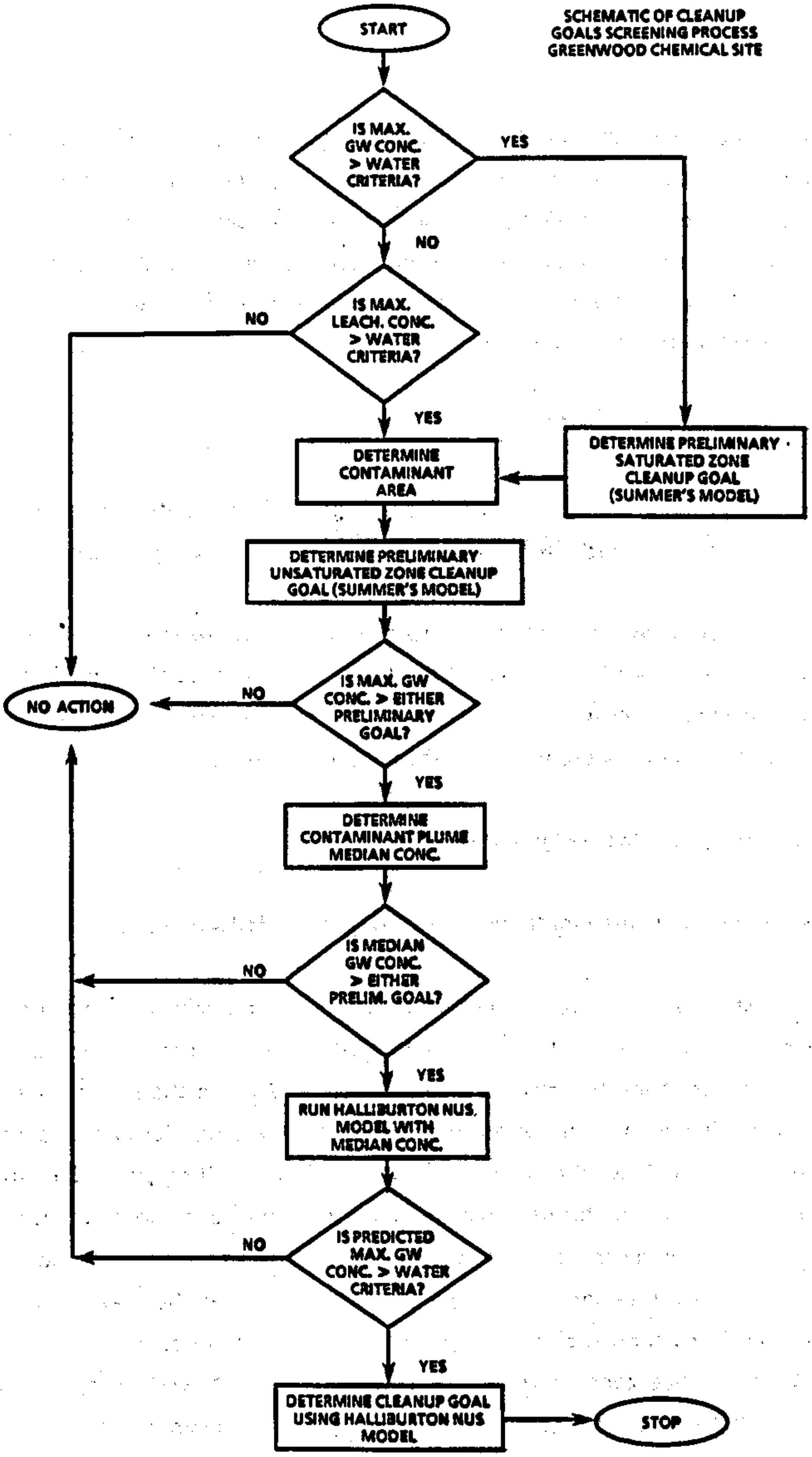

TABLE 3-1

COMPARISON OF WATER CRITERIA WITH MAXIMUM THEORETICAL GROUNDWATER CONCENTRATIONS FOR SATURATED ZONE SOILS GREENWOOD CHEMICAL SITE

Chemical	Koc (or K_D)	Water Criteria (µg/L)	Maximum Saturated Soil (mg/kg) FOC = 0.0015		Maximum Groundwater Concentration Exceeds Criteria	
			Area 1A	Area 1B	Area 1A	Area 1B
Arsenic	924	50	13.500	16.200	NO	NO
Cyanide	1,700	200	1.680	9.200	NO	NO
Acetone	9.2	3,500	74.800	1.400	YES	YES
Benzene	83	5	0.130	ND	YES	NO
4-Chloroaniline	52	140	0.180	ND	YES	NO
Chlorobenzene	330	100	0.480	ND	YES	NO
Methylene chloride	8.8	5	ND	ND	NO	NO
Tetrachloroethene	364	5	ND	ND	NO	NO
Trichloroethene	126	5	ND	ND	NO	NO
Toluene	300	1,000	20.600	ND	YES	NO
Naphthalene	940	140	10.560	ND	YES	NO
Naphthaleneacetic acid	160	305	ND	ND	NO	NO
Tetrahydrofuran	42.39	73	7.760	ND	YES	NO
Bis (2-ethylhexyl) phthalate	2e9	4	8.410	1.760	NO	NO
Chloroform	44	100	0.063	ND	YES	NO
1,2-Dichloroethane	14	5	0.940	ND	YES	NO
Di-n-butyl phthalate	170,000	3,500	2.290	ND	NO	NO
Xylene	248	10,000	3.960	ND	YES	NO
2,4,6-Trichlorophenol	3,020	3.2	ND	ND	NO	NO

Groundwater Conc. = Soil Conc. / K_D

ND	Nondetect
N/C	No Criteria Available
Area 1A	Main Source Area
Area 1B	Northern Warehouse Area

ORIGINAL
(Red)

2. The second step consists of calculating saturated soil cleanup goals using the Summer's Model, which is a conservative method to estimate groundwater concentrations from soil contamination. Summer's Model cleanup goals for the saturated zone soil are equal to the water criteria multiple by K_D for each chemical, respectively. Table 3-2 illustrates the maximum saturated zone soil concentrations and the results of the Summer's Method cleanup goals. No goals are calculated for areas where no detections of a particular chemical are observed. Chemicals whose maximum theoretical concentrations were observed not to exceed the water criteria in Table 3-1 were not evaluated in Table 3-2.

3. The third step in this procedure is to calculate the maximum theoretical leachate concentration that could result from the unsaturated zone soil contamination. Similar to Step 1, these maximum leachate concentrations were determined by dividing the maximum unsaturated zone soil concentration by the distribution coefficient. The resulting values were compared to the water criteria (SDWA MCLs or toxicity based values). The results of this calculation are summarized in Table 3-3, which includes the maximum unsaturated soil concentrations observed in each area, and the result of the comparison between the theoretical maximum aqueous chemical concentration and the water criteria. A "yes" in the last two columns of the table indicate that further evaluation of the unsaturated zone soil contamination is necessary for the chemical.

4. The fourth step consists of calculating unsaturated zone Summer's Model soil cleanup goals and comparing these goals with the maximum unsaturated zone soil concentrations for each area of contamination. Table 3-4 illustrates the maximum unsaturated zone soil concentrations and the results of the Summer's Model cleanup goals. No goals are calculated for areas where no detections of a particular chemical are observed. Chemicals whose maximum theoretical concentrations were observed not to exceed the water criteria in Table 3-3 were not evaluated in Table 3-4.

5. Table 3-5 is a reproduction of Table 3-4 with the three chemicals (cyanide, chloroform, and 2,4,6-trichlorophenol) omitted, because the maximum soil concentrations are less than the Summer's Model soil cleanup goals.

6. Step 6 is a comparison of the Summer's Model cleanup goals, for both zones developed previously, with the median soil concentrations determined from the isoconcentration contour mapping for both zones at the two areas. This comparison is illustrated in Table 3-6. The last two columns of the table indicate with a "yes" instances where the median saturated or

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(Red)

TABLE 3-2

COMPARISON OF SUMMER'S MODEL CLEANUP GOAL WITH MAXIMUM SATURATED ZONE SOIL CONCENTRATION GREENWOOD CHEMICAL SITE

Chemical	Koc (or K_D)	Water Criteria (µg/L)	Maximum Saturated Soil (mg/kg) FOC = 0.0015		Saturated Zone Cleanup Goal (mg/kg) Based on Summer's Model	
			Area 1A	Area 1B	Area 1A	Area 1B
Acetone	9.2	3,500	74.800	1.400	0.048	0.048
Benzene	83	5	0.130	ND	0.001	N/A
4-Chloroaniline	52	140	0.180	ND	0.011	N/A
Chlorobenzene	330	100	0.480	ND	0.050	N/A
Toluene	300	1,000	20.600	ND	0.450	N/A
Naphthalene	940	140	10.560	ND	0.197	N/A
Tetrahydrofuran	42.39	73	7.76	ND	0.0046	N/A
Chloroform	44	100	0.063	ND	0.007	N/A
1,2-Dichloroethane	14	5	0.940	ND	0.000	N/A
Xylene	248	10,000	3.960	ND	3.720	N/A

ND	Nondetect
N/A	Not Applicable

Area 1A	Main Source Area
Area 1B	Northern Warehouse Area

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(Red)

TABLE 3-3

COMPARISON OF WATER CRITERIA WITH MAXIMUM THEORETICAL GROUNDWATER CONCENTRATION FOR UNSATURATED ZONE SOILS GREENWOOD CHEMICAL SITE

Chemical	Koc (or K_D)	Water Criteria (µg/L)	Maximum Unsaturated Soil (mg/kg) FOC = 0.0045		Maximum Leachate Concentration Exceeds Criteria	
			Area 1A	Area 1B	Area 1A	Area 1B
Arsenic	924	50	2,470.000	33.400	YES	NO
Cyanide	1,700	200	1,000.000	12.800	YES	NO
Acetone	9.2	3,500	201.300	17.030	YES	YES
Benzene	83	5	0.160	ND	YES	NO
4-Chloroaniline	52	140	6.310	ND	YES	NO
Chlorobenzene	330	100	5.120	ND	YES	NO
Methylene chloride	8.8	5	0.597	ND	YES	NO
Tetrachloroethene	364	5	20.140	ND	YES	NO
Trichloroethene	126	5	0.024	ND	YES	NO
Toluene	300	1,000	125.800	ND	YES	NO
Naphthalene	940	140	757.200	556.900	YES	YES
Naphthaleneacetic acid	160	305	17.000	ND	YES	NO
Tetrahydrofuran	42.39	73	9.000	ND	YES	NO
Bis(2-ethylhexyl) phthalate	2e9	4	104.400	ND	NO	NO
Chloroform	44	100	0.041	ND	YES	NO
1,2-Dichloroethane	14	5	0.051	ND	YES	NO
Di-n-butyl phthalate	170,000	3,500	9.418	1.484	NO	NO
Xylene	248	10,000	34.020	ND	YES	NO
2,4,6-Trichlorophenol	3,020	3.2	0.468	ND	YES	NO

Leach Conc. = Soil Conc. / K_D

ND	Nondetect
N/C	No Criteria Available
Area 1A	Main Source Area
Area 1B	Northern Warehouse Area

TABLE 3-4

COMPARISON OF SUMMER'S MODEL CLEANUP GOAL WITH MAXIMUM UNSATURATED ZONE SOIL CONCENTRATION GREENWOOD CHEMICAL SITE

Chemical	Koc (or K_D)	Water Criteria (µg/L)	Maximum Unsaturated Soil (mg/kg) FOC = 0.0045		Unsaturated Zone Cleanup Goal (mg/kg) Based on Summer's Model	
			Area 1A	Area 1B	Area 1A	Area 1B
Arsenic	924	50	2,470.000	33.400	136.137	N/A
Cyanide	1,700	200	1,000.000	12.800	1,332.811	N/A
Acetone	9.2	3,500	201.300	17.030	0.582	2.853
Benzene	83	5	0.160	ND	0.014	N/A
4-Chloroaniline	52	140	6.310	ND	0.150	N/A
Chlorobenzene	330	100	5.120	ND	0.842	N/A
Methylene chloride	8.8	5	0.597	ND	0.004	N/A
Tetrachloroethene	364	5	20.140	ND	0.036	N/A
Trichloroethene	126	5	0.024	ND	0.056	N/A
Toluene	300	1,000	125.800	ND	8.169	N/A
Naphthalene	940	140	757.200	556.900	3.505	7.509
Naphthaleneacetic acid	160	305	17	ND	0.22	N/A
Tetrahydrofuran	42.39	73	9	ND	0.014	N/A
Chloroform	44	100	0.041	ND	0.482	N/A
1,2-Dichloroethane	14	5	0.051	ND	0.012	N/A
Xylene	248	10,000	34.020	ND	58.560	N/A
2,4,6-Trichlorophenol	3,020	3.2	0.468	ND	0.856	N/A

ND	Nondetect
NA	Not Applicable

Area 1A	Main Source Area
Area 1B	Northern Warehouse Area

ORIGINAL
(Red)

TABLE 3-5

SUMMARY OF CHEMICALS IN THE UNSATURATED ZONE THAT MAY EXCEED SUMMER'S MODEL CLEANUP GOALS GREENWOOD CHEMICAL SITE

Chemical	Koc (or K_D)	Water Criteria (µg/L)	Maximum Unsaturated Soil (mg/kg) FOC = 0.0045		Unsaturated Zone Cleanup Goal (mg/kg) Based on Summer's Model	
			Area 1A	Area 1B	Area 1A	Area 1B
Arsenic	924	50	2,470.000	33.400	136.137	N/A
Acetone	9.2	3,500	201.300	17.030	0.582	2.853
Benzene	83	5	0.160	ND	0.014	N/A
4-Chloroaniline	52	140	6.310	ND	0.150	N/A
Chlorobenzene	330	100	5.120	ND	0.842	N/A
Methylene chloride	8.8	5	0.597	ND	0.004	N/A
Tetrachloroethene	364	5	20.140	ND	0.036	N/A
Trichloroethene	126	5	0.024	ND	0.056	N/A
Toluene	300	1,000	125.800	ND	8.169	N/A
Naphthalene	940	140	757.200	556.900	3.505	7.509
Naphthaleneacetic acid	160	305	17	ND	0.22	N/A
Tetrahydrofuran	42.39	73	9	ND	0.014	N/A
1,2-Dichloroethane	14	5	0.051	ND	0.012	N/A
Xylene	248	10,000	34.020	ND	58.560	N/A

ND	Nondetect
N/A	Not Applicable

Area 1A	Main Source Area
Area 1B	Northern Warehouse Area

TABLE 3-6

COMPARISON OF MEDIAN SOIL CONCENTRATIONS WITH SUMMER'S MODEL CLEANUP GOALS GREENWOOD CHEMICAL SITE

Chemical	Median Soil Concentration (mg/kg)				Soil Cleanup Goals Based on Summer's Model (mg/kg)				May Require Cleanup Action	
	Area 1A		Area 1B		Area 1A		Area 1B		Area 1A	Area 1B
	Unsaturated	Saturated	Unsaturated	Saturated	Unsaturated	Saturated	Unsaturated	Saturated		
Arsenic	15.000	5.000	2.000	6.000	136.137	N/A	N/A	N/A	NO	NO
Cyanide	8.000	0.300	0.200	2.000	N/A	N/A	N/A	N/A	NO	NO
Acetone	5.000	10.000	2.000	0.300	0.582	0.048	2.853	0.048	YES	YES
Benzene	0.005	0.020	ND	ND	0.014	0.001	N/A	N/A	YES	NO
4-Chloroaniline	0.100	0.100	ND	ND	0.150	0.011	N/A	N/A	YES	NO
Chlorobenzene	0.010	0.050	ND	ND	0.842	0.050	N/A	N/A	YES	NO
Methylene chloride	0.300	ND	ND	ND	0.004	N/A	N/A	N/A	YES	NO
Tetrachloroethene	0.100	ND	ND	ND	0.036	N/A	N/A	N/A	YES	NO
Trichloroethene	0.010	ND	ND	ND	0.056	N/A	N/A	N/A	NO	NO
Toluene	0.500	1.000	ND	ND	8.169	0.450	N/A	N/A	YES	NO
Naphthalene	5.000	0.100	10.000	ND	3.505	0.197	7.509	N/A	YES	YES
Naphthaleneacetic acid	0.050	ND	ND	ND	0.22	N/A	N/A	N/A	NO	NO
Tetrahydrofuran	0.050	0.500	ND	ND	0.014	0.0046	N/A	N/A	YES	NO
Bis(2-ethylhexyl)phthalate	2.000	0.300	0.400	0.500	N/A	N/A	N/A	N/A	NO	NO
Chloroform	0.003	0.020	ND	ND	N/A	0.007	N/A	N/A	YES	NO
1,2-Dichloroethane	0.002	0.200	ND	ND	0.012	0.000	N/A	N/A	YES	NO
Di-n-butyl phthalate	1.000	0.100	0.300	ND	N/A	N/A	N/A	N/A	NO	NO
Xylene	0.200	0.200	ND	ND	N/A	3.720	N/A	N/A	NO	NO
2,4,6-Trichlorophenol	0.090	ND	ND	ND	N/A	N/A	N/A	N/A	NO	NO

ND	Nondetect
N/C	No Criteria Available
N/A	Not Applicable

Area 1A	Main Source Area
Area 1B	Northern Warehouse Area

unsaturated soil concentration is greater than the conservative Summer's Model cleanup goals. A "no" in these columns indicates that remediation is not necessary.

7. Step 7 is the final phase of the screening procedure. The median unsaturated and saturated soil concentration of each chemical is used in the Halliburton NUS Model, and the need for remediation in a particular contaminated area of the site for a particular chemical is indicated by a yes in the last two columns of Table 3-7. The "yes" indicates that the modeled maximum groundwater concentrations exceed the water criteria for the particular chemical. At this point, a set of cleanup goals calculated using the Halliburton NUS Model will be determined.

3.1.2 Drum Disposal Area

The Drum Disposal Area screening was performed in the same manner as described in Section 3.1.1, with the exception that actual groundwater data was used in Step 1. This data was used because of the lack of saturated zone soil analytical data available in this area. The groundwater data used was from REM III sampling of monitoring wells MW01 and MW04 during May of 1988 and February of 1989, as reported in the August 1990 RI Report (see Table 3-8).

1. Analogous to Table 3-1 in Section 3.1.1, Table 3-9 presents the comparison of the maximum groundwater concentrations to the water criteria (MCLs or toxicity based values). A "yes" in the last column of Table 3-9 indicates that further evaluation of the saturated zone contamination is necessary.

2. In Table 3-10, the results of the saturated zone soil cleanup goals calculated using the Summer's Model are presented. Chemicals whose maximum groundwater concentrations were observed not to exceed the water criteria in Table 3-9 were not evaluated in Table 3-10.

3. The maximum theoretical leachate concentrations that could result from unsaturated zone soil contamination are calculated and summarized in Table 3-11. These calculated leachate concentrations are compared with the water criteria. If the calculated leachate concentration is greater than the water criteria, a YES is in the last column of Table 3-11.

4. Table 3-12 summarizes the results of the unsaturated zone soil cleanup goals calculated using the Summer's Model. Only those chemicals for which the calculated leachate concentration exceeded the water criteria in Table 3-11 are included in Table 3-12.

ORIGINAL
(Red)

TABLE 3-7

CHEMICALS REQUIRING REMEDIATION BASED ON HALLIBURTON NUS MODEL RUN USING SOIL CONCENTRATIONS GREENWOOD CHEMICAL SITE

Chemical	Median Soil Concentration (mg/kg)				Cleanup Action	
	Area 1A		Area 1B		Area 1A	Area 1B
	Unsaturated	Saturated	Unsaturated	Saturated		
Arsenic	15.000	5.000	2.000	6.000	NO	NO
Cyanide	8.000	0.300	0.200	2.000	NO	NO
Acetone	5.000	10.000	2.000	0.300	YES	YES
Benzene	0.005	0.020	ND	ND	YES	NO
4-Chloroaniline	0.100	0.100	ND	ND	YES	NO
Chlorobenzene	0.010	0.050	ND	ND	YES	NO
Methylene chloride	0.300	ND	ND	ND	YES	NO
Tetrachloroethene	0.100	ND	ND	ND	NO	NO
Trichloroethene	0.010	ND	ND	ND	NO	NO
Toluene	0.500	1.000	ND	ND	YES	NO
Naphthalene	5.000	0.100	10.000	ND	NO	NO
Naphthaleneacetic acid	0.050	ND	ND	ND	NO	NO
Tetrahydrofuran	0.050	0.500	ND	ND	YES	NO
Bis(2-ethylhexyl) phthalate	2.000	0.300	0.400	0.500	NO	NO
Chloroform	0.003	0.020	ND	ND	YES	NO
1,2-Dichloroethane	0.002	0.200	ND	ND	YES	NO
Di-n-butyl phthalate	1.000	0.100	0.300	ND	NO	NO
Xylene	0.200	0.200	ND	ND	NO	NO
2,4,6-Trichlorophenol	0.090	ND	ND	ND	NO	NO

ND	Nondetect
N/C	No Criteria Available
Area 1A	Main Source Area
Area 1B	Northern Warehouse Area

ORIGINAL
(Red)

TABLE 3-8

COMPARISON OF MAXIMUM AND MEDIAN MEASURED GROUNDWATER CONCENTRATIONS GREENWOOD CHEMICAL SITE

Chemical	Water Criteria (µg/L)	Monitoring Well Measurements (mg/L)(1)				Maximum Measured Groundwater Concentration (mg/L)	Median Measured Groundwater Concentration (mg/L)
		MW01 (5/88)	MW01 (2/14/89)	MW04 (5/88)	MW04 (2/17/89)		
Arsenic	50	R	R	0.004	R	0.004	0.004
Cyanide	200	0.012	ND	ND	ND	0.012	0.003
Acetone	3,500	1.500 B	0.055 B	0.027JB	2.200 J	2.200	0.946
Benzene	5	0.200 J	0.230	0.018 J	0.054	0.230	0.126
4-Chloroaniline	140	ND	ND	ND	0.013	0.013	0.003
Chlorobenzene	100	ND	0.097	0.027	0.072	0.097	0.049
Methylene chloride	5	1.000 B	0.002 B	0.047 B	0.005 B	1.000	0.264
Tetrachloroethene	5	ND	0.008	ND	0.007	0.008	0.004
Trichloroethene	5	0.098 J	0.025	0.024 J	0.006	0.098	0.038
Toluene	1,000	5.100	0.093	0.640	1.800	5.100	1.908
Naphthalene	140	0.035	0.070	0.019	0.058	0.070	0.046
Naphthaleneacetic acid	305	0.600 J	0.560 J	0.060 J	11.000 J	11.000	3.055
Tetrahydrofuran	73	0.830 J	0.510 J	0.047 J	0.350 J	0.830	0.434
Bis(2-ethylhexyl)phthalate	4	ND	0.006 J	ND	0.003 J	0.006	0.002
Chloroform	100	0.220	0.570	0.093	0.077	0.570	0.240
1,2-Dichloroethane	5	ND	ND	ND	ND	ND	ND
Di-n-butyl phthalate	3,500	ND	ND	ND	ND	ND	ND
Xylene	10,000	NA	NA	NA	NA	N/A	N/A
2,4,6-Trichlorophenol	3.2	NA	NA	NA	NA	N/A	N/A

(1)	Ebasco Data for Area 2 (Drum Disposal Area)
ND	Nondetect
NA	Not Analyzed
N/A	Not Applicable
R	Unreliable
J	Estimated
B	Found in blank

ORIGINAL
(Red)

TABLE 3-9

COMPARISON OF WATER CRITERIA WITH MAXIMUM' MEASURED GROUNDWATER CONCENTRATIONS GREENWOOD CHEMICAL SITE

Chemical	Water Criteria (µg/L)	Maximum Measured(1) Groundwater (µg/L)	Maximum Groundwater Concentration Exceeds Water Criteria
Arsenic	50	4.400	NO
Cyanide	200	12.000	NO
Acetone	3,500	2.2e3	NO
Benzene	5	230.000	YES
4-Chloroaniline	140	13.000	NO
Chlorobenzene	100	97.000	NO
Methylene chloride	5	1,000.000	YES
Tetrachloroethene	5	8.000	YES
Trichloroethene	5	98.000	YES
Toluene	1,000	5,100.000	YES
Naphthalene	140	70.000	NO
Naphthaleneacetic acid	305	11,000.000	YES
Tetrahydrofuran	73	830.000	YES
Bis(2-ethylhexyl)phthalate	4	6.000	YES
Chloroform	100	570.000	YES
1,2-Dichloroethane	5	ND	NO
Di-n-butyl phthalate	3,500	ND	NO
Xylene	10,000	N/A	N/A
2,4,6-Trichlorophenol	3.2	N/A	N/A

(1)	Ebasco Data for Area 2 (Drum Disposal Area)
ND	Nondetect
NA	Not Analyzed
N/A	Not Applicable

ORIGINAL
(Red)

TABLE 3-10

COMPARISON OF PRELIMINARY SOIL CLEAN UP GOAL WITH MAXIMUM CALCULATED SATURATED ZONE SOIL CONCENTRATION GREENWOOD CHEMICAL SITE

Chemical	Koc	Water Criteria (µg/L)	Maximum Saturated Zone Concentrations(1)		Saturated Zone Cleanup Goal Based on Equilibrium Partitioning(3) (mg/kg)
			Measured Groundwater (mg/L)	Calculated Soil(2) (mg/kg)	
Benzene	83	5	0.230	0.029	0.0006
Methylene chloride	8.8	5	1.000	0.013	0.0001
Tetrachloroethene	364	5	0.008	0.004	0.0027
Trichloroethene	126	5	0.098	0.019	0.0009
Toluene	300	1,000	5.100	2.295	0.4500
Naphthaleneacetic acid	160	305	11.000	2.640	0.1680
Tetrahydrofuran	42.39	73	0.830	0.053	0.0046
Bis(2-ethylhexyl) phthalate	2e9	4	0.006	18,000.000	12,000.0000
Chloroform	44	100	0.570	0.038	0.0066

(1) Ebasco Data for Area 2 (Drum Disposal Area)
(2) Soil Conc. = Groundwater Conc. * K_D
(3) Cleanup Goal = Water Criteria * K_D
Saturated Zone FOC = 0.0015

ORIGINAL
(Red)

TABLE 3-11

COMPARISON OF WATER CRITERIA WITH MAXIMUM CALCULATED LEACHATE CONCENTRATION FOR UNSATURATED ZONE GREENWOOD CHEMICAL SITE

Chemical	Koc (or K_D)	Water Criteria (µg/L)	Maximum Unsaturated Zone Concentration(1)		Maximum Leachate Concentration Exceeds Water Criteria
			Measured Soil (mg/kg)	Calculated Leachate(2) (mg/L)	
Arsenic	924	50	29.000	0.031	NO
Cyanide	1,700	200	80.300	0.047	NO
Acetone	9.2	3,500	19.000	458.937	YES
Benzene	83	5	230.000	615.797	YES
4-Chloroaniline	52	140	32.300	138.034	YES
Chlorobenzene	330	100	16.000	10.774	YES
Methylene chloride	8.8	5	305.500	7,714.646	YES
Tetrachloroethene	364	5	15.000	9.158	YES
Trichloroethene	126	5	32.000	56.437	YES
Toluene	300	1,000	6,000.00	4,444.444	YES
Naphthalene	940	140	755.000	178.487	YES
Naphthaleneacetic acid(3)	160	305	3,780.000	5,250.000	YES
Tetrahydrofuran	42.39	73	ND	ND	NO
Bis(2-ethylhexyl)phthalate	2e9	4	17.000	1.89e-6	NO
Chloroform	44	100	16.000	80.808	YES
1,2-Dichloroethane	14	5	0.026	0.413	YES
Di-n-butyl phthalate	170,000	3,500	1.800	0.002	NO
Xylene	248	10,000	4.700	4.211	NO
2,4,6-Trichlorophenol	3,020	3.2	NA	NA	N/A

(1) Ebasco Data for Area 2 (Drum Disposal Area)
(2) Leach Conc. = Soil Conc./K_D
(3) Assumed to be the Sum of Semivolatile TICs Unsaturated Zone FOC = 0.0045
ND Nondetect
NA Not Analyzed
N/A Not Applicable

ORIGINAL
(Red)

TABLE 3-12

COMPARISON OF SUMMER'S MODEL CLEANUP GOAL WITH MAXIMUM UNSATURATED ZONE SOIL CONCENTRATION GREENWOOD CHEMICAL SITE

Chemical	Koc (or K_D)	Water Criteria (µg/L)	Maximum Unsaturated Zone Concentration(1)		Unsaturated Zone Cleanup Goal Based on Summer's Model (mg/kg)	Maximum Soil Conc. Exceeds Cleanup Goal
			Measured Soil (mg/kg)	Calculated Leachate(2) (mg/L)		
Acetone	9.2	3,500	19.000	458.937	0.734	YES
Benzene	83	5	230.000	615.797	0.010	YES
4-Chloroaniline	52	140	32.300	138.034	0.249	YES
Chlorobenzene	330	100	16.000	10.774	2.110	YES
Methylene chloride	8.8	5	305.500	7,714.646	0.002	YES
Tetrachloroethene	364	5	15.000	9.158	0.062	YES
Trichloroethene	126	5	32.000	56.437	0.049	YES
Toluene	300	1,000	6,000.00	4,444.444	6.838	YES
Naphthalene	940	140	755.000	178.487	3.000	YES
Naphthaleneacetic acid(3)	160	305	3,780.000	5,250.000	2.635	YES
Chloroform	44	100	16.000	80.808	0.281	YES
1,2-Dichloroethane	14	5	0.026	0.413	0.034	NO

(1) Ebasco Data for Area 2 (Drum Disposal Area)
(2) Leach Conc. = Soil Conc./K_D
(3) Assumed to be the Sum of Semivolatile TICs Unsaturated Zone FOC = 0.0045
ND Nondetect

5. Table 3-13 is a comparison of the calculated Summer's Model cleanup goals with the median soil concentrations determined from the isoconcentration contour maps. A YES in the last column indicates that the median soil concentrations will exceed the Summer's Model soil cleanup goals.

6. Table 3-14 summarizes the results of analysis using the median soil concentrations in the Halliburton NUS Model. The predicted maximum groundwater concentration is compared with the water criteria. If a YES is present in the last column, remediation of soil containing this chemical is required.

3.1.3 Screening Procedure Summary

The screening procedure was used to reduce the number of chemicals which require modeling. Based on the screening, arsenic, cyanide, naphthalene, bis(2-ethylhexyl)phthalate, and xylene were removed from further consideration, as the concentrations of these chemicals found in soils at the site would not warrant remedial action to protect groundwater via the leaching to groundwater pathway. Safe Drinking Water Act MCLs in groundwater would not be exceeded for these chemicals via this exposure route.

3.2 HALLIBURTON NUS MODELING

For the chemicals passing the screening procedure, the computer modeling procedure was conducted using the median soil concentrations, the areal extent of contamination, and the site and chemical data described in the earlier sections of this report. For a given groundwater containment period, the cleanup goals for the unsaturated soil zone were determined using an iterative process whereby a soil cleanup goal is selected, the model run, and the resulting maximum groundwater concentration at the end of the groundwater containment period compared with the water criteria. If the groundwater concentration at the end of the containment period is greater than the criteria, the cleanup goal is decreased and the model run is repeated. This procedure is repeated until the groundwater concentration at the end of the containment period is less than the criteria and the difference between the groundwater concentration and the criteria is less than 2.5 percent of the criteria. It was determined that only the unsaturated zone contaminants could be affected by a remediation action. The saturated zone contaminants were assumed to be changed only via contaminant washout. The output of the modeling are included in Appendix G (Volume II).

ORIGINAL
(Red)

TABLE 3-13

COMPARISON OF MEDIAN SOIL CONCENTRATION WITH PRELIMINARY CLEANUP GOALS GREENWOOD CHEMICAL SITE

Chemical	Median Soil Concentration(1)		Unsaturated Zone Cleanup Goal Based on Summer's Model(3) (mg/kg)	Saturated Zone Cleanup Goal Based on Equilibrium Partitioning(4) (mg/kg)	Exceed Either Preliminary Goal
	Unsaturated (mg/kg)	Calculated Saturated Soil(2) (mg/kg)			
Arsenic	3.000	4.066	N/A	N/A	NO
Cyanide	2.000	5.100	N/A	N/A	NO
Acetone	2.000	0.013	0.734	N/A	YES
Benzene	0.950	0.016	0.010	0.0006	YES
4-Chloroaniline	2.000	3e-4	0.249	N/A	YES
Chlorobenzene	2.500	0.024	2.110	N/A	YES
Methylene chloride	1.000	0.004	0.002	0.0001	YES
Tetrachloroethene	1.500	0.002	0.062	0.0027	YES
Trichloroethene	3.000	0.007	0.049	0.0009	YES
Toluene	100.000	0.859	6.838	0.4500	YES
Naphthalene	5.000	0.064	3.000	N/A	YES
Naphthaleneacetic acid(5)	100.000	0.733	2.635	0.1680	YES
Tetrahydrofuran	ND	0.028	N/A	0.0046	YES
Bis(2-ethylhexyl)phthalate	0.300	6,750.000	N/A	1.2e4	NO
Chloroform	1.500	0.016	0.281	0.0066	YES
1,2-Dichloroethane	0.004	ND	0.034	N/A	NO
Di-n-butyl phthalate	0.580	ND	N/A	N/A	NO
Xylene	0.300	NA	N/A	N/A	NO(6)
2,4,6-Trichlorophenol	NA	NA	N/A	N/A	NO(6)

(1) Ebasco Data for Area 2 (Drum Disposal Area)
(2) Soil Conc. = Groundwater Conc. * K_D
(3) Values Taken from Table 3-12
(4) Values Taken from Table 3-10
(5) Assumed to be the Sum of Semivolatile TICs (Only for Unsaturated Zone)
(6) No Action Due to Insufficient Data

ND Nondetect
NA Not Analyzed
N/A Not Applicable (dropped out in Table 3-9 or Table 3-11)

TABLE 3-14

COMPARISON OF WATER CRITERIA WITH MODELED MAXIMUM SATURATED ZONE CONCENTRATION FOR CHEMICALS WHICH EXCEED THE PRELIMINARY CLEANUP GOALS GREENWOOD CHEMICAL SITE

Chemical	Median Soil Concentration(1)		Water Criteria (µg/L)	Halliburton NUS Model-Predicted Maximum Groundwater Concentration (µg/L)	Cleanup Action Required
	Unsaturated (mg/kg)	Calculated Saturated Soil(2) (mg/kg)			
Acetone	2.000	0.013	3,500	942.03	NO
Benzene	0.950	0.016	5	125.30	YES
4-Chloroaniline	2.000	3e-4	140	105.59	NO
Chlorobenzene	2.500	0.024	100	49.01	NO
Methylene chloride	1.000	0.004	5	263.64	YES
Tetrachloroethene	1.500	0.002	5	28.14	YES
Trichloroethene	3.000	0.007	5	170.96	YES
Toluene	100.000	0.859	1,000	1,908.00	YES
Naphthalene	5.000	0.064	140	45.50	NO
Naphthaleneacetic acid(3)	100.000	0.733	305	23,161.17	YES
Tetrahydrofuran	ND	0.028	73	434.06	YES
Chloroform	1.500	0.016	100	520.54	YES

(1) Ebasco Data for Area 2 (Drum Disposal Area)
(2) Soil Conc. = Groundwater Conc. * K_D
(3) Assumed to be the Sum of Semivolatile TICs (Only for Unsaturated Zone)
ND Nondetect

3.3 DISCUSSION OF RESULTS

Based on concentrations of some contaminants in the saturated zone (e.g., acetone and toluene), it was determined that the groundwater concentrations are in excess of the water criteria, as determined by the distribution coefficient. Therefore, groundwater containment and treatment is required. Using this assumption, the modeling was used to determine the unsaturated zone soil cleanup goal for a corresponding remediation time period, during which continued groundwater containment and treatment would be required after the initial unsaturated zone soil remediation was completed. Where soil remediation is required, the output from the model runs (See Appendix G, Volume II) illustrate the groundwater concentrations versus time for various cleanup time frames. Table 3-7 indicated that soil remediation is required as a result of contaminant leaching to groundwater from the unsaturated zone in excess of the water criteria for acetone, benzene, 4-chloroaniline, chlorobenzene, methylene chloride, toluene, chloroform, and 1,2-dichloroethane in Area 1A (Main Source Area) and for acetone in Area 1B (Northern Warehouse Area). The results of the Drum Disposal Area (Area 2) screening procedure summarized in Table 3-14 indicate remediation is required for benzene, methylene chloride, tetrachloroethene, trichloroethene, toluene, naphthaleneacetic acid, tetrahydrofuran, and chloroform. No action is required for other chemicals of concern, based on soil concentrations measured during the pre-design sampling.

The soil cleanup goals for the unsaturated zone soils are summarized in Table 3-15. The table indicates that the value of the soil cleanup goals is dependent upon the period of groundwater containment after the cleanup goal is attained.

The values presented in Table 3-15 are given as total concentration (Ct). The modeling and screening efforts were completed using concentrations reported by the laboratory as sorbed concentrations (C_s), as described in the USACE Pre-Design and REM III RI Reports. The soil cleanup goals in Table 3-15 include contributions from solid (C_s) and liquid phases (chemical concentration in the pore water, C_W) of the individual soil sample. Chemical concentration present in the air space of the soil voids is assumed to be negligible. The equation and terms defining the method of conversion are described in the Table 3-15 footnotes. Based on the equation, for a given soil concentration, the total concentration will be a slightly larger value.

Table 3-15 indicates the residual unsaturated zone soil concentrations that must be attained via remediation to attain MCLs or protective levels for a particular groundwater containment period. Longer containment periods allow higher concentrations of chemicals to be left in the soil. The reduction of the chemical concentration in the soil will occur in any event via leaching to infiltrating precipitation which will percolate into the saturated soil zone, washing out of chemicals from the

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TABLE 3-15

SOIL CLEANUP GOALS SUMMARY
(TOTAL CONCENTRATION, CT, MG/KG)
GREENWOOD CHEMICAL SITE

Chemical(3)	Area(4)	Saturated Zone Average Initial Soil Concentration (mg/kg)	Unsaturated Soil Goal, Ct (mg/kg) for Containment Period Indicated (Years)									
			0.25	0.38	0.43	0.5	1	1.5	2	2.5	3	3.5
Acetone	1A(1)	167.2	NA	NA	NA	NA	NA	NA	288.4	1,462.1	6,010.6	NC
	1B(1)	5.0	NA	NA	NA	10.1	67.9	281.8	1,194.0	5,170.5	NC	NC
	2(2)	–	No Cleanup Required for Contaminant at This Area									
Benzene	1A(1)	0.054	NA	NA	NA	NA	NA	NA	0.057	0.225	0.473	NC
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	0.1825	NA	NA	NA	NA	NA	NA	0.0224	0.1696	0.3805	0.7239
4-Chloroaniline	1A(1)	0.372	NA	NA	NA	NA	8.6	34.9	139.0	565.7	2,330.8	NC
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	–	No Cleanup Required for Contaminant at This Area									
Chlorobenzene	1A(1)	0.071	NA	NA	NA	27.5	93.8	374.3	1,648.1	7,708.7	37,957.9	
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	–	No Cleanup Required for Contaminant at This Area									
Methylene chloride	1A(1)	ND	NA	NA	NA	0.10	1.07	13.7	189.2	2,665.1	NC	NC
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	0.0596	NA	NA	NA	NA	0.8222	10.83	NC	NC	NC	NC
Toluene	1A(1)	1.47	NC	NC	NC	152.5	629.7	2,379.4	9,534.1	40,917.6	NC	NC
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	1.2626	48.38	NC	NC	NC	NC	NC	NC	NC	NC	NC
Chloroform	1A(1)	0.084	NA	NA	NA	NA	0.033	0.135	0.182	0.209	0.226	NC
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	0.0667	NA	NA	NA	NA	0.2130	NC	0.3262	NC	NC	NC
1,2-Dichloroethane	1A(1)	2.22	NA	NA	NA	NA	NA	NA	NA	0.124	0.422	NC
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	–	No Cleanup Required for Contaminant at This Area									
Tetrachloroethene	1A(1)	–	No Cleanup Required for Contaminant at This Area									
	1B(1)	–	No Cleanup Required for Contaminant at This Area									
	2(2)	0.0029	NA	NA	NA	NA	0.2033	0.2081	0.2364	NC	NC	NC

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TABLE 3-15
SOIL CLEANUP GOALS SUMMARY
(TOTAL CONCENTRATION, CT, MG/KG)
GREENWOOD CHEMICAL SITE
PAGE TWO

Chemical(3)	Area(4)	Saturated Zone Average Initial Soil Concentration (mg/kg)	Unsaturated Soil Goal, Ct (mg/kg) for Containment Period Indicated (Years)									
			0.25	0.38	0.43	0.5	1	1.5	2	2.5	3	3.5
Trichloroethene	1A(1)	0.0021	No Cleanup Required for Contaminant at This Area									
	1B(1)		No Cleanup Required for Contaminant at This Area									
	2(2)	0.0153	NA	NA	NA	NA	NA	NA	0.0974	NC	NC	NC
Naphthaleneacetic Acid	1A(1)	0.207	No Cleanup Required for Contaminant at This Area									
	1B(1)		No Cleanup Required for Contaminant at This Area									
	2(2)	1.3801	NA	NA	NA	NA	NA	NA	158.6	211.4	NA	NA
Tetrahydrofuran	1A(1)	0.1255	0.0365	NC	NC	7.295	NC	1,216	3,648	97,269	NC	NC
	1B(1)		No Cleanup Required for Contaminant at This Area									
	2(2)	0.1148	NC(5)	NC	NC	NC	NC	NC	NC	NC	NC	NC

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TABLE 3-15
SOIL CLEANUP GOALS SUMMARY
(TOTAL CONCENTRATION, CT, MG/KG)
GREENWOOD CHEMICAL SITE
PAGE THREE

Chemical(3)	Area(4)	Unsaturated Soil Goal, Ct (mg/kg) for Containment Period Indicated (Years)											
		3.8	3.92	4	4.5	5	6	7.4	9	9.2	10	20	20.8
Acetone	1A(1)	NC	NC	49,411.8	NC	NC	NC	NC	NC	NC	NC	NC	NC
	1B(1)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	2(2)	No Cleanup Required for Contaminant at This Area											
Benzene	1A(1)	NC	NC	1.60	NC	5.19	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	1.1307	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
4-Chloroaniline	1A(1)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	No Cleanup Required for Contaminant at This Area											
Chlorobenzene	1A(1)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	No Cleanup Required for Contaminant at This Area											
Methylene Chloride	1A(1)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Toluene	1A(1)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Chloroform	1A(1)	NC	NC	0.250	NC	0.269	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	NC	NC	NC	NC	0.4466	NC	NC	NC	NC	0.6968	NC	1.8190
1,2-Dichloroethane	1A(1)	NC	NC	2.01	NC	8.66	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	No Cleanup Required for Contaminant at This Area											
Tetrachloroethene	1A(1)	No Cleanup Required for Contaminant at This Area											
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	NC	NC	0.4285	NC	NC	NC	1.5398	NC	NC	NC	NC	NC

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TABLE 3-15
SOIL CLEANUP GOALS SUMMARY
(TOTAL CONCENTRATION, CT, MG/KG)
GREENWOOD CHEMICAL SITE
PAGE FOUR

Chemical(3)	Area(4)	Unsaturated Soil Goal, Ct (mg/kg) for Containment Period Indicated (Years)											
		3.8	3.92	4	4.5	5	6	7.4	9	9.2	10	20	20.8
Trichloroethene	1A(1)	No Cleanup Required for Contaminant at This Area											
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	NC	NC	NC	NC	0.4624	NC	NC	2.9695	NC	NC	NC	NC
Naphthaleneacetic Acid	1A(1)	No Cleanup Required for Contaminant at This Area											
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)		NA	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Tetrahydrofuran	1A(1)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
	1B(1)	No Cleanup Required for Contaminant at This Area											
	2(2)	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC

(1) Data for this cleanup goal from results of Army Corps of Engineers pre-design Field Sampling, Third Phase, Conducted in 1991.

(2) Data for this cleanup goal from results of REM III sampling as reported in the RI Report, August 1990, EBASCO Services, Inc.

(3) Chemicals for which cleanup goals were investigated but, based on groundwater modeling, do not require remediation include: arsenic, cyanide, napthalene, bis(2-ethylhexyl)phthalate, and xylene.

(4) Areas include 1A = Main Source Area; 1B = North Warehouse Area; 2 = Drum Disposal Area.

(5) Tetrahydrofuran present in groundwater at Area 2, but not found in unsaturated zone. An 0.25 year containment period is required until groundwater concentration attains MCLs.

NA Cleanup of unsaturated soil zone to meet drinking water standards in groundwater not attainable in groundwater containment period indicated due to contamination in the saturated soil zone.

NC Cleanup goal not calculated for containment period.

Total Concentration $Ct = \{(Cs * Db) + (Cw * Ps) + (Ca * Pa)\}/Db$

Where:
Cs = Chemical Concentration absorbed to the solid surface (mg/kg dry weight). Cs = Cwao *Kd sat in the saturated model output; Cs = soil goal in unsat. model output.
Cw = Chemical concentration in the pore water (mg/L) at equilibrium with Cs. Cw = Cwo in unsat. model output; Cw = Cwao in sat. model output.
Ps = Water filled porosity (Saturation water content = 0.35) (Residual water content = 0.07).
Ca = Concentration in the chemical in soil gas (μg/cc) (assumed negligible).
Pa = Air filled porosity (1-0.35 * 0.35).
Db = Dry bulk density of soil (1.7 g/cc).

saturated zone soils into the groundwater, and downgradient transport. Remedial action allows groundwater standards to be attained in a shorter time period. The volume of soil to be remediated varies depending on the containment period selected. To provide for compliance with the groundwater standards in the containment time period indicated, soils with concentrations greater than those shown on the table must be removed or otherwise treated to the concentration level displayed. An "NA" entry for a particular chemical in the Table indicates that the groundwater standard cannot be attained due to existing concentrations of the chemical present in either the saturated soil or the groundwater.

3.3.1 Main Source and North Warehouse Areas

The Main Source Area and the North Warehouse Area are referenced as areas 1A and 1B, respectively in Table 3-15. Cleanup for 9 chemicals is required in the Main Source Area, including acetone, benzene, 4-chloroaniline, chlorobenzene, methylene chloride, toluene, chloroform, 1,2-dichloroethane and tetrahydrofuran. A minimum of two and a half years of groundwater containment is required because the groundwater standards cannot be met for 1,2-dichloroethane (DCA) in a shorter time period. Thus, if it is desirable to attain groundwater standards in 2.5 years, the resulting DCA concentration must be reduced to 0.124 mg/kg (total concentration), acetone must be reduced to 1,462 mg/kg, benzene reduced to 0.225 mg/kg, and so on.

In the North Warehouse Area, remediation is required for only acetone. A minimum groundwater containment period of 0.5 years must be provided before the groundwater standards are met if the soil concentrations are reduced to 10.1 mg/kg acetone. Table ES-1 summarizes the soil cleanup goals for the Main Source and North Warehouse Areas.

3.3.2 Drum Disposal Area

The Drum Disposal Area is denoted as Area 2 in Table 3-15. For the 11 chemicals modeled, only 7 require unsaturated zone remediation, including benzene, methylene chloride, toluene, chloroform, tetrachloroethene (PCE), trichloroethene (TCE), and naphthaleneacetic acid (NAA). No cleanup of tetrahydrofuran in the unsaturated zone soils is necessary because it was undetected in the samples collected during investigations. However, existing concentrations in the saturated zone require an 0.25 year period of containment before groundwater standards are met. The minimum groundwater containment period for the Drum Disposal Area is 2 years. For this time frame, benzene concentrations in soil must be reduced to 0.0224 mg/kg, methylene chloride reduced to 1.42 mg/kg (1.5 year containment period), and so on. The cleanup goals for some chemicals may be greater than the actual concentrations found in the field, so that no soil cleanup may need be performed for a

2 year groundwater containment period. Comparison of the actual unsaturated zone soil concentrations is required for each chemical prior to determining the need for cleanup for the containment period selected. Table ES-1 summarizes the soil cleanup goals for the Drum Disposal Area.

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REPORT OR DOCUMENT TITLE Final Fate + Transport Modeling

DATE OF DOCUMENT 01-Feb-93

DESCRIPTON OF IMAGERY Maximum Potentiometric surface Elevation map.

NUMBER AND TYPE OF IMAGERY ITEM(S) 1 oversized map

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PAGE # AR300369

IMAGERY COVER SHEET
UNSCANNABLE ITEM

SITE NAME Greenwood Chemical

OPERABLE UNIT UAO

ADMINISTRATIVE RECORDS- SECTION 11 **VOLUME**

REPORT OR DOCUMENT TITLE Final Fate + Transport Modeling

DATE OF DOCUMENT 01-Feb-93

DESCRIPTON OF IMAGERY Cross Sections A-A, B-B, + C,C

NUMBER AND TYPE OF IMAGERY ITEM(S) 1 oversized map

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SUPERFUND DOCUMENT MANAGEMENT SYSTEM

DOC ID 138823
PAGE # AR000370

IMAGERY COVER SHEET
UNSCANNABLE ITEM

SITE NAME Greenwood Chemical

OPERABLE UNIT U40

ADMINISTRATIVE RECORDS- SECTION 11 **VOLUME**

REPORT OR DOCUMENT TITLE Final Fate + Transport Modeling

DATE OF DOCUMENT

DESCRIPTON OF IMAGERY Cross Sections D-D + E-E

NUMBER AND TYPE OF IMAGERY ITEM(S) 1 oversized map

APPENDICES

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APPENDIX A

HALLIBURTON NUS CONTAMINANT FATE AND TRANSPORT MODEL DESCRIPTION

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DEVELOPMENT AND APPLICATION OF A SPREADSHEET-BASED MULTIMEDIA CONTAMINANT FATE AND TRANSPORT MODEL

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INTRODUCTION

A spreadsheet-based, multimedia contaminant, fate and transport model was developed to support screening-level risk assessment, remediation goal, and simple remedial alternative selection for hazardous waste treatment, storage, and disposal facilities. This paper provides a discussion of this model system consisting of analytical models used to simulate contaminant washout from the source area, a model used to simulate downgradient solute transport, and the models used to estimate receptor concentrations under various types of exposure scenarios. A PC spreadsheet was used to implement and link the various simulation modules and to simplify the model input, interactive execution, and output presentation processes. The model also guides the user regarding the influence of various processes on the contaminant concentration at the point of compliance and, therefore, which variables should be focused on to improve the remediation or data collection efforts.

MODEL DEVELOPMENT

Contaminant Source Module

A system of analytical models which describes various aspects of source loading and contaminant washout from both the unsaturated and saturated zones was configured via straightforward mass balances. Although several simplifying assumptions were made, the model can simulate very complex source-loading scenarios. For example, any combinations of the following aspects of source loading and contaminant washout can be simulated:

- Surface infiltration and percolation
- Contaminant loading via infiltration
- Sorption in the unsaturated zone
- Upgradient groundwater flow
- Contaminant loading via upgradient flow
- Sorption in the saturated zone

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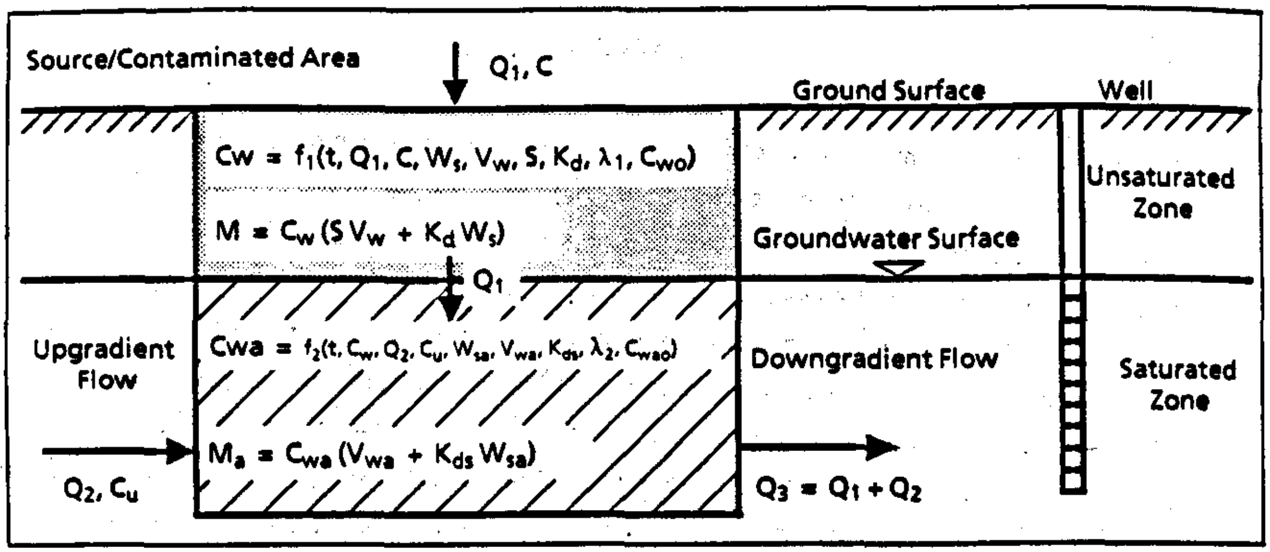
- Zone-specific contaminant decay rates
- Zone-specific initial contaminant concentrations
- Constant or time varying concentration in the unsaturated zone

In the model, variables used to describe/quantify these processes are shown in Figure 1 and defined as follows:

FIGURE 1: CONCEPTUAL MODEL OF THE SOURCE AREA



- C is the contaminant concentration in infiltrating precipitation (mg/L)
- Q_1 is the infiltration rate (L/day)
- C_w is the aqueous concentration in the unsaturated zone (mg/L)
- C_{wo} is the initial value of Cw (mg/L)
- S is the saturation fraction (dimensionless)
- M is the total mass of contaminant in the unsaturated zone (mg)
- W_s is the weight of soil in the unsaturated zone (kg)
- V_w is the void volume in the unsaturated zone (L)
- C_u is the contaminant concentration in upgradient groundwater (mg/L)
- Q_2 is the upgradient groundwater flow rate (L/day)
- C_{wa} is the aqueous concentration in the saturated zone (mg/L)
- C_{wao} is the initial value of C_{wao} (mg/L)
- M_a is the total mass of contaminant in the saturated zone below the source (mg)
- V_{wa} is the void volume in the saturated zone (L)
- W_{sa} is the weight of soil in the saturated zone (kg)
- Q_3 is the combined downgradient flow ($Q_1 + Q_2$) (L/day)
- λ_1, λ_2 are the first-order decay rates in the unsaturated and saturated zone (day^{-1})

- K_d, K_{ds} are the aqueous/solid phase distribution coefficients in the unsaturated and saturated zone, *respectively* (L/kg)
- t is the time (day)

1. Unsaturated Zone

A mass balance for the wash out of contaminants from an unsaturated source area, assuming that the infiltrating precipitation contains background contamination and that dispersion in the unsaturated zone is negligible, yields the following expression for the time-dependent concentration in the unsaturated zone:

$$\frac{dCw}{dt} = \left[\frac{Q_1}{SV_w + K_d W_s}\right] * \left[C - C_w\right] - \lambda_1 C_w \qquad (1)$$

For an initial condition of $C_w = C_{wo}$, this equation may be solved via direct integration to yield the following solution:

$$Cw = \frac{C - \left\{C - \left[1 + \left(SV_w + K_d W_s\right)\left(\lambda_1/Q_1\right)\right] C_{wo}\right\} \exp\left[-\frac{Q_1 + \left(SV_w + K_d W_s\right)\lambda_1}{SV_w + K_d W_s} t\right]}{\left[1 + \left(SV_w + K_d W_s\right)\left(\lambda_1/Q_1\right)\right]} \qquad (2)$$

2. Saturated Zone

Using a similar approach, a general case for the saturated zone which includes a time-dependent source loading term (C_w as above) and an upgradient contribution as a result of background contamination may be written in the following form:

$$\frac{dC_{wa}}{dt} + \frac{K_2}{K_1} C_{wa} = \frac{K_3}{K_1} + \frac{K_4}{K_1} \exp\left[-K_5 t\right] \qquad (3)$$

Where:

$K_1 = V_{wa} + K_{ds} W_{sa}$
$K_2 = Q_3 + (V_{wa} + K_{ds} W_{sa})\lambda_2$
$K_3 = Q_1 C / [1 + (SV_w + K_d W_s)(\lambda_1/Q_1)] + Q_2 C_u$
$K_4 = Q_1 C_{wo} - Q_1 C / [1 + (SV_w + K_d W_s)(\lambda_1/Q_1)]$
$K_5 = [Q_1 + (SV_w + K_d W_s)\lambda_1]/(SV_w + K_d W_s)$

This equation is of the general form:

$$C'_{wa} + p(t)C_{wa} = r(t)$$

and has a general solution as follows:

$$C_{wa} = \exp[-h] * [\int \exp(h)r(t)\,dt + K]$$

Where: $h = \int p(t)dt$ and K is a constant of integration

This equation may be solved for the initial condition of $C_{wa} = C_{wao}$ using the preceding integrating factor approach or the method of undetermined coefficients to yield the following:

$$C_{wa} = \frac{K_3}{K_2} + \frac{K_4}{K_2 - K_1K_5}\exp\left(-K_5t\right) + \left[C_{wao} - \frac{K_3}{K_2} - \frac{K_4}{K_2 - K_1K_5}\right]\exp\left(-\frac{K_2t}{K_1}\right) \qquad (4)$$

3. Special Case

In addition to this standard form of the solution, the following two special cases were also considered:

- For a constant-concentration unsaturated zone (i.e., $C_w = C$), the saturated zone equation becomes:

$$C_{wa} = \frac{Q_1C + Q_2C_u - \left\{Q_1C + Q_2C_u - K_2C_{wao}\right\}\exp\left(-\frac{K_2t}{K_1}\right)}{K_2} \qquad (5)$$

- In the case of $K_2 = K_1K_5$, the solution of Eq. (3) and thus the saturated zone equation becomes:

$$C_{wa} = \frac{K_3}{K_2} + \left[Cwao - \frac{K_3}{K_2} + \frac{K_4}{K_1}t\right]\exp\left(-K_5t\right) \qquad (6)$$

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Downgradient Solute Transport Module

A simplified version of a general solution to a three-dimensional advection/dispersion/sorption/decay equation was used to simulate solute transport. It provides an estimate of the contaminant concentration at a receptor location or discharge area downgradient of the source area under different source-loading conditions. As a result of the complexity of this model, a separate, executable file was required to perform the calculations. The linkage between the main spreadsheet and this executable file was accomplished by using macro commands in the spreadsheet.

The basic equation, a modified version of a general constant-source equation developed by Domenico (1987), for the plume centerline is as follows:

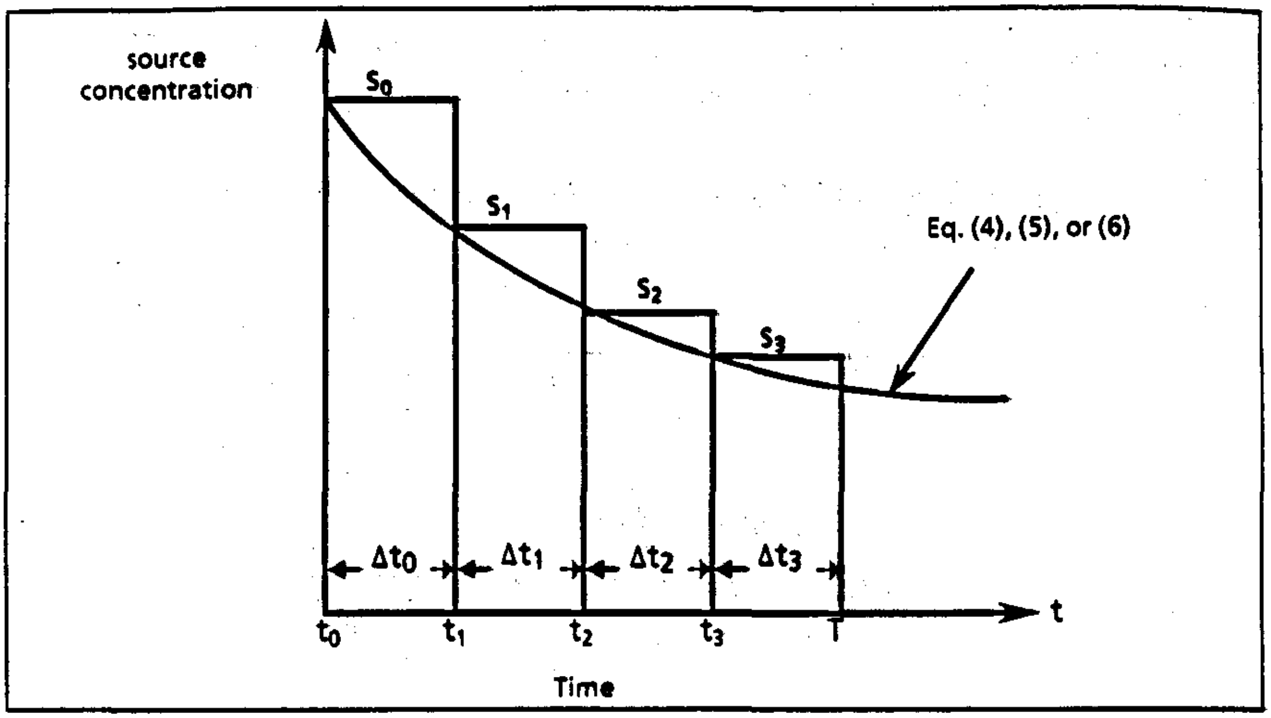
$$C(x,t,Co) = \frac{Co}{2}\exp\left\{\left(\frac{x}{2\left(D_x/V\right)}\right)\left[1-\left(1+\frac{4\lambda_3 D_x}{V^2}\right)^{1/2}\right]\right\}$$

$$\operatorname{erfc}\left[\frac{x-Vt\left(1+\frac{4\lambda_3 D_x}{V^2}\right)^{1/2}}{2\left(D_x t\right)^{1/2}}\right]\operatorname{erf}\left[\frac{Y}{4\left(\frac{D_y}{V}x\right)^{1/2}}\right] \qquad (7)$$

Where:
C = the downgradient concentration along the plume centerline (mg/L)
C_0 = the constant groundwater concentration at/below the source (mg/L)
x = the distance downgradient of the source (ft)
V = the contaminant velocity (ft/year)
t = elapsed time since the beginning of the source loading (years)
D_x = the principle value of the Dispersion tensor in the x (longitudinal) direction (ft^2/year)
Y = source dimension in the y (lateral) direction (ft)
D_y = the principle value of the Dispersion tensor in the y (lateral) direction (ft^2/year)
λ_3 = decay rate (years^{-1})

In the preceding expression, erf and erfc are the error function and the complimentary error function, respectively. The vertical dispersion was not considered in equation (7) in order to provide a conservative estimate of the exposure point concentration. The contaminant velocity is determined as the groundwater interstitial pore velocity divided by the retardation factor. This retardation factor can be estimated by using distribution coefficient, bulk density, and porosity of the soil. Equation (7) was applied using superposition to simulate the time-dependent source loading. For this time-dependent source, the concentration at a downgradient location at a given time T can be estimated by the following procedure. First the continuous function of the time-dependent source *concentration [Eq. (4), (5), or (6)] is approximated by a series of step impulses which simplifies the* solution and is also more conservative than the original function as shown in Figure 2.

FIGURE 2: CONCEPTUAL MODEL OF THE SOURCE CONCENTRATION



The concentration at x feet downgradient of the source at time T can therefore be estimated by superposition of constant source solutions [Eq. (7)] for all impulses prior to time T as follows:

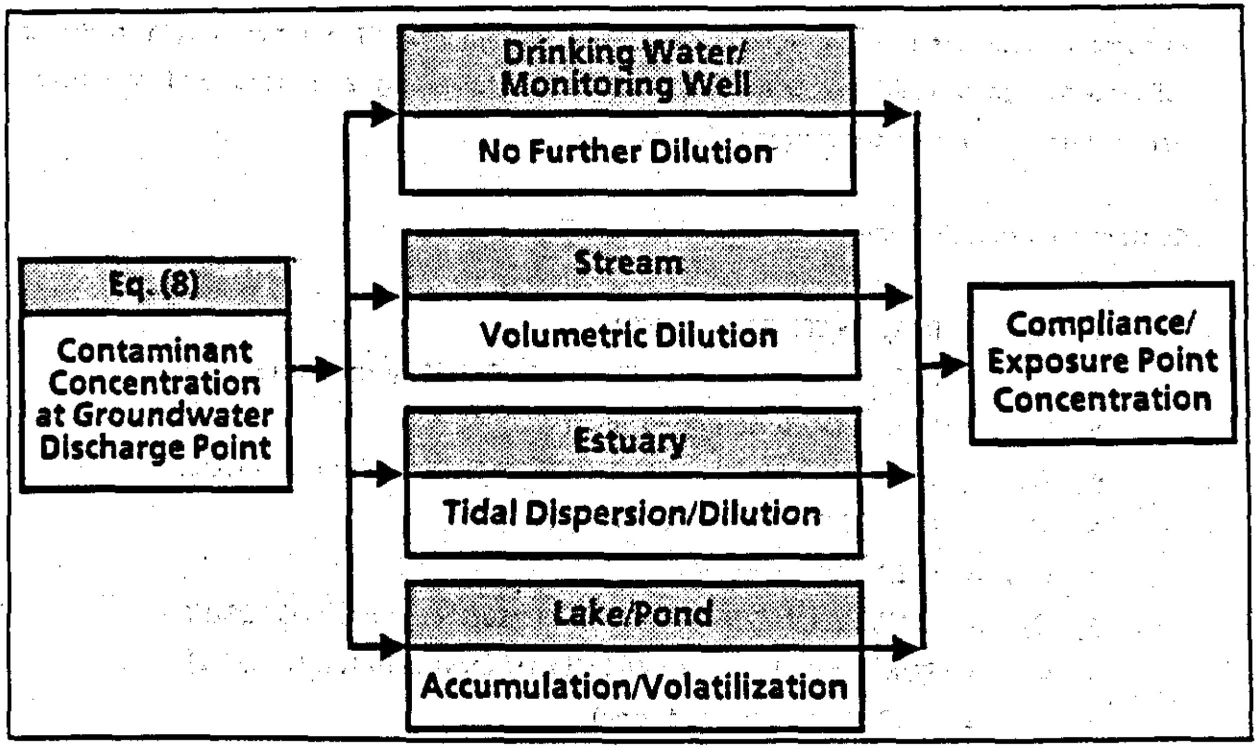
$$
\begin{aligned}
C(x,T) &= \sum_{i=0}^{n} \left[C\left(x, T-t_i, S_i\right) - C\left(x, T-t_i-\Delta t_i, S_i\right) \right] \\
&= C\left(x, T-t_o, S_o\right) - C\left(x, T-t_o-\Delta t_o, S_o\right) + \\
&\quad C\left(x, T-t_1, S_1\right) - C\left(x, T-t_1-\Delta t_1, S_1\right) + \ldots + \\
&\quad C\left(x, T-t_n, S_n\right) - C\left(x, T-t_n-\Delta t_n, S_n\right) \qquad (8)
\end{aligned}
$$

Where: S_i is the source concentration of the i^{th} impulse; t_i is the starting time of the i^{th} impulse; Δt_i is the time interval for the i^{th} impulse; $T-t_n-\Delta t_n = 0$; and C (x, T) is the combined effects of n + 1 impulses. In the preceding equation, C (x, t, s) [i.e., Eq. (7)] is the concentration at x caused by a constant source with concentration S for a duration of t. Therefore, C(x,t,s) needs to be applied twice to determine each single impulse's net lasting effect at time T. This approach is similar to the procedure used in the Expert ROKEY Computer System (McClymont and Schivarte, 1987). The Expert ROKEY Computer System is a saturated-zone contaminant fate and transport model with an expert system that assists the user to estimate necessary hydrogeological and chemical parameters for the model. The source loading from the unsaturated zone needs to be specified by the user, which is considered a weak point of the model.

Discharge/Exposure Module

Analytical models for estimating contaminant concentrations at four different types of exposure points were developed and incorporated into the spreadsheet. They include direct use of groundwater, as well as groundwater discharge into a flowing stream, a closed lake/pond, or an estuary. As shown in Figure 3, the discharge/exposure module of the model estimates the dilution caused by mixing contaminated groundwater with background surface water and, thus, the contaminant concentration at the compliance/exposure point.

FIGURE 3: TYPES OF EXPOSURE POINT AND ASSOCIATED ATTENUATION IMPLEMENTED



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Although the basic equations for estimating dilution factors (Thomann and Mueller, 1987) are simple, it is usually necessary to modify or combine several equations, based on the site-specific situation, to obtain the final results. Therefore, the details of development of the dilution factor used in this module for the exposure scenarios included in Figure 3 will not be described in this paper.

MODEL PARAMETER ESTIMATION

Table 1 is an example of the modeling result using the developed model under direct use of the groundwater scenario. Values of input parameters that must be determined by the user (or other modeling tools) externally are circled. These parameters can be estimated based on site-specific conditions such as the extent of source contamination (i.e., LENGTH and WIDTH); soil characteristics (i.e., POROSITY, DENSITY, and FOC); hydrogeological information (i.e., GW VEL., DISTANCE, DISPERSIVITY, and THICKNESS); water budget simulation using HELP (Hydrologic Evaluation of Landfill Performance) Model (i.e., INFILT. and SATURATION); contaminant concentration (i.e., CWAO); and background contamination (i.e., C and CU). As one of the user-specified input values, the upgradient groundwater flow velocity (GW VEL.) can be estimated by the following equation:

$$\text{GW VEL.} = \text{average GW gradient} \times \text{average hydraulic conductivity/POROSITY} \tag{9}$$

The longitudinal dispersivity (Ax) is usually taken as 1/10 of the DISTANCE, where the transverse dispersivity (Ay) is equal to 1/3 of the longitudinal value. The rest of the parameters in Table 1, as well as *some parameters used in Figure 1 and Equations (4) and (7) but not shown in the table, are* calculated automatically by the model, using the following equations and the user-specified parameters with proper conversions of units.

Contaminant source model parameters shown in Figure 1:

- Q_1 = INFILT. x LENGTH x WIDTH
- V_w = POROSITY x LENGTH x WIDTH x THICKNESS (unsaturated zone)
- K_d = KOC x FOC (unsaturated zone)
- W_s = DENSITY x LENGTH x WIDTH x THICKNESS (unsaturated zone)
- M = C_w x (SATURATION x V_w + K_d x W_s)
- C_{w0} = CLEAN-UP GOAL / K_d
- Q_2 = GW VEL. x WIDTH x THICKNESS (saturated zone) x POROSITY
- V_{wa} = POROSITY x LENGTH x WIDTH x THICKNESS (saturated zone)
- K_{ds} = KOC x FOC (saturated zone)

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TABLE 1: EXAMPLE OF MODEL OUTPUT

```
Copyright 1991                  HALLIBURTON NUS ENVIRONMENTAL CORPORATION
                        SCREENING-LEVEL MULTIMEDIA CONTAMINANT FATE AND TRANSPORT MODEL
                    EXPOSURE SCENARIO #1: TIME VARYING SOURCE AND DIRECT USE OF GROUNDWATER

SITE:              X CHEMICAL                  CONTAMINANT:      BENZENE
                   SUPERFUND SITE                KOC (L/KG):       65.00    ALLOWABLE EXPOSURE CONC. (UG/L):
                                                 HALF LIFE (YRS):                                      5.0
                                                  UNSATURATED:      5.00    UNSATURATED ZONE SOIL
INVESTGATOR:       J. D. CHIOU                    SATURATED:        5.00    CLEAN UP GOAL (MG/KG):      .024
DATE:              10-21-91                       D.G. PLUME:       5.00

     SOURCE AREA:          UNSATURATED ZONE          SATURATED ZONE            DOWN GRADIENT AREA / EXPOSURE POINT

LENGTH (FT):       720 | FOC (KG/KG):      .001 | FOC (KG/KG):     .0010 | Q3 (L/DAY):       1462.40  FOC (KG/KG):    .001
WIDTH (FT):        160 | KD (L/KG):        .065 | KD (L/KG):        .065 | GW V.(FT/YR):       48.09  KD (L/KG):      .065
                       | SATURATION:         .4 | SATURATION:       1.00 | DISTANCE (FT):     120.00  RETARDATION:   1.316
POROSITY:          .35 | THICKNESS (FT):   7.00 | THICKNESS (FT):   7.00 | POROSITY:             .35
DENSITY (G/CM3):   1.7 | DECAY (1/DAY):  3.8e-4 | DECAY (1/DAY): 3.798e-4 | DECAY (1/YR):   1.386e-1    ACCEPT
                       | CWO (PPB):      4.65e4 | CWAO (PPB):        1e2 | DISPERSIVITY:               THE GOAL!
INFILT. (FT/YR): .0275 | C (PPB):             0 | CU (PPB):            0 |   Ax (FT):         112.00
GW VEL. (FT/YR):    40 | Q1 (L/DAY):     245.80 | Q2 (L/DAY):    1216.60 |   Ay (FT):          37.30

                         | UNSATURATED ZONE CONC. | SATURATED ZONE CONC. | EXPOSURE POINT CONC. | 70-YEAR AVERAGE
ELAPSED TIME - YRS  DAYS |        (UG/L)          |        (UG/L)        |        (UG/L)        |     (UG/L)

                 0     0 |       46523.08         |        100.00        |        .0000         |
                 2   730 |       34168.82         |        631.62        |        .0000         |
                 4  1460 |       25095.25         |        846.07        |        .0000         |
                 6  2190 |       18431.17         |        883.06        |        .0003         |
                 8  2920 |       13536.75         |        827.72        |        .0069         |
                10  3650 |        9942.05         |        730.59        |        .0600         |
                12  4380 |        7301.93         |        620.57        |        .2621         |
                14  5110 |        5362.89         |        513.28        |        .7179         |
                16  5840 |        3938.77         |        416.36        |       1.4400         |
                18  6570 |        2892.82         |        332.75        |       2.3340         |
                20  7300 |        2124.63         |        262.85        |       3.2480         |
                22  8030 |        1560.43         |        205.69        |       4.0400         |
                24  8760 |        1146.06         |        159.72        |       4.6140         |
                26  9490 |         841.72         |        123.23        |       4.9310         |
                28 10220 |         618.20         |         94.56        |       4.9990         |
                30 10950 |         454.04         |         72.23        |       4.8560         |
                32 11680 |         333.47         |         54.95        |       4.5540         |
                34 12410 |         244.91         |         41.66        |       4.1490         |
                36 13140 |         179.88         |         31.49        |       3.6870         |
                38 13870 |         132.11         |         23.74        |       3.2090         |
                40 14600 |          97.03         |         17.85        |       2.7430         |
                42 15330 |          71.26         |         13.40        |       2.3090         |
                44 16060 |          52.34         |         10.04        |       1.9180         |
                46 16790 |          38.44         |          7.50        |       1.5740         |
                48 17520 |          28.23         |          5.60        |       1.2780         |
                50 18250 |          20.74         |          4.18        |       1.0290         |
                52 18980 |          15.23         |          3.11        |        .8213         |
                54 19710 |          11.18         |          2.32        |        .6509         |
                56 20440 |           8.21         |          1.72        |        .5125         |
                58 21170 |           6.03         |          1.28        |        .4011         |
                60 21900 |           4.43         |           .95        |        .3123         |
                62 22630 |           3.25         |           .70        |        .2421         |
                64 23360 |           2.39         |           .52        |        .1868         |
                66 24090 |           1.76         |           .39        |        .1436         |
                68 24820 |           1.29         |           .29        |        .1099         |
                70 25550 |            .95         |           .21        |        .0839         |     1.7062
                72 26280 |            .70         |           .16        |        .0639         |     1.7080
                74 27010 |            .51         |           .12        |        .0485         |     1.7093
                76 27740 |            .38         |           .08        |        .0367         |     1.7103
                78 28470 |            .28         |           .06        |        .0277         |     1.7111
                80 29200 |            .20         |           .05        |        .0209         |     1.7115
                82 29930 |            .15         |           .03        |        .0157         |     1.7103
                84 30660 |            .11         |           .03        |        .0118         |     1.7033
                86 31390 |            .08         |           .02        |        .0089         |     1.6836
                88 32120 |            .06         |           .01        |        .0066         |     1.6438
                90 32850 |            .04         |           .01        |        .0050         |     1.5791
                92 33580 |            .03         |           .01        |        .0037         |     1.4890
                94 34310 |            .02         |           .01        |        .0028         |     1.3769
                96 35040 |            .02         |           .00        |        .0021         |     1.2487
                98 35770 |            .01         |           .00        |        .0015         |     1.1118
               100 36500 |            .01         |           .00        |        .0011         |      .9730

        MAXIMUM:         |       46523.08         |        883.06        |        4.999         |     1.7115
```

- W_{sa} = DENSITY x LENGTH x WIDTH x THICKNESS (saturated zone)
- M_a = C_{wa} x (V_{wa} + K_{ds} x W_{sa})
- Q_3 = $Q_1 + Q_2$
- DECAY RATE = -ln(0.5) / HALF LIFE (zone specific)

Downgradient solute transport module parameters used in Equation (7):

- RETARDATION = 1 + DENSITY x Kds / POROSITY
- C_0 = S_0, S_1, S_2, or S_3 as shown in Figure 2.
- x = DISTANCE (distance from the downgradient edge of the source area to the exposure point)
- GW V. = Q_3/ (POROSITY x WIDTH x THICKNESS)
- V = GW V. / RETARDATION
- Y = WIDTH
- Dx = V x DISPERSIVITY (Ax) = V x 0.1 x DISTANCE
- Dy = V x DISPERSIVITY (Ay) = Dx / 3
- DECAY RATE = -ln(0.5) / HALF LIFE (zone specific)

Although the contaminant source module assumes a homogeneous unsaturated zone, the use of the HELP Model to determine the infiltration rate and the degree of saturation externally can allow the layered structure of the unsaturated zone to be considered, if necessary. The percolation from the bottom layer and the weighted average of saturations in each layer estimated by the HELP Model can be used as the infiltration rate and the unsaturated zone saturation rate in this model. The thickness of the saturated zone, which represents the vertical extent of contamination in the model, is usually derived from the minimum of the following three possible values:

- The thickness of the entire saturated zone.
- The lowest position of detected contaminants of concern.
- The mixing zone depth calculated by the following equation (Salhotra et al., 1990):

$$H = B\left[1 - \exp\left(-V_{zo}L/(BV_x)\right)\right] + \left(2\,\alpha_v L\right)^{1/2} \tag{10}$$

where: H is the mixing zone depth (ft); B is the total saturated zone thickness (ft); V_{zo} is the vertical seepage velocity (ft/yr); L is the length of the source area (ft); V_x is the horizontal seepage velocity (ft/yr); and α_v is the vertical dispersivity (ft).

With all the parameters determined (either direct inputs or calculated internally by the model), Eqs. (2), (4) [or (5) and (6)], and (8) are then used in the model to calculate C_w, C_{wa}, and C, respectively.

APPLICATION

Following are three case studies describing instances in which the developed model has been utilized to select cleanup goals.

Cleanup Goal Selection - EPA Superfund Site

The model is being used to determine soil cleanup goals at an EPA Superfund site in Virginia. At the site, soil media in localized areas is contaminated within the saturated and unsaturated zones. The model is being run under an interactive approach to determine the maximum unsaturated zone soil concentrations that will allow the Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs) to be attained at the downgradient edge of the saturated zone beneath the site.

For this particular application, existing contamination is being input from actual chemical analysis data from the saturated zone only. Infiltration rate (Q_1) is estimated using the HELP Model, based on local meteorological conditions. Soil mechanical and hydraulic properties, which were determined from samples collected from the site, are used as model inputs to simulate contaminant washout from the unsaturated zone and contaminant transport in the saturated zone. The model will be run for 19 different compounds and for varying contaminant concentration levels. From the results of the modeling efforts, a variety of potential cleanup conditions will be established, and remedial alternatives for each condition will be developed for EPA review.

Cleanup Goal Selection - DOD Facility

This model was used to develop remedial goals for contaminated areas in a DOD facility in Texas according to specific remediation objectives. Figure 4 shows the contaminated zone in the facility and contaminants of concern. The overall remediation objective used to establish the remediation goals was to protect human health and the environment and achieve Applicable, or Relevant and Appropriate Requirements (ARARs). The goals were established based on EPA and TWC (Texas Water Committee) "acceptable" risk levels and assumptions regarding ultimate land uses and contaminant exposure pathways, based on existing site information, EPA guidance, regulatory requirements, and professional judgment.

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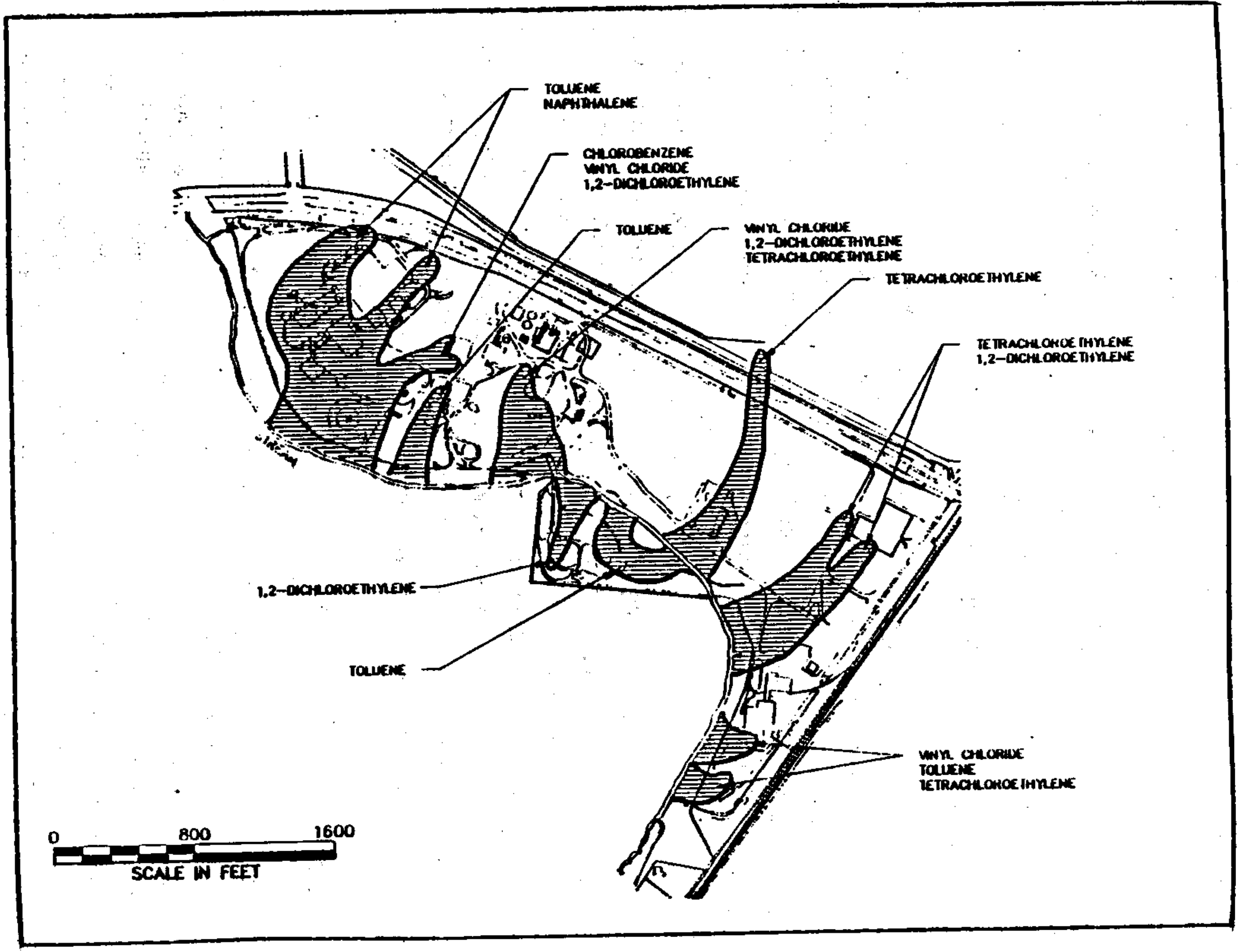
FIGURE 4 SITE MAP AND ROUTE OF CONTAMINANT MIGRATION



Leachate generation, dilution in the aquifer beneath the sites, and downgradient transport, including hydrodynamic dispersion and sorption, were considered to determine soil concentrations that correspond to the groundwater remediation goals at the point of exposure (i.e., the base boundary or a stream flowing through the facility as appropriate). Although many of the soil contaminants at the various sites are subject to environmental degradation via hydrolysis or microbial degradation, these decay mechanisms were not considered. Model input parameters were determined based on available site information and on professional judgment if site-specific values were not available.

Two other models were also used to determine certain input parameters for this model. The groundwater velocity for each site was determined from a calibrated, particle-tracking, groundwater model completed in support of a remedial investigation study at the facility. This model was used to delineate flow paths and to predict the travel time of a particle from the various sources to the stream or other exposure points. The lengths of the flow paths from each site (or discrete site-specific sources) were divided by the simulated travel times to determine an interstitial pore velocity. The annual recharge (Q_1) for each site was determined using the HELP Model.

Soil remediation goals were determined based on the assumption that the groundwater was either uncontaminated or that it would be restored to acceptable concentrations. Therefore, for model execution, C (the concentration in infiltrating precipitation), C_u (the concentration in upgradient groundwater, and C_{wa} (the concentration in groundwater beneath the site) were all set equal to zero at time $t = 0$. Furthermore, the concentration in infiltrating precipitation and the upgradient concentration remain at zero throughout the model execution. The saturated zone groundwater concentration is contingent upon loading from the source and fluctuates as a function of time.

Once the input parameters had been established for each site and contaminant, an interactive, trial-and-error approach was used to determine acceptable source concentrations. A soil concentration was entered and adjusted until the maximum downgradient concentration at the point of exposure did not exceed the groundwater remediation goal. The model suggests a new goal whenever the criteria is exceeded or when a higher goal may be acceptable.

ACL Demonstration - Major Chemical Manufacturer

In an ACL (Alternate Concentration Limit) demonstration study, exposure to groundwater contaminants that have discharged to surface waters in the vicinity of a major chemical manufacturer's facility is considered the only realistic potential route of contaminant exposure. Incidental ingestion of surface water and ingestion of aquatic organisms that have accumulated discharged groundwater contaminants are considered the exposure routes of concern for human receptors. These points of exposure and exposure routes are considered to develop Maximum Allowable Exposure Concentrations (MAECs). ACLs are then determined via contaminant fate and transport analysis so that the MAECs are not exceeded.

Several unsuccessful attempts to develop a complex, numerical, groundwater flow and transport simulation of the facility have been completed to date by two other consultant firms. In view of the complexity of the site hydrologic conditions, HALLIBURTON NUS deemed it more appropriate to employ simplified analytical solutions to simulate contaminant migration. Nevertheless, these previous studies provided values for most of the required parameters in this more efficient modeling approach.

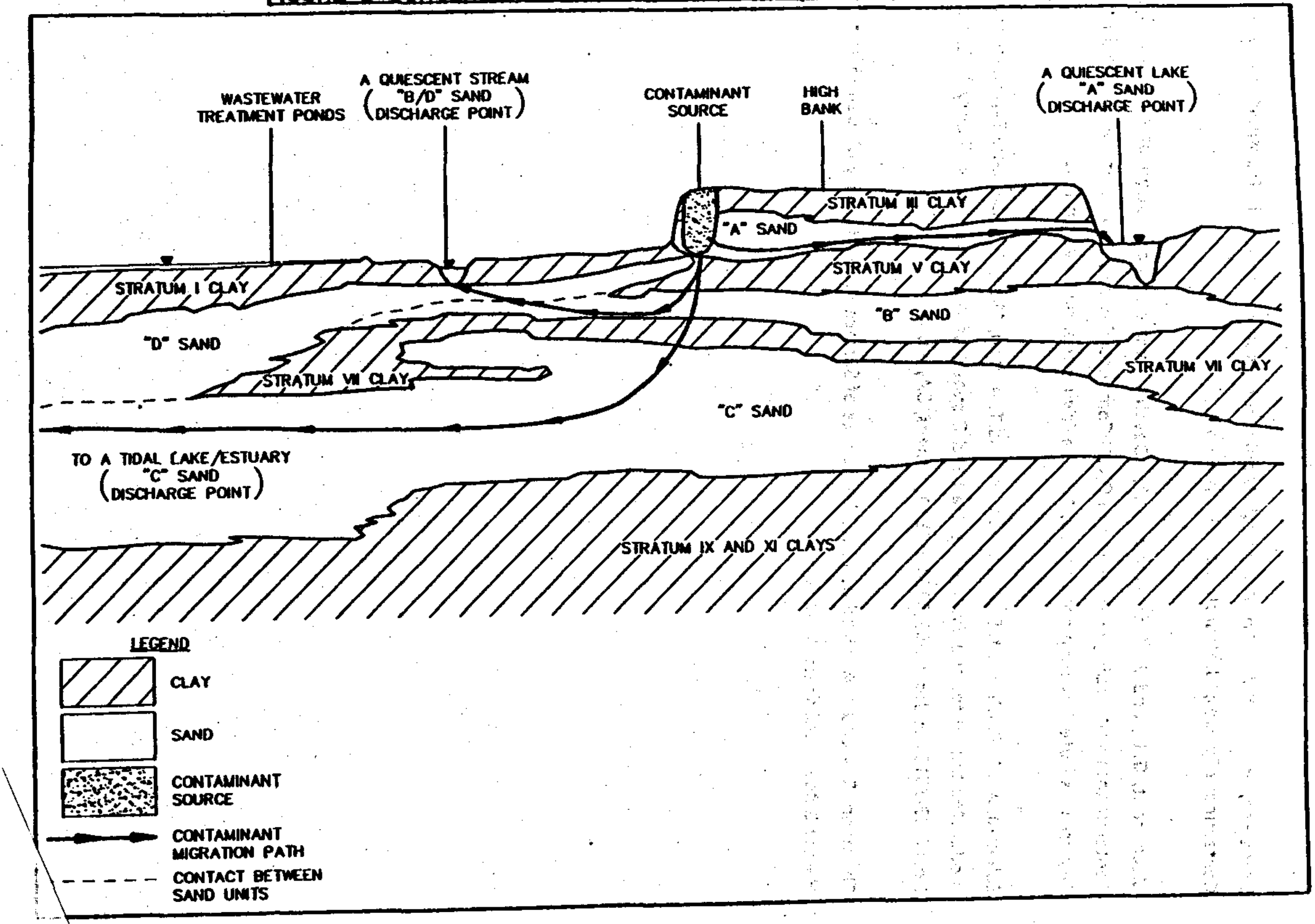
Figure 5 depicts the conceptualized cross section of the study site. Two of the three surface water bodies in the vicinity of the site were treated as quiescent bodies with virtually no dilution potential. An accumulation/volatilization model was developed and incorporated into the spreadsheet to simulate the exposure point concentrations in these two surface water bodies. A tidal dilution model was developed for the third surface water body to estimate chemical concentration distribution in the tidal lake. Based on groundwater discharge rate, chemical concentrations in the groundwater, and a tidal amplitude, the model can be used to estimate the steady-state daily maximum or average chemical concentrations in the lake. Therefore, the dilution factor between groundwater and each model segment resulting from mixing and tidal movement was determined.

ACLs were eventually developed for each of the chemicals of concern using the developed model. The observed concentrations of some chemicals exceed the ACLs derived based on the exposure pathways of concern. The fact that some of the protective ACLs have been exceeded indicates that containment efforts (interceptor trenches) are necessary and were implemented in a timely manner. Continued interception of groundwater plume is planned until acceptable concentrations (ACLs) are attained at the unit boundary.

SUMMARY

Several advantages of a spreadsheet-based model over a traditional "pre/post-processor and main program approach" are apparent. Because the simulation is implemented by a spreadsheet, the model input and output data are contained in the same file. It is extremely easy for the user to change values of any specific input parameters, and the effects of various input values can be seen on the computer screen. The graphical and statistical capability provided by the spreadsheet makes presentation of the model results very efficient and flexible.

FIGURE 5 CONCEPTUAL MODEL OF THE SITE (ACL DEMONSTRATION)



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APPENDIX B

CHEMICAL SPECIFIC PARAMETER DERIVATIONS AND SAMPLE CALCULATIONS

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NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA ARCS 3	FILE NO.: 2752	BY: J. Hubbard	PAGE 1 OF 1
SUBJECT: Sample-biodegrad. coeff. (Greenwood) from half-life		CHECKED BY:	DATE: 8/29/91

Calculations and Derivations - Table 1-2A

Objective: Calculate a biodegradation coefficient

Approach: Use half-life, which is available in literature

Relevant Equations:

$$t_{1/2} = 0.693/k \quad \text{(Dragun, 1988)}$$

where $t_{1/2}$ = half-life for biodegradation

k = biodegradation coefficient (rate constant)

Assumptions: N/A

Sample Calculation:

Chlorobenzene $t_{1/2} = 37$ days (Dragun, 1988)

$$37\,d = \frac{.693}{k}$$

$$k = \frac{.693}{37\,d} = .0187\ \text{day}^{-1}$$

$$\frac{.0187}{\text{day}} \times \frac{365\ \text{day}}{\text{yr}} = 6.8\ \text{yr}^{-1}$$

References:

see Dragun, 1988, Ref. for Table 2A

ORIGINAL
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NUS CORPORATION AND SUBSIDIARIES — STANDARD CALCULATION SHEET

CLIENT: EPA ARCS 3	FILE NO.: 2752	BY: J. Hubbard	PAGE 1 OF 2
SUBJECT: Sample biodegrad. coeff. (Greenwood) from rate-time info.		CHECKED BY:	DATE: 8/29/91

Calculations and Derivations - Table 1,2,3

Objective: Calculate a biodegradation coefficient

Approach: Use information from literature (percent degradation and time)

Relevant Equations:

$$K = \frac{2.303}{t} \log\left(\frac{a}{a-x}\right) \quad \text{(Dragun, 1988)}$$

where k = biodegradation coefficient (rate constant)
t = time
a = initial concentration
x = amount degraded in time t

Assumptions: If degradation is 100%, assume time t was required for all degradation, and the number of time periods of length t per year will be the rate constant, since the equation will not accept a-x=0
Let t include any lag time required for the reaction to start

Sample Calculations:

1) 2,4,6-trichlorophenol - anaerobic
$a = 1$
$x = .28$
$t = 80\text{ days}$ (HSDB, 1991 ~~Dragun, 1988~~)

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NUS CORPORATION AND SUBSIDIARIES | **STANDARD CALCULATION SHEET**

CLIENT: EPA ARCS 3	FILE NO.: 2752	BY: J. Hubbard	PAGE 2 OF 2
SUBJECT: Sample - biodegrad. coeff. (Greenwood) from rate-time info.		CHECKED BY:	DATE: 8/29/91

$$K = \frac{2.303}{30d} \log \frac{1}{1-.28}$$

$$K = .004 \text{ days}^{-1}$$

$$\frac{.004}{\text{days}} \times \frac{365 \text{ days}}{\text{yr}} = 1.5 \text{ yr}^{-1}$$

(2) acetone - anaerobic

100% degradation in 4 days + 5 day lag

$$t = 9 \text{ days}$$

$$\frac{1}{9 \text{ days}} \times \frac{365 \text{ days}}{\text{yr}} = 40 \text{ yr}^{-1}$$

References:

see Dragun, 1988 and HSDB, 1991, Ref. for Table ~~2A~~ 1-2

NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA ARCS 3	FILE NO.: 2752	BY: J. Hubbard	PAGE 1 OF 1
SUBJECT: Greenwood / Calc. of Koc		CHECKED BY:	DATE: 8/21/91

Calculations and Derivations - Table 1-1

(a)

Objective: Calculate Koc for tetrahydrofuran (THF)

Approach: Base Koc on log Kow, which is available for THF

Relevant Equations:

$$\log K_{oc} = 0.544 \log K_{ow} + 1.377$$

where K_{oc} = organic carbon adsorption coefficient

K_{ow} = octanol-water partition coefficient

(Kenaga and Goring, 1978)

Assumptions: N/A

Sample Calculation

$\log K_{ow} = 0.46$ (Treiner and Chattopadhyay, 1986)

$$\log K_{oc} = (0.544)(0.46) + 1.377$$

$$\log K_{oc} = 1.62724$$

$$K_{oc} = \text{inv} \log 1.62724 = 42.39$$

References:

see Ref. list following; Ref. 10 and 14 for Table 1

(Red)

NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA ARCS 3	FILE NO.: 2752	BY: J. Hubbard	PAGE 1 OF 1
SUBJECT: Greenwood/calc. of Koc		CHECKED BY:	DATE: 8/21/91

Calculations and Derivations - Table 1-1

(b)
Objective: Calculate Koc for 2,4,6-trichlorophenol (TCP)
Approach: Base Koc on log Kow, which is available for TCP

Relevant Equation:

$$\log K_{oc} = 1.00 \log K_{ow} - 0.21$$

where K_{oc} = organic carbon adsorption coefficient
K_{ow} = octanol-water partition coefficient
(Karickhoff and Brown, 1978)

Assumptions: This equation is especially appropriate for aromatics, possibly chlorinated

Sample Calculation:

$\log K_{ow} = 3.69$ (Leo et. al., 1971)

$$\log K_{oc} = (1.00)(3.69) - 0.21$$

$$\log K_{oc} = 3.48$$

$$K_{oc} = \text{inv} \log 3.48 \approx 3020$$

References:
see Ref. list following, Ref. 11 and 13 for Table 1

OR

NUS CORPORATION AND SUBSIDIARIES — **STANDARD CALCULATION SHEET**

CLIENT: EPA ARCS 3	FILE NO.: 2752	BY: J. Hubbard	PAGE 1 OF 2
SUBJECT: Greenwood / Calc. of K_{Henry}		CHECKED BY:	DATE: 8/21/91

Calculations and Derivations - Table 1-1

(c)

Objective: Calculate the Henry's Law Constant (K_{Henry}) for naphthaleneacetic acid (NAA).

Approach: Use vapor pressure and solubility, which are available for NAA.

Relevant Equation:

$$H = vp / sol$$ (Lyman et. al., 1990)

where $H = K_{Henry}$ (atm/mol/m^3)
vp = vapor pressure (atm)
sol = solubility in water (mol/m^3)

Assumptions: Use data for 1-NAA

Sample Calculation:

vp = 2.01×10^{-6} torr @ 25 C (HSDB, 8/5/91)
sol = 0.042 g / 100 g water @ 20 C (HSDB, 8/19/91)

$$sol = \frac{0.042 \text{ g NAA}}{100 \text{ g } H_2O} \times \frac{1 \text{ mol NAA}}{186.21 \text{ g NAA}} \times \frac{10^6 \text{ cm}^3 H_2O}{1 \text{ m}^3 H_2O} \times \frac{1 \text{ mL } H_2O}{1 \text{ cm}^3 H_2O} \times \frac{1 \text{ g } H_2O}{1 \text{ mL } H_2O}$$

$$= 2.25 \text{ mol/m}^3$$

$$vp = 2.01 \times 10^{-6} \text{ torr} \times \frac{\text{atm}}{760 \text{ torr}} = 2.6 \times 10^{-9} \text{ atm}$$

$$H = vp/sol = \frac{2.6 \times 10^{-9} \text{ atm}}{2.25 \text{ mol/m}^3} = 1.2 \times 10^{-9} \frac{\text{atm}}{\text{mol/m}^3}$$

ORIGINAL
(Red)

NUS CORPORATION AND SUBSIDIARIES — **STANDARD CALCULATION SHEET**

CLIENT: EPA ARCS 3	FILE NO.: 2752	BY: J. Hubbard	PAGE 2 OF 2
SUBJECT: Greenwood / Calc. of K Henry		CHECKED BY:	DATE: 8/21/91

References:

Ref. list, Ref. 9 for Table 1-1

National Library of Medicine. Hazardous Substances DataBank (HSDB). Record for 1-naphthaleneacetic acid, August 19, 1991.

Lyman, W.J., W.F. Reehl, and D.H. Rosenblatt. ~~et al~~, 1990. Handbook of Chemical Property Estimation Methods. McGraw-Hill Book Co., New York, NY.

ORIGINAL
(Red)

Greenwood Chemical Statistical Summary
of TOC and Foc Values — Unsaturated Zone Samples

SAMPLE NUMBER	SAMPLE DEPTH, ft	TOC, ug/g	LN TOC	location	Foc
A101	1	5,970	8.649371	unsaturated	0.00597
A101	5	26,000	10.16585	unsaturated	0.026
A101	10	760	6.633318	unsaturated	0.00076
A101	15	427	6.056784	unsaturated	0.000427
A101	20	1,390	7.237059	unsaturated	0.00139
A209	1	18,000	9.798127	unsaturated	0.018
A209	1d	10,600	9.268609	unsaturated	0.0106
A209	5	7,660	8.943767	unsaturated	0.00766
A209	10	3,960	8.283999	unsaturated	0.00396
BNE2	1	1,320	7.185387	unsaturated	0.00132
BNE2	5	1,210	7.098376	unsaturated	0.00121
BNE2	10	1,300	7.17012	unsaturated	0.0013
BNE2	10d	1,160	7.056175	unsaturated	0.00116
DHA1	1	25,100	10.13062	unsaturated	0.0251
DHA1	1d	17,000	9.740969	unsaturated	0.017
DHA1	5	4,930	8.503094	unsaturated	0.00493
DHA1	5d	3,050	8.022897	unsaturated	0.00305
DHA1	15	913	6.816736	unsaturated	0.000913
DHA1	15d	1,090	6.993933	unsaturated	0.00109
QCDHA1	20	1,130	7.029973	unsaturated	0.00113
QCDHA1	20d	1,040	6.946976	unsaturated	0.00104
DHA1	25	1,450	7.279319	unsaturated	0.00145
DHA2	1	8,010	8.988446	unsaturated	0.00801
DHA2	5	2,360	7.766417	unsaturated	0.00236
DHA2	10	3,390	8.128585	unsaturated	0.00339
DHA2	15	2,490	7.820038	unsaturated	0.00249
DHA2	20	3,340	8.113726	unsaturated	0.00334
DHA2	25	1,300	7.17012	unsaturated	0.0013
DHA3	1	7,990	8.985946	unsaturated	0.00799
DHA3	5	3,910	8.271293	unsaturated	0.00391
DHA3	10	3,880	8.26359	unsaturated	0.00388
DHA3	15	1.470	7.293018	unsaturated	0.00147
DHA3	20	1,490	7.306531	unsaturated	0.00149
DHA3	25	1,580	7.36518	unsaturated	0.00158
DHA4	1	3,870	8.26101	unsaturated	0.00387
DHA4	5	2,900	7.972466	unsaturated	0.0029
DHA4	10	1,110	7.012115	unsaturated	0.00111
DHA4	10d	1,240	7.122867	unsaturated	0.00124
DHA4	15	804	6.689599	unsaturated	0.000804
DHA4	20	1,160	7.056175	unsaturated	0.00116
QCDH4	20	726	6.58755	unsaturated	0.000726
NW01	1	11,600	9.35876	unsaturated	0.0116
NW01	5	15,600	9.655026	unsaturated	0.0156
NW01	5d	15,600	9.655026	unsaturated	0.0156
NW01	10	3,720	8.221479	unsaturated	0.00372
NW01	15	853	6.74876	unsaturated	0.000853
QCNW01	15	1.730	7.455877	unsaturated	0.00173
QCNW01	15d	1,660	7.414573	unsaturated	0.00166
NW01	20	1,570	7.358831	unsaturated	0.00157
NW01	25	590	6.380123	unsaturated	0.00059
no of data points		50	(x)		50
maximum value		26,000			0.026
average		4,848	7.87269		0.0048
minimum value		427			0.0004
standard deviation		6186.563	1.056549		0.00616656
geometric mean			4,586.35		0.00459
geometric std			6572.29		[illegible]

ORIGINAL
(Red)

Greenwood Chemical Statistical Summary of TOC and Foc Values – Saturated Zone Samples

SAMPLE NUMBER	SAMPLE DEPTH, ft	TOC, ug/g	LN TOC	location	Foc	LN Foc
A101	25	1,450	7.2793	saturated	0.00145	–6.53619
A101	30	630	6.4457	saturated	0.00063	–7.36979
A101	35	2,290	7.7363	saturated	0.00229	–6.0792
DHA1	30	939	6.8448	saturated	0.000939	–6.9707
DHA1	35	544	6.2989	saturated	0.000544	–7.51656
DHA2	30	1,660	7.4146	saturated	0.00166	–6.40094
DHA2	35	4,680	8.4511	saturated	0.00468	–5.36446
DHA2	40	2,360	7.7664	saturated	0.00236	–6.04909
DHA3	30	1,480	7.2998	saturated	0.00148	–6.51571
DHA3	35	2,250	7.7187	saturated	0.00225	–6.09683
DHA4	25	917	6.8211	saturated	0.000917	–6.9944
DHA4	30	1,130	7.0300	saturated	0.00113	–6.78554
NW01	30	668	6.5043	saturated	0.000668	–7.31122
NW01	35	467	6.1463	saturated	0.000467	–7.66918
NW01	35d	580	6.3630	saturated	0.00058	–7.45248

	TOC, ug/g	LN TOC	Foc	LN Foc
no of data points	15		15	
maximum value	4,680	8.4511	0.0047	–5.3645
average	1,470	7.0747	0.0015	–6.7408
minimum value	467	6.1463	0.0005	–7.6692
standard deviation	1068.374	0.6452	0.001068	0.6452
geometric mean		1455.07		0.00146
geometric std dev		1045.48		0.00105

C

ORIGINAL
(Red)

APPENDIX C

ARSENIC DISTRIBUTION COEFFICIENT CALCULATIONS

ORIGINAL
(Red)

NUS CORPORATION AND SUBSIDIARIES — **STANDARD CALCULATION SHEET**

CLIENT: US EPA	FILE NO.: 2752 GREENWOOD	BY: DAVE BRAYACK	PAGE 1 OF 1
SUBJECT: K_D from leachate test		CHECKED BY: Paul Alessio	DATE: 9/10/91

To DETERMINE K_D from leachate test and soil analytical results

ASSUMES YOU have
- soil concentration of chemical (mg/kg) initial
- leachate concentration of chemical (mg/l)

TCLP: USES 0.1 kg of soil diluted in 2 liters of liquid (water + reagent

MASS BALANCE
Eg, ARSENIC

Arsenic in soil = ARSENIC Remaining in soil after leachate test + Arsenic in leachate after extraction

$$0.1\ \text{kg soil}\ (\text{As, mg/kg}_{\text{initial}}) = 0.1\ \text{kg soil}\ (\text{As, mg/kg}_{f}) + 2\ \ell\ H_2O\ (\text{As mg}/\ell)_{\text{leachate}}$$

Solving for $As_f = 1.\ (\text{mg/kg initial}) - 20\ (\text{mg}/\ell)_{\text{leachate}}$

i. $= As_f$, mg/kg in soil after leach

$$K_D = \frac{As_f(\text{mg/kg})\ \text{in soil after leach}}{\cancel{As}_{\text{leachate}}(\text{mg}/\ell)\ \text{in leachate}} = \frac{\frac{\text{mg}}{\text{kg}}}{\frac{\text{mg}}{\ell}} = \frac{\ell}{\text{kg}}$$

Page 2 of 5

Greenwood Chemical Site Arsenic Kd calculations (Army Corps' data)
Unsaturated Zone Kd =8,258 (geo mean)

Sample Location	TCLP (mg/l)	initial soil (mg/kg)	final TCLP soil conc. (mg/kg)	Kd, L/Kg	log Kd L/Kg
BN01	0.1432	205	202.136	1,412	3.150
	0.0111	119	118.778	10,701	4.029
	0.0011 #	50.5	50.478	45,889	4.662
	0.0011 #	1.5	1.478	1,344	3.128
	0.0011 #	1.6	1.578	1,435	3.157
D	0.0011 #	1.5	1.478	1,344	3.128
L302	0.0011 #	12.3	12.278	11,162	4.048
	0.0011 #	8.3	8.278	7,525	3.877
	0.0011 #	4.2	4.178	3,798	3.580
L301	0.0011 #	88.2	88.178	80,162	4.904
	0.0011 #	3.7	3.678	3,344	3.524
L102	0.0011 #	67.1	67.078	60,980	4.785
	0.0011 #	63	62.978	57,253	4.758
	0.0011 #	19.6	19.578	17,798	4.250
	0.0011 #	9.4	9.378	8,525	3.931
	0.0011 #	6.4	6.378	5,798	3.763
BN06	0.0011 #	0.27	0.248	225	2.353
	0.0011 #	0.55	0.528	480	2.681
	0.0011 #	1.4	1.378	1,253	3.098
BN03	0.0011 #	3.7	3.678	3,344	3.524
D	0.0011 #	4.1	4.078	3,707	3.569
BN03	0.0011 #	196	195.978	178,162	5.251
	0.0011 #	7.6	7.578	6,889	3.838
	0.0011 #	95.6	95.578	86,889	4.939
	0.0011 #	7	6.978	6,344	3.802
BN08	0.0011 #	6.2	6.178	5,616	3.749
	0.0044	149	148.912	33,844	4.529
	0.0011 #	43.3	43.278	39,344	4.595
D	0.0011 #	12.2	12.178	11,071	4.044
D	0.0011 #	6.55	6.528	5,935	3.773
	0.0011 #	5.3	5.278	4,798	3.681
L305	0.003	2.8	2.74	913	2.961
D	0.00605	16.65	16.529	2,732	3.436
SA01	0.0011 #	3.4	3.378	3,071	3.487
	0.0011 #	2.1	2.078	1,889	3.276
	0.429	701	692.42	1,614	3.208
L101	0.0011 #	5.3	5.278	4,798	3.681
	0.003	31.6	31.54	10,513	4.022
	0.0011 #	1.5	1.478	1,344	3.128
D	0.0011 #	1.265	1.243	1,130	3.053
	0.0423	0.82	-0.026	-0.615	0.000
A401-D	0.0046	12.2	12.108	2,632	3.420
	0.0011 #	1.5	1.478	1,344	3.128
A402-D	0.4085	38.9	30.73	75	1.876
BNE1	0.136	110	107.28	789	2.897
	0.656	74.5	61.38	94	1.971
D	0.04075	83.75	82.935	2,035	3.309
BNE4	0.0067	13	12.866	1,920	3.283
SA03	0.0391	99.9	99.118	2,535	3.404
	1.14	1000	977.2	857	2.933
	0.731	538	523.38	716	2.855
A208-D	0.0011 #	6.6	6.578	5,980	3.777

ORIGINAL
(Red)

```
Greenwood Chemical Site    Arsenic Kd calculations (Army Corps' data)
Unsaturated Zone Kd =8,258 (geo mean)
                                         final
Sample                      initial      TCLP soil                    log Kd
Location    TCLP (mg/l)     soil (mg/kg) conc. (mg/kg) Kd, L/Kg         L/Kg
----------------------------------------------------------------------------
A209          0.0011 #         41.7        41.678       37,889      4.579
========    ========       ========     ========     ========    ========   ========
                                         average        14,929      3.543 =    3,493
                                         maximum       178,162      5.251 =  178,162
                                         minimum        -0.615          0 =        1
                                         standard dev.  30,231     0.8645     7.3205
                                                    arithmetic logorithmic antilog
                                                    values     values      log value

                                                      ========
                                         average =       8,258
                                         maximum =
                                         minimum =
                                         standard dev.  17,692
                                                    geometric
                                                    mean

      # = Analysis result was not detected; value indicated is
          1/2 of the detection limit.
```

0278

GEOMETRIC MEAN $\hat{\mu} = \exp\left(\bar{Y} + \frac{S_y^2}{2}\right)$

where $\bar{Y}$ and S_y^2 are the arithmetic mean and variance of the n transformed values $Y_i = \ln X_i$ (ref.: Gilbert, "Statistical Methods For Environmental Pollution Monitoring", Van Nostrand Reinhold Co., NY, NY 1987)

Page 4 of 5

ORIGINAL
(Red)

0270   13-Nov-91

Greenwood Chemical Site   Arsenic Kd calculations (Army Corps' data)
Saturated Zone Kd = 3,242 (geo mean)

Sample Location	TCLP (mg/l)	initial soil (mg/kg)	TCLP soil conc. (mg/kg)	Kd, L/Kg	log Kd L/Kg
BN01	0.0011 #	1.7	1.678	1,525	3.183
D	0.0011 #	2.06	2.038	1,853	3.268
L302	0.0011 #	6.2	6.178	5,616	3.749
L102-D	0.0011 #	4.65	4.628	4,207	3.624
D	0.0011 #	6.84	6.818	6,198	3.792
BN08-D	0.0011 #	2.31	2.288	2,080	3.318
	0.0011 #	1.6	1.578	1,435	3.157
BN03	0.0011 #	2.8	2.778	2,525	3.402
	0.0011 #	2.6	2.578	2,344	3.370
BN08	0.0011 #	13.5	13.478	12,253	4.088
L101	0.0011 #	1.8	1.778	1,616	3.209
			========	========	========
			average	3,787	3.469
			maximum	12,253	4.088
			minimum	1,435	0
			standard dev	3,114	
				arithmetic values	logorithmic values
			average	2,945	3,242
			maximum	12,253	
			minimum	1	
			standard dev		1,489
				antilog of log values	geometric mean

= Analysis result was not detected; value indicated is 1/2 of the detection limit.

0270

Page 5 of 5

TABLE 3

SUMMARY OF PHYSICO-CHEMICAL DATA

CHEMICAL	KOC	KD
Arsenic	NA	924 *
Benzene	83 (a)	8.3
Chlorobenzene	330 (b)	33
Cyanide	NA	1,700 *
Methylene chloride	8.8 (b)	1 (e)
Naphthalene acetic acid	940 (c)	94
Naphthylacetonitrile	940 (c)	94
PAH (Naphthalene)	940 (b)	94
Tetrachloroethene	364 (b)	36.4
Tetrahydrofuran	1.78 (d)	1 (e)
Trichloroethene	126 (b)	12.6

(a) Lyman et al. (1982)

(b) Mabey et al. (1982)

(c) Physico-chemical properties are assumed to be similar to naphthalene

(d) Value from MEDCHEM database as implemented in AUTOCHEM

(e) KD equivalent to water.

* = Site-specific value based on ASTM shake test data.

NA = Not available

KD = Koc x foc, where foc = 10% (EBASCO 1989)

APPENDIX B

CLEAN-UP GOALS FOR GREENWOOD CHEMICAL SITE

FINAL FOCUSED FEASIBILITY
STUDY REPORT - OPERABLE UNIT 1

GREENWOOD CHEMICAL SITE
ALBEMARLE COUNTY, VIRGINIA

AUGUST 1989

D

ORIGINAL
(Red)

APPENDIX D

TOTAL SEMIVOLATILE
TENTATIVELY IDENTIFIED COMPOUND (TIC)
ANALYTICAL DATA
(from REM III RI Report)

ORIGINAL

HALLIBURTON NUS Environmental Corporation and Subsidiaries

STANDARD CALCULATION SHEET

CLIENT: USEPA	FILE NO.: 2752.1047	BY: TJR	PAGE 1 OF 4
SUBJECT: Greenwood Chemical Sampling Summary		CHECKED BY: P	DATE: 1/15/92

Total Semivolatile TIC

AVERAGE IN CIRCLE USED TO CREATE ISO-CONCENTRATION MAP

Boring	Depth	Amount	
A-3	4-5.5	380.000	
	5.5-7	1400.000	927
	12-13.5	1001.400	
A-11	4.5-6.5	1179.700	
	6.5-8.5	4215.000	
	6.5-8.5	3345.000	1,472
	13.5-15	27.000	
	20-21.5	33.000	
	25-26.5	31.000	
B-11	7-8.5	359.6000	
	9-10.5	20.0000	270
	14-15.5	430.0000	
A-5	9-10.5	1001.4000	
	10.5-12.5	2600.0000	
	10.5-12.5	700.0000	876
	15.5-17	27.0000	
	18.5-20	52.0000	
B-8	3-4.5	800.000	
	5-6.5	450.000	463
	11-13	140.000	
A-4	4-5.5	51.6000	
	6-7.5	55.1000	41.6
	10-11.5	1[illegible].0000	
A-1	5-6.5	18.7000	

Boring	Depth	Amount	
A-8	3-4.5	102.50	
	5-6.5	16.20	46.1
	10-11.5	19.50	
B-10	4-5.5	199.00	
	9-10.5	125.00	135
	11-12.5	81.90	
B-12	4-4.5	110.5100	
	6-7.5	—	36.8
	11-12.5	—	
A-7	5-6.5	111.1000	
	7-8.5	210.0000	167
	12-13.5	180.0000	
B-9	7-8.5	23.000	
	7-8.5	—	
	10-11.5	0.400	10.2
	15-16.5	17.370	
A-9	6-7.5	1.7000	
A-10	0-1.5	138.000	
	4-5.	156.000	
	4-5	110.000	190
	8-9	356.000	
DH1-SO-01	0-2	7322,000	
DH1-[illegible]	[illegible]	[illegible]80.000	

HALLIBURTON NUS Environmental Corporation and Subsidiaries

STANDARD CALCULATION SHEET

CLIENT: USEPA	FILE NO.: 2752.1047	BY: TJR	PAGE 2 OF 4
SUBJECT: Greenwood Chemical Sampling Summary		CHECKED BY:	DATE: 1/15/92

Total Semivolatile TIC

Boring	Depth	Amount	
SS01-01	0-0.5	50.0000	25.4
-02	2-2.5	0.7000	
ED-SO-01	5-5.5	160.7000	
Test Pit 10	at 7	29960.0000	
SB01-01	4-6	42.4000	
-02	8-9.5	140.0000	648
-03	14-15.5	12.0000	
Test Pit 5	1.5-2	329.000	
SB03	4-6	4800.000	
	6-7.5	6200.000	3845
	10-11.5	535.000	
WDS 01	0-2	167.890	944
02	2-4	1721.000	
WDS01-SS	0-2	83.300	
BNEI	0-0.5	7860.0000	
	0-0.5	4962.000	4321
	0.5-1.0	142.0000	
B4	2-4	0.1900	
	4-6	-	
	8-9.5	0.7500	0.1933
	12-13.5	-	
	14-15.5	0.2200	
	16-17.5	-	

Boring	Depth	Amount	
FB01	2-3.6	132.00	154
	2-3.6	176.000	
FB04	0-2	27.740	
	0-2	24.500	26.12
FB05	0-2	5.360	
FB06	0-2	202.800	
	0-2	115.100	159.0
FB07	0-2	632.000	
FB02	2.3-3.5	54.000	53.0
	4.0-4.5	52.000	
FB08	0-1	412.900	
FB09	0-1	4.100	
FB10	0-1	197.000	
FB11	0-1	822.100	493
	2-4	165.200	
SS1101	NA	12780.000	
FB03	0-1	348.47	
FB12	0-1	1087.60	

ORIGINAL
(Red)

HALLIBURTON NUS Environmental Corporation and Subsidiaries | **STANDARD CALCULATION SHEET**

CLIENT: USEPA	FILE NO.: 2752.1047	BY: TJR	PAGE 3 OF 4
SUBJECT: Greenwood Chemical Sampling Summary		CHECKED BY:	DATE: 1/15/92

Total Semivolatile TIC

Boring	Depth (ft)	Amount
FB13	0-1	30.80
FB14	0-1	124.500
FB15	0-1	248.70 ⑯⑤.① 165.1
	2-4	81.50
PS01	0-1	9.1000
PS02	0-1	8.3200 11.2
	0-1	14.1000
PS03	0-1	13.8000
PS04	0-1	30.9000
PS05	0-1	12.1000
PS06	0-1	25.1000
SB5001	3-4	10700.0000
SS07	0-0.4	277.000 208
	0-0.4	138.000
SS06	0-0.5	219.700
SS03	0.3-0.8	0.490
SS04	0.5-1.2	2.900
SS05	0.5-1.2	0.220

Boring	Depth (ft)	Amount
UPGS0	0-2	-
	2-6	70.3000
CLNS0	0-1.5	4.000
	3-4.5	-
SD07-01	0-1	67.9400
LGSD01	0.5-1	12.4000
LGSD02	0.5-1	11.1000
LGSD03	1.0+	298.0000
LGSD04	1.0+	21.2000
LGSD05	1.0+	38.200
SD01	0.5-1	145.2000
SD03	0.5-1	44.1500
SD07	0.5-1	211.0000
SD08-01	0-2	13.3000
SD02	1.0+	2200
SD04	1.0+	2.8000
SD06	1.0+	2700.0000

HALLIBURTON NUS Environmental Corporation and Subsidiaries

STANDARD CALCULATION SHEET

CLIENT: USEPA	**FILE NO.:**	**BY:** TJR	**PAGE** 4 **OF** 9
SUBJECT: Greenwood Chemical Sampling Summary		**CHECKED BY:**	**DATE:** 1/15/92

Total Semivolatile TIC

Boring	Depth (ft)	Amount
SD05	1.0+	5.5000
SPS1	0-2	1.2000
SPS2	0-2	40000
SPS3	0-2	5.7000
EPS1	0-2	6.1000
EPS2	0-2	61.8000
EPS3	0-2	25.8000

No Data

7	SB1301
10	SB1302
03B	SDR-SD-01
06B	BFSS0
04	BAS0
05B	01B
8	02B
A2	
9	
A6	

ADJUSTMENT FOR BACKGROUND SEMI-VOLATILE TIC CONCENTRATIONS

27-Jan-92 Page 1 of 2

ORIGINAL
(Red)

Greenwood Chemical Site
Semi-volatile TIC Data from Ebasco REM III Investigation
Adjustment to account for background concentrations found in West Stream Upgradient
Average background semi volatile TICs = (43.3 + 6.9) 25.1

Boring	Average Conc. mg/kg	Average Back. Conc. mg/kg	Average Site Conc. mg/kg
A-3	927	25.1	901.9
A-11	1472	25.1	1,446.9
B-11	270	25.1	244.9
A-5	876	25.1	850.9
B-8	463	25.1	437.9
A-4	41.6	25.1	16.5
A-1	18.7	25.1	(6.4)
A-8	46.1	25.1	21.0
B-10	135	25.1	109.9
B-12	36.8	25.1	11.7
A-7	167	25.1	141.9
B-9	10.2	25.1	(14.9)
A-9	1.7	25.1	(23.4)
A-10	190	25.1	164.9
DH1-SO-01	7322	25.1	7,296.9
DH1-SO-02	9680	25.1	9,654.9
SS01	25.4	25.1	0.3
ED-SO-01	160.7	25.1	135.6
TP-10	28960	25.1	28,934.9
SB01-01	64.8	25.1	39.7
TP-5	328	25.1	302.9
SB-03	3845	25.1	3,819.9
WDS01 & 02	944	25.1	918.9
WDS01-SS	83.3	25.1	58.2
BNE1	4321	25.1	4,295.9
B-4	0.1933	25.1	(24.9)
FB-01	154	25.1	128.9
FB-04	26.12	25.1	1.0
FB-05	5.36	25.1	(19.7)
FB-06	159	25.1	133.9
FB-07	632	25.1	606.9
FB-02	53	25.1	27.9
FB-08	412.8	25.1	387.7
FB-09	4.1	25.1	(21.0)
FB-10	197	25.1	171.9
FB-11	493.7	25.1	468.6
SS1101	12780	25.1	12,754.9
FB-03	348.47	25.1	323.4
FB-12	1087.6	25.1	1,062.5
FB-13	30.8	25.1	5.7
FB-14	124.5	25.1	99.4
FB-15	165.1	25.1	140.0
PS01	9.1	25.1	(16.0)
PS02	11.2	25.1	(13.9)
PS03	13.8	25.1	(11.3)
PS04	30.9	25.1	5.8

ORIGINAL
(Red)

Greenwood Chemical Site
Semi-volatile TIC Data from Ebasco REM III Investigation
Adjustment to account for background concentrations found in West Stream Upgradient
Average background semi volatile TICs = (43.3 + 6.9)   25.1

Boring	Average Conc. mg/kg	Average Back. Conc. mg/kg	Average Site Conc. mg/kg
PS05	12.1	25.1	(13.0)
PS06	25.1	25.1	0.0
SB5001	10700	25.1	10,674.9
SS07	208	25.1	182.9
SS06	219.7	25.1	194.6
SS03	0.49	25.1	(24.6)
SS04	2.9	25.1	(22.2)
SS05	0.22	25.1	(24.9)
UPG50	70.3	25.1	45.2
CLNS0	4	25.1	(21.1)
SD07-01	67.94	25.1	42.8
LGSD01	12.4	25.1	(12.7)
LGSD02	11.1	25.1	(14.0)
LGSD03	298	25.1	272.9
LGSD04	21.2	25.1	(3.9)
LGSD05	31.2	25.1	6.1
SD01	145.2	25.1	120.1
SD03	44.15	25.1	19.1
SD07	211	25.1	185.9
SD08-01	13.3	25.1	(11.8)
SD02	2.2	25.1	(22.9)
SD04	2.8	25.1	(22.3)
SD06	2700	25.1	2,674.9
SD05	5.5	25.1	(19.6)
SPS1	1.2	25.1	(23.9)
SPS2	4	25.1	(21.1)
SPS3	5.7	25.1	(19.4)
EPS1	6.1	25.1	(19.0)
EPS2	61.8	25.1	36.7
EPS3	25.8	25.1	0.7

ORIGINAL
(Red)

E

[illegible]

ORIGINAL
(Red)

APPENDIX E

UNCONSOLIDATED MATERIAL MODEL DATA CALCULATIONS

(Red)

NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA	FILE NO.:	BY: D. YOST	PAGE 1 OF 3
SUBJECT: GREENWOOD % COMPOSITION CALCULATIONS		CHECKED BY: MKL	DATE: 11-11-91

SOURCE AREA

FILL - LAYER 1 0 - 1'

BORING NUMBER	CLAY %	SAND %	SILT %	GRAVEL %
L101	24.5	34.7	35.7	5.1
L203	41.4	24.2	34.4	0
L204	58.1	14.1	25.9	1.9
L305	36.9	58.2	36.9	4.9
AVG	40.2	32.8	33.2	2.98
* ROUNDED	30	35	30	5

REWORKED MATERIAL - LAYER 2 1 - 6'

BORING NUMBER	CLAY %	SAND %	SILT %	GRAVEL %
L101	19	40.9	20.6	19.5
L203	51.6	20.0	28.4	0
AVERAGE	35.3	30.5	24.5	9.75
ROUNDED	35	30	25	10

NATURAL OVERBURDEN 6-13' LAYER 3

BORING NUMBER	CLAY %	SAND %	SILT %	GRAVEL %
L203	66.7	12.6	20.7	0
L204	23.8	38.7	30.4	7.1
3N02	30	30.4	39.6	0
AVERAGE	40.2	27.2	30.2	2.4
ROUNDED	40	25	30	5

NOTE: THE PERCENTAGES SHOWN WERE TAKEN FROM "CLASSIFICATION TESTS ON SOIL" IN THE <u>TRANSMITTAL RECORD</u> SUPPLIED BY THE ARMY CORPS OF ENGINEERS, 11/1/90.

* BORING LOGS DESCRIBE LAYER 1 (0-1') AS SAND AND SILT. THE SIEVE ANALYSES SAMPLES FOR LAYER 1 WERE TAKEN FROM 0-2' AND DEPICT A HIGHER CLAY CONTENT THAN SAND AND SILT. THE HIGH CLAY CONTENT CAN BE ATTRIBUTED TO THE SAMPLE INTERVAL FROM 1-2' (BASED ON [illegible]) AND NOT FROM THE INTERVAL OF 0-1'. THE NUMBERS ~~IN TABLE 2-6~~ SHOWN WERE ROUNDED TO ACCOUNT FOR THE SAMPLE FROM THE 1-2' INTERVAL.

NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA	**FILE NO.:**	**BY:** D. YOST	**PAGE** 2 **OF** 3
SUBJECT: GREEN WOOD		**CHECKED BY:** MSC	**DATE:** 11-12-91

% COMPOSITION CALCULATIONS

SAPROLITE - LAYER 4 13-26'

BORING NUMBER	CLAY %	SAND %	SILT %	GRAVEL %
L101	20.8	18.8	60.4	0
ST01 (1st SAMPLE)	40	25	14	52
ST01 (2nd SAMPLE)	23	28	0	18
AVERAGE	27.9	23.9	24.8	23.3
ROUNDED	30	25	25	20

BORING LOGS WERE PROVIDED BY:

1) ARMY CORPS OF ENGINEERS
2) EBASCO SERVICES

SIEVE ANALYSIS WAS PROVIDED BY ARMY CORPS OF ENGINEERS

ORIGINAL
(R-M)

NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA	FILE NO.:	BY: D. YOST	PAGE 3 OF 3
SUBJECT: GREENWOOD % COMPOSITION CALCULATIONS		CHECKED BY: MJL	DATE: 11-12-91

DRUM STORAGE AREA

THERE WERE NO SIEVE ANALYSIS OF SAMPLES IN THE BORINGS OF THE DRUM STORAGE AREA. THEREFORE, THE ~~THE [illegible] OF THE TWO LAYERS WERE DERIVED FROM THE BORING LOGS~~ AND PERCENTAGES OF MATERIALS WERE ~~ALSO~~ ESTIMATED FROM THE DESCRIPTIONS ON THE BORING LOGS.

- Trace 0 - 10 percent
- Some 11 - 30 percent
- And 31 - 50 percent

NOTE: TAKEN FROM USCS AND BURMEISTER

FOR EXAMPLE: IF THE SOIL WAS DESCRIBED AS CLAY AND SILT SOME SAND TRACE GRAVEL, CLAY AND SILT WOULD BE ASSIGNED A JUDGEMENTAL PERCENTAGE BETWEEN 31-50%, SAND WOULD BE ASSIGNED A JUDGEMENTAL PERCENTAGE BETWEEN 11-30% AND GRAVEL ASSIGNED A ~~[illegible]~~ PERCENTAGE FROM 0-10%. PERCENTAGES THAT APPEAR ON THE TABLE ~~ONE~~ WERE JUDGEMENTAL APPROXIMATED* ~~[illegible]~~ FROM ALL OF THE BORING LOGS IN THE DRUM STORAGE AREA.

NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA	FILE NO.:	BY: D. YOST	PAGE 1 OF 2
SUBJECT: GREENWOOD		CHECKED BY: MSC	DATE: 11 13-91

MOISTURE CONTENT CALCULATIONS

DRUM STORAGE AREA

LAYER 1 0-7' Fill

BORING NUMBER	MOISTURE CONTENT (%)
DD01	25.9
AVG	25.9

LAYER 2 SAPROLITE 7-17'

BORING NUMBER	MOISTURE CONTENT (%)
DD01	33.1
AVG	33.1

SOURCE AREA

LAYER 1 - Fill (0-1') - . NO DATA

LAYER 2 REWORKED NATURAL MATERIAL 1-6

BORING NUMBER	MOISTURE CONTENT (%)
BN02	27.0
A101	31.9
A101	16.4
A201	29.5
DH01	29.2
A209	36.6
A209	32.4
A601	30.9
A601	29.5
DHA2	36.8
DHA2	33.9
BN04	32.1
AVERAGE	30.5

NUS 155A REVISED 0285

ORIGINAL
(Red)

NUS CORPORATION AND SUBSIDIARIES **STANDARD CALCULATION SHEET**

CLIENT: EPA	FILE NO.:	BY: D.Yost	PAGE 2 OF 2
SUBJECT: GREENWOOD		CHECKED BY: M&C	DATE: 11-13-91

MOISTURE CONTENT CALCULATIONS

SOURCE AREA (CONT.)

LAYER 3 NATURAL MATERIAL 6-13

BORING NUMBER	MOISTURE CONTENT (%)
BN02	25.3
A101	23.4
A201	29.2
A209	33.4
A601	22.2
SA03	28.4
BN04	37.8
BN04	23.6
BN04	27.1
BN04	31.5
BN04	32.6
A201	29.2
AVERAGE	28.6

LAYER 4 SAPROLITE 13-26

BORING NUMBER	MOISTURE CONTENT	BORING NUMBER	MOISTURE CONTENT
DH01	31.7	A601	34.9
DH01	36.1	A601	33.8
DH01	17.2	A601	38.0
DH01	34.6	DHA2	31.1
BN02	39.7	DHA2	33.7
BN02	37.0	DHA2	40.6
BN02	36.9	DHA2	33.4
BN02	36.6	DHA2	34.0
A101	33.5	SA03	28.5
A101	30.5	SA03	31.1
A101	32.4	AVERAGE	33.5
A101	32.6		

NOTE: THE MOISTURE CONTENT PERCENTAGES WERE T[illegible] BORING [illegible] LOGS.

NUS 155A REVISED 0285

MAXIMUM POTENTIOMETRIC SURFACE ELEVATIONS

ORIGINAL (Red)

TABLE 3-4
MONITORING WELL POTENTIOMETRIC DATA
GREENWOOD CHEMICAL SITE
REMEDIAL INVESTIGATION

WELL	TOC	5-14-87	6-22-87	7-15-87	2-12-88	1-7-89	3-2-89	4-6-89	7-18-89	10-10-89
MW-1	912.62	886.83	885.79	884.24	883.27	878.19	878.88	881.99	882.95	883.20
MW-2S	918.41	901.14	900.49	899.00	898.63	892.10	892.41	895.41	897.26	898.66
MW-2D	915.40	898.80	898.11	896.63	896.13	889.57	889.93	893.33	894.87	895.35
MW-3	908.00	890.33	889.70	888.09	887.07	881.50	882.09	885.43	886.44	888.50
MW-4	906.49	887.41	886.53	884.93	884.22	879.14	879.76	883.34	883.85	884.14
MW-5	884.00	873.17	871.17	869.99	881.54	868.32	869.89	870.77	x [illegible]	870.83
MW-6R	837.02	832.52	831.83	831.56	831.88	--	831.72	831.58	832.77	832.43
MW-7S	870.96	863.13	863.71	862.92	863.48	860.88	861.66	864.33	865.74	864.54
MW-7D	870.23	865.81	864.40	863.56	864.11	861.40	862.10	864.89	865.35	864.82
MW-9	911.86	894.66	893.54	891.71	893.83	886.07	887.71	890.17	892.25	894.86
MW-10	933.10	905.75	905.83	904.62	903.36	--		899.77	--	902.94
MW-10D	934.01	--	--	--	--	--	895.58	899.26	901.97	903.18
MW-11	934.71	913.28	912.13	910.69	910.98	903.88	903.75	907.21	908.45	909.59
MW-12S	884.77	871.60	869.85	868.73	869.42	865.81	866.76	868.39	871.61	870.23
MW-12D	885.03	--	876.26	875.09	877.61	872.49	874.49	876.21	876.41	874.53
MW-13	837.52	851.36	846.75	844.44	--	--	837.52	--	--	--
MW-14S	868.09	867.76	866.46	865.59	--	--	863.65	865.06	867.20	866.76
MW-14D	866.56	864.52	863.21	862.69	864.98	862.40	863.97	858.97	865.85	866.56
MW-16S	924.88	896.98	896.38	894.03	896.20	887.95	889.41	892.31	894.57	897.13
MW-16D	924.25	896.88	895.54	894.02	896.14	887.71	888.45	892.10	894.50	896.67
MW-17S	963.49	--	--	--	--	--	923.71	926.73	931.93	942.32
MW-17D	962.58	--	--	--	--	--	933.15	936.18	942.32	946.08
MW-18S	910.48	--	--	--	--	--	885.96	888.46	890.59	891.64
MW-18D1	909.36	--	--	--	--	--	885.62	887.15	890.44	891.56
MW-18D2	909.36	--	--	--	--	--	887.05	889.60	891.92	893.19
MW-19	897.30	--	--	--	--	--	875.19	872.19	873.22	873.21
MW-20S	865.57	--	--	--	--	--	855.92	857.37	860.89	859.07
MW-20D	865.10	--	--	--	--	--	860.62	859.19	861.65	860.61
MW-21S	851.04	--	--	--	--	--	842.21	846.94	844.07	843.12
MW-21D	848.78	--	--	--	--	--	844.67	841.56	844.87	843.69
OLD Well	871.90	--	--	--	--	--	--	866.51	--	866.32
Dug Well	896.40	--	--	--	--	--	884.19	889.22	--	--

NOTE: All data reported in feet above Mean Sea Level
(x = Top of casing elevation

*-

NOTE: MAXIMUM POTENTIOMETRIC SURFACE ELEVATIONS USED FOR

ORIGINAL
(Red)

F

APPENDIX F

INFILTRATION RATE CALCULATIONS (HELP MODEL)

TABLE 3-8
WEATHER DATA FOR THE PERIOD 1941-1979
CHARLOTTESVILLE, VA
GREENWOOD CHEMICAL SITE
REMEDIAL INVESTIGATION

MONTH	AVERAGE TEMPERATURE (°F)	TOTAL PRECIPITATION (IN)
January	36.1	3.21
February	37.8	2.94
March	46.5	3.97
April	57.7	3.19
May	66.3	4.19
June	73.5	3.69
July	77.3	4.78
August	76.2	4.73
September	69.9	4.43
October	59.5	4.02
November	49.1	3.12
December	38.4	3.54
Annual*	57.1	43.74

* Average of annual averages and totals for period.
Source: Commonwealth of Virginia, State Water Control Board, <u>Groundwater Resources of Albermarle County, Virginia</u>, 1980, p.6

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GREENWOOD CHEMICAL
CLEANUP GOAL SELECTION
9/3/91
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AREA 1 - MAIN SOURCE AREA

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**********************************************************************
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                              EXCELLENT GRASS

                                 LAYER  1
                                 --------

                         VERTICAL PERCOLATION LAYER
  THICKNESS                                =     12.00 INCHES
  POROSITY                                 =      0.4370 VOL/VOL
  FIELD CAPACITY                           =      0.1053 VOL/VOL
  WILTING POINT                            =      0.0466 VOL/VOL
  INITIAL SOIL WATER CONTENT               =      0.3000 VOL/VOL
  SATURATED HYDRAULIC CONDUCTIVITY         =      0.008500000462 CM/SEC


                                 LAYER  2
                                 --------

                         VERTICAL PERCOLATION LAYER
  THICKNESS                                =     60.00 INCHES
  POROSITY                                 =      0.4200 VOL/VOL
  FIELD CAPACITY                           =      0.3104 VOL/VOL
  WILTING POINT                            =      0.1875 VOL/VOL
  INITIAL SOIL WATER CONTENT               =      0.3050 VOL/VOL
  SATURATED HYDRAULIC CONDUCTIVITY         =      0.000064000000 CM/SEC


                                 LAYER  3
                                 --------

                         VERTICAL PERCOLATION LAYER
  THICKNESS                                =     84.00 INCHES
  POROSITY                                 =      0.3500 VOL/VOL
  FIELD CAPACITY                           =      0.3104 VOL/VOL
  WILTING POINT                            =      0.1875 VOL/VOL
  INITIAL SOIL WATER CONTENT               =      0.2620 VOL/VOL
  SATURATED HYDRAULIC CONDUCTIVITY         =      0.000064000000 CM/SEC


                                 LAYER  4
                                 --------
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ORIGINAL
(Red)

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                      VERTICAL PERCOLATION LAYER
        THICKNESS                                =     156.00 INCHES
        POROSITY                                 =       0.4200 VOL/VOL
        FIELD CAPACITY                           =       0.3418 VOL/VOL
        WILTING POINT                            =       0.2099 VOL/VOL
        INITIAL SOIL WATER CONTENT               =       0.3380 VOL/VOL
        SATURATED HYDRAULIC CONDUCTIVITY         =       0.000042000000 CM/SEC


                        GENERAL SIMULATION DATA
                        -----------------------

        SCS RUNOFF CURVE NUMBER                  =       40.48
        TOTAL AREA OF COVER                      =   102000.  SQ FT
        EVAPORATIVE ZONE DEPTH                   =       30.00 INCHES
        POTENTIAL RUNOFF FRACTION                =        0.900000
        UPPER LIMIT VEG. STORAGE                 =       12.8040 INCHES
        INITIAL VEG. STORAGE                     =        9.0900 INCHES
        INITIAL SNOW WATER CONTENT               =        0.0000 INCHES
        INITIAL TOTAL WATER STORAGE IN
          SOIL AND WASTE LAYERS                  =       96.6360 INCHES

                 SOIL WATER CONTENT INITIALIZED BY USER.


                          CLIMATOLOGICAL DATA
                          -------------------

        SYNTHETIC RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
        SOLAR RADIATION FOR      RICHMOND               VIRGINIA

        MAXIMUM LEAF AREA INDEX                     =  4.50
        START OF GROWING SEASON (JULIAN DATE)       =   103
        END OF GROWING SEASON (JULIAN DATE)         =   303

               NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

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

        36.10        37.80        46.50        57.70        66.30        73.50
        77.30        76.20        69.90        59.50        49.10        38.40

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

           AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH   20
-----------------------------------------------------------------------

                             JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                             ------- ------- ------- ------- ------- -------
       PRECIPITATION
       -------------
         TOTALS                3.37    3.10    3.82    2.90    4.18    3.76
                               4.92    4.46    4.01    4.79    3.37    3.71

         STD. DEVIATIONS       1.57    1.60    2.02    1.48    2.20    1.82
                               2.51    2.09    1.84    3.82    1.58    2.21

       RUNOFF
       ------
         TOTALS                0.000   0.000   0.00                    0.000
                               0.000   0.000   0.00                    0.000
```

```
    STD. DEVIATIONS      0.000    0.000    0.000    0.000    0.000    0.000
                         0.000    0.000    0.000    0.000    0.000    0.000

  EVAPOTRANSPIRATION
  ------------------
    TOTALS               1.450    1.764    2.717    2.665    5.196    4.000
                         4.490    4.195    3.062    2.273    1.678    1.370

    STD. DEVIATIONS      0.212    0.319    0.640    0.807    0.979    1.573
                         1.455    1.826    1.195    0.618    0.388    0.209

  PERCOLATION FROM LAYER  4
  -------------------------
    TOTALS               0.9112   1.0217   1.2800   1.3038   1.2824   1.0895
                         0.9656   0.8335   0.7113   0.6654   0.7715   0.8409

    STD. DEVIATIONS      0.6457   0.7652   0.8949   0.6835   0.5848   0.4165
                         0.3003   0.2129   0.1527   0.1455   0.8568   0.8868
*******************************************************************************


*******************************************************************************
 AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH   20
-------------------------------------------------------------------------------
                                      (INCHES)          (CU. FT.)     PERCENT
                                  ----------------     ----------    -------
  PRECIPITATION                   46.37   ( 8.031)       394111.     100.00

  RUNOFF                           0.000  ( 0.000)           0.        0.00

  EVAPOTRANSPIRATION              34.859  ( 3.586)       296305.      75.18

  PERCOLATION FROM LAYER  4       11.6767 ( 4.8282)       99252.      25.18

  CHANGE IN WATER STORAGE         -0.170  ( 4.383)        -1446.      -0.37
*******************************************************************************


*******************************************************************************
            PEAK DAILY VALUES FOR YEARS     1 THROUGH   20
    ---------------------------------------------------------------------
                                               (INCHES)     (CU. FT.)
                                               --------     ---------
       PRECIPITATION                             4.48        38080.0

       RUNOFF                                    0.000           0.0

       PERCOLATION FROM LAYER  4                 0.1775       1508.5

       SNOW WATER                                1.65        14025.0

       MAXIMUM VEG. SOIL WATER (VOL/VOL)             0.3841

       MINIMUM VEG. SOIL WATER (VOL/VOL)             0.1311
*******************************************************************************
```

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

          FINAL WATER STORAGE AT END OF YEAR   20
    ----------------------------------------------------------------
              LAYER        (INCHES)        (VOL/VOL)
              -----        --------        ---------
                1            0.84           0.0702
                2           18.18           0.3030
                3           22.63           0.2694
                4           51.59           0.3307
             SNOW WATER      0.00

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

ORIGINAL
(Red)

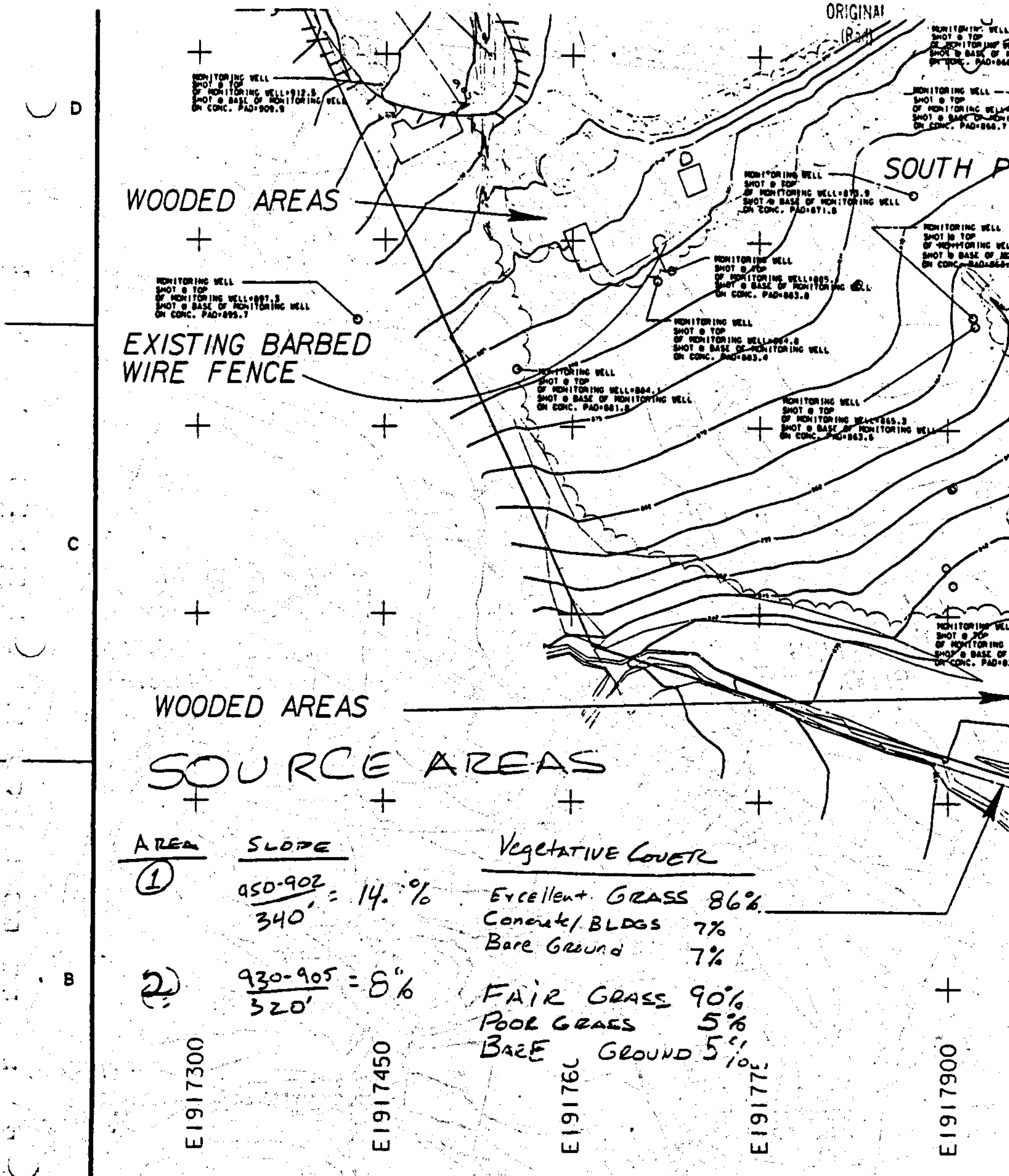
AREA 2 - DRUM DISPOSAL AREA

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

 GREENWOOD CHEMICAL
 CLEANUP GOAL SELECTION
 9/3/91

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



                              GOOD GRASS

                               LAYER  1
                               --------

                      VERTICAL PERCOLATION LAYER
  THICKNESS                            =     84.00 INCHES
  POROSITY                             =      0.3800 VOL/VOL
  FIELD CAPACITY                       =      0.3104 VOL/VOL
  WILTING POINT                        =      0.1875 VOL/VOL
  INITIAL SOIL WATER CONTENT           =      0.2590 VOL/VOL
  SATURATED HYDRAULIC CONDUCTIVITY     =      0.000268799980 CM/SEC


                               LAYER  2
                               --------

                      VERTICAL PERCOLATION LAYER
  THICKNESS                            =    120.00 INCHES
  POROSITY                             =      0.4300 VOL/VOL
  FIELD CAPACITY                       =      0.3418 VOL/VOL
  WILTING POINT                        =      0.2099 VOL/VOL
  INITIAL SOIL WATER CONTENT           =      0.3310 VOL/VOL
  SATURATED HYDRAULIC CONDUCTIVITY     =      0.000042000000 CM/SEC



                       GENERAL SIMULATION DATA
                       -----------------------

  SCS RUNOFF CURVE NUMBER              =      81.59
  TOTAL AREA OF COVER                  =   32000. SQ FT
  EVAPORATIVE ZONE DEPTH               =      30.00 INCHES
  POTENTIAL RUNOFF FRACTION            =       0.900000
  UPPER LIMIT VEG. STORAGE             =      11.4000 INCHES
  INITIAL VEG. STORAGE                 =       7.7700 INCHES
  INITIAL SNOW WATER CONTENT           =       0.0000 INCHES
  INITIAL TOTAL WATER STORAGE IN
    SOIL AND WASTE LAYERS              =      61.4760 INCHES

             SOIL WATER CONTENT INITIALIZED BY USER.
```

ORIGINAL
(Red)

```
                          CLIMATOLOGICAL DATA
                          -------------------

    SYNTHETIC RAINFALL WITH SYNTHETIC DAILY TEMPERATURES AND
    SOLAR RADIATION FOR      RICHMOND              VIRGINIA

    MAXIMUM LEAF AREA INDEX                  = 4.50
    START OF GROWING SEASON (JULIAN DATE)    =  103
    END OF GROWING SEASON (JULIAN DATE)      =  303

          NORMAL MEAN MONTHLY TEMPERATURES, DEGREES FAHRENHEIT

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

    36.10        37.80        46.50        57.70        66.30        73.50
    77.30        76.20        69.90        59.50        49.10        38.40

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

      AVERAGE MONTHLY VALUES IN INCHES FOR YEARS     1 THROUGH  20
-----------------------------------------------------------------------

                         JAN/JUL FEB/AUG MAR/SEP APR/OCT MAY/NOV JUN/DEC
                         ------- ------- ------- ------- ------- -------
  PRECIPITATION
  -------------
    TOTALS                 3.37    3.10    3.82    2.90    4.18    3.76
                           4.92    4.46    4.01    4.79    3.37    3.71

    STD. DEVIATIONS        1.57    1.60    2.02    1.48    2.20    1.82
                           2.51    2.09    1.84    3.82    1.58    2.21

  RUNOFF
  ------
    TOTALS                0.043   0.024   0.057   0.023   0.058   0.107
                          0.179   0.117   0.184   0.296   0.045   0.089

    STD. DEVIATIONS       0.084   0.052   0.186   0.062   0.156   0.192
                          0.321   0.321   0.283   0.787   0.075   0.130

  EVAPOTRANSPIRATION
  ------------------
    TOTALS                1.474   1.859   2.883   2.889   4.544   3.659
                          4.423   4.026   2.982   2.399   1.712   1.400

    STD. DEVIATIONS       0.218   0.323   0.784   0.916   1.250   1.458
                          1.414   1.681   1.171   0.688   0.444   0.232

  PERCOLATION FROM LAYER  2
  -------------------------
    TOTALS               1.0862  1.2687  1.4448  1.3259  1.0866  0.8193
                         0.6801  0.5782  0.4901  0.4803  0.7001  0.8807

    STD. DEVIATIONS      0.7085  0.8950  0.8844  0.7415  0.5023  0.2912
                         0.1953  0.1440  0.1172  0.1532  0.8935  0.8188
***********************************************************************


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

 AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR [illegible]          20)
-----------------------------------------------------------------------
```

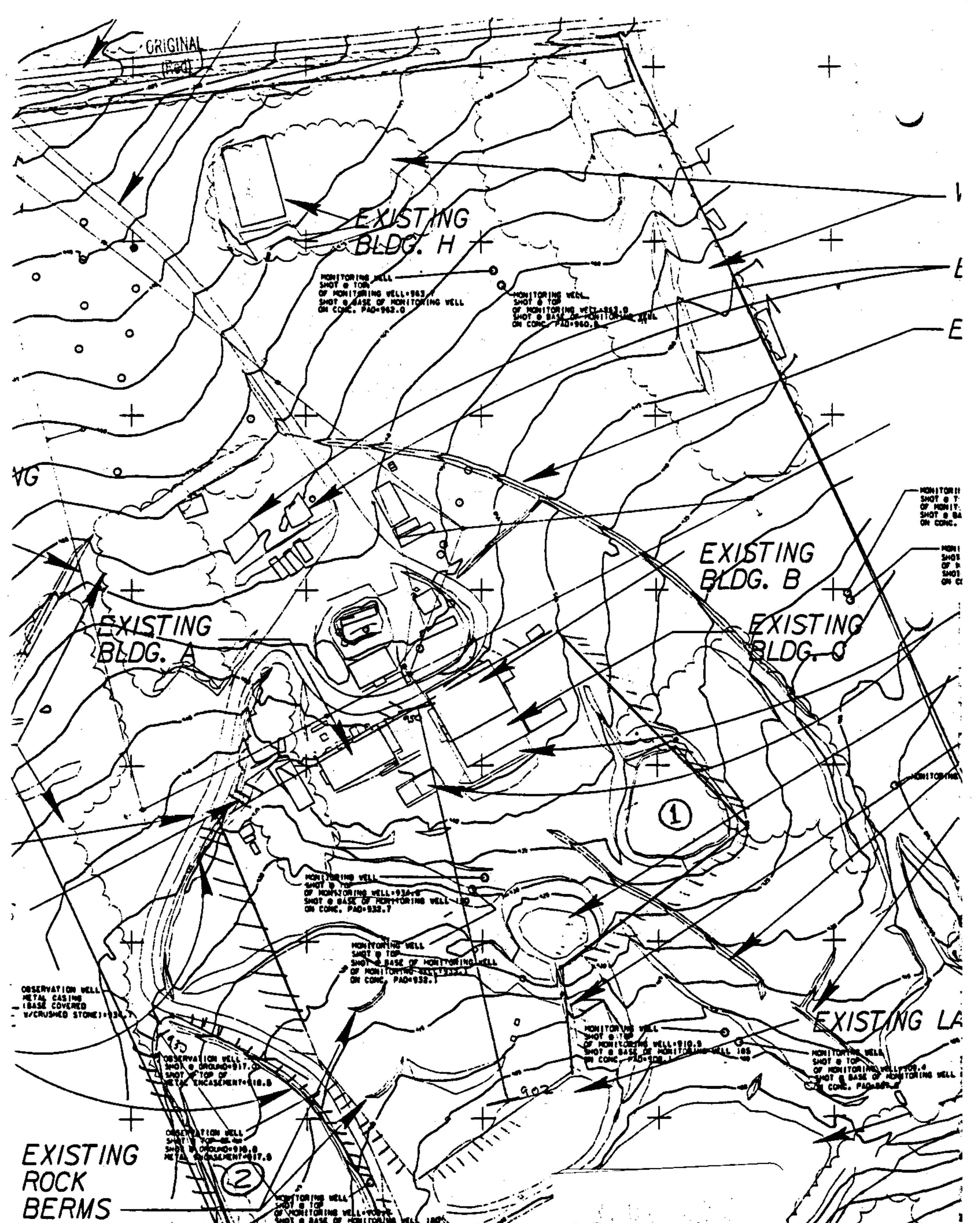
```
                                    (INCHES)          (CU. FT.)    PERCENT
                                  ---------------    ----------    -------
PRECIPITATION                     46.37   ( 8.031)      123643.     100.00

RUNOFF                             1.220  ( 1.101)        3254.       2.63

EVAPOTRANSPIRATION                34.251  ( 3.457)       91337.      73.87

PERCOLATION FROM LAYER  2         10.8411 ( 4.5531)      28910.      23.38

CHANGE IN WATER STORAGE            0.054  ( 3.475)         143.       0.12
***************************************************************************


***************************************************************************
                PEAK DAILY VALUES FOR YEARS    1 THROUGH   20
        -------------------------------------------------------------------
                                                 (INCHES)     (CU. FT.)
                                                 --------     ---------
             PRECIPITATION                         4.48        11946.7

             RUNOFF                                2.197        5857.8

             PERCOLATION FROM LAYER  2             0.1737        463.3

             SNOW WATER                            1.65         4400.0

             MAXIMUM VEG. SOIL WATER (VOL/VOL)          0.3641

             MINIMUM VEG. SOIL WATER (VOL/VOL)          0.1872
***************************************************************************


***************************************************************************
                   FINAL WATER STORAGE AT END OF YEAR   20
        -------------------------------------------------------------------
                     LAYER        (INCHES)       (VOL/VOL)
                     -----        --------       ---------
                       1           22.00          0.2619

                       2           40.55          0.3379

                   SNOW WATER       0.00

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



SOURCE AREAS

AREA	SLOPE	Vegetative Cover
①	$\frac{950-902}{340'} = 14.\%$	Excellent GRASS 86% Concrete/BLDGS 7% Bare Ground 7%
2)	$\frac{930-905}{320'} = 8\%$	FAIR GRASS 90% POOR GRASS 5% BARE GROUND 5%

Scale 1"=100'


ORIGINAL
EXISTING BLDG. H
MONITORING WELL
SHOT @ TOP
OF MONITORING WELL=963.?
SHOT @ BASE OF MONITORING WELL
ON CONC. PAD=962.0
MONITORING WELL
SHOT @ TOP
OF MONITORING WELL=963.0
SHOT @ BASE OF MONITORING WELL
ON CONC. PAD=960.8
EXISTING BLDG. B
EXISTING BLDG. A
EXISTING BLDG. C
①
MONITORING WELL
SHOT @ TOP
OF MONITORING WELL=934.6
SHOT @ BASE OF MONITORING WELL
ON CONC. PAD=932.7
MONITORING WELL
SHOT @ TOP
SHOT @ BASE OF MONITORING WELL
OF MONITORING WELL=933.1
ON CONC. PAD=932.1
OBSERVATION WELL
METAL CASING
(BASE COVERED
W/CRUSHED STONE)=934.7
OBSERVATION WELL
SHOT @ GROUND=917.0
SHOT @ TOP OF
METAL ENCASEMENT=918.8
OBSERVATION WELL
SHOT @ GROUND=916.8
METAL ENCASEMENT=917.8
②
EXISTING ROCK BERMS
MONITORING WELL
SHOT @ TOP
OF MONITORING WELL
SHOT @ BASE OF MONITORING WELL
ON CONC. PAD
MONITORING WELL
SHOT @ TOP
OF MONITORING WELL=910.3
SHOT @ BASE OF MONITORING WELL
ON CONC. PAD=909.1
MONITORING WELL
SHOT @ TOP
OF MONITORING WELL=909.4
SHOT @ BASE OF MONITORING WELL
ON CONC. PAD
EXISTING LA
902

the program responds with

```
    THERE ARE NO DEFAULT VALUES FOR ____________________.
```

and asks question 3.4. In most cases, only the first four letters of the city are needed; however, for San Diego and San Francisco, the entire city name is needed. If the entire city name is needed but not supplied, the program responds

```
    PLEASE TYPE ENTIRE NAME OF CITY.
```

and returns to question 3.6.

Once the city name has been entered correctly, control passes to subroutine 7. TRRCF (question 7.1), where temperature, radiation and rainfall coefficients are read from a data file.

After reading the coefficients, the program computes daily temperatures and solar radiation values and stores them on a data file. If the location was not changed (a NO response to question 3.3), the program prints, for example,

```
    3.7  CURRENT MAXIMUM LEAF AREA INDEX IS 4.20.
                                            ----
    DO YOU WANT TO SELECT A NEW MAXIMUM LEAF AREA INDEX?
    ENTER YES OR NO.
```

The program skips this question if a new location has been chosen. The user answers YES to question 3.7 if it is desired to change the vegetative cover, and the program responds

```
    3.8  ENTER THE MAXIMUM LEAF AREA INDEX.

    TYPICAL VALUES ARE:
                       0 FOR BARE GROUND,
                     1.0 FOR POOR GRASS,
                     2.0 FOR FAIR GRASS,
                     3.3 FOR GOOD GRASS, AND
                     5.0 FOR EXCELLENT GRASS.
```

The value entered in question 3.8 is used in computing the daily leaf area indices. If the user enters a value greater than the maximum LAI value stored on the default data base, the program responds

```
    LOCATION CANNOT SUPPORT THIS LEAF AREA INDEX UNLESS IRRIGATED
    DUE TO LOW RAINFALL AND SHORT GROWING SEASON.

    TYPICAL MAXIMUM FOR TULSA           OKLAHOMA           IS 2.50.
                        ----------------------------------    ----
    3.9  DO YOU WANT TO SELECT A DIFFERENT LEAF AREA INDEX?
    ENTER YES OR NO.
```