

AR TARGET SHEET

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SECTION: 2 of 8

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TITLE: Final RI/FS Report for
1100-EM-1 OU, Hanford

5.0 CONTAMINANTS OF CONCERN

The contaminants of concern were identified through the baseline risk assessment process. Summaries of the risk assessments are presented in paragraphs 5.1, 5.2, and 5.3. Complete Risk Assessments can be found in appendixes K and L of this RI/FS Report. The contaminants of concern were derived from the soil contaminants assessed in the industrial scenario and groundwater contaminants assessed in the residential scenario. The contaminants of concern are:

- Arsenic
- BEHP
- Chromium
- Chlordane
- Nitrate
- PCB's
- Trichloroethene

The toxicity profiles of these contaminants are contained in the appendix K. The risk from these contaminants are summarized in tables 5.1 and 5.2.

5.1 SUMMARY OF BASELINE INDUSTRIAL SCENARIO RISK ASSESSMENT

The baseline industrial scenario risk assessment (BISRA) was conducted according to Hanford Site Baseline Risk Assessment Methodology (HSBRAM) (DOE-RL-91-45). The HSBRAM was developed using EPA Region X guidance. Contaminants were determined by comparing maximum detected concentrations of parameters to the UTL for that parameter. The contaminants of potential concern derived from this comparison were presented in table 4-9.

The contaminants were evaluated in a two step process to minimize statistical analyses and allow comparison of maximum value concentrations and 95-percent upper confidence limit (UCL) concentrations. Maximum concentrations were used not only for preliminary risk based screening but also for the initial risk based assessment calculations. If a health risk was indicated using maximum concentration, then the 95-percent UCL concentration was used to refine quantification of the health risk.

The maximum concentrations of contaminants of potential concern detected within each subunit were evaluated for each subunit. Conservative assumptions were made with respect to the contaminants present. For three subunits, UN-1100-6, the Ephemeral Pool, and HRL, soil contaminants that were estimated to have an Incremental Cancer Risk (ICR) greater than $1E-06$, based on the maximum detected contaminant concentrations, were evaluated using a 95-percent UCL concentration.

The exposure pathways for the industrial scenario were defined in the HSBRAM (DOE-RL-91-45). These are conservative default parameters for a generic industrial worker. The BISRA evaluated only pathways associated with exposure to soils (*i.e.*, soil ingestion, dermal exposure to soil, and fugitive dust inhalation). Potential exposures associated with groundwater and surface water are not evaluated in this BISRA. Neither groundwater use nor direct use of surface water occurs within the 1100 Area because the City of Richland supplies the water. The air inhalation pathway assumes exposure to concentrations of dust

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Table 5-1. Summary of the Risks Derived from Contaminants of Concern for Soil Contaminants Based on the 95-percent UCL for UN-1100-6, the Ephemeral Pool, and the Horn Rapids Landfill.

Contaminant	Pathway						Contaminant Totals		Subunit Totals	
	Soil Ingestion		Fugitive Dust Inhalation		Dermal Exposure		HQ*	ICR*	HI†	ICR‡
	HQ*	ICR*	HQ*	ICR*	HQ*	ICR*				
UN-1100-6										
BEHP	0.3	2E-05	--	2E-08	0.03	2E-08	0.3	2E-05		
Chlordane	0.008	2E-07	--	2E-10	0.009	2E-07	0.01	4E-07		
Pathway Totals	0.3	2E-05	--	2E-08	0.04	2E-08			0.3	2E-05
Ephemeral Pool										
Chlordane	0.009	2E-07	--	6E-10	0.01	2E-07	0.02	4E-07		
PCBs	-	9E-08	--	3E-08	--	1E-05	-	2E-05		
Pathway Totals	0.009	9E-08	--	3E-08	0.01	1E-05			0.02	2E-05
Horn Rapids Landfill										
Arsenic	0.001	2E-07	--	1E-08	0.00003	4E-08	0.001	2E-07		
Chromium	0.005	--	--	2E-08	0.00009	--	0.005	2E-08		
PCBs	-	2E-05	--	2E-07	--	3E-05	-	5E-05		
Pathway Totals	0.007	2E-05	--	2E-08	0.0001	3E-05			0.007	5E-05
*Hazard Quotient †Lifetime Incremental Cancer Risk ‡Hazard Index *Based on 30% absorption of inhaled arsenic (EPA 1992b) -- Not Applicable										

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Table 5-2. Summary of Risk Derived from Groundwater Based on the 95-percent UCL Concentrations from the Baseline Residential Scenario Risk Assessment

Contaminant	Pathway			
	Groundwater Ingestion		Groundwater Inhalation	
	HQ ^a	ICR ^b	HQ ^a	ICR ^b
Nitrate	0.8	-- ^c	-- ^d	-- ^{c,d}
Trichloroethene	-- ^e	1E-05	-- ^e	2E-05
^a Hazard Quotient ^b Lifetime Incremental Cancer Risk ^c Not considered to be a carcinogen ^d Not a volatile contaminant ^e RfD not available to evaluate this pathway UCL = Upper Confidence Level -- Indicates not applicable				

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directly from each subunit. The EPA Fugitive Dust Model (FDM) was used to estimate concentrations of airborne particulates at each site based on conservative estimation of soil and climatic conditions. Chromium present in the soil at HRL was the only contaminant that may be associated with risks greater than $1E-06$. However, all chromium was assumed to be chromium(VI) which is a conservative assumption.

Evaluation of the potential contaminants of concern using the maximum and 95-percent UCL identified the contaminants of concern for the individual subunits in the 1100-EM-1. Contaminants of concern for individual subunits as determined in the BISRA are:

UN-1100-6
BEHP

Ephemeral Pool
PCB's

HRL
Chromium
PCB's

A summary of the industrial scenario risk assessment based on the 95-percent UCL for UN-1100-6, Ephemeral Pool, and HRL is presented in table 5-3.

5.2 SUMMARY OF BASELINE RESIDENTIAL SCENARIO RISK ASSESSMENT

The baseline residential scenario risk assessment (BRSRA) was conducted to fulfill an agreement made between DOE-RL, EPA, and Ecology. The scope of the BRSRA was defined by an EPA letter [Einan, 1991 (see appendix K)]. Further discussion and correspondence is contained in appendix K.

Based on the results of the Phase I RI Report, EPA selected the following contaminants of potential concern, and these were evaluated in the BRSRA:

1100-2	Tetrachlorethene
1100-3	Arsenic Chromium Lead
UN-1100-6	Bis (2-ethylhexyl) phthalate (BEHP) Chlordane

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Table 5-3. Comparison of the Baseline Industrial Incremental Cancer Risk Assessment Results using the Maximum Contaminant Concentrations and 95-percent UCL for UN-1100-6, the Ephemeral Pool, and the Horn Rapids Landfill.

Subunit	Pathway	95% UCL Pathway Totals	Maximum Concentration Pathway Totals	95% UCL Subunit Totals	Maximum Concentration Subunit Totals
		ICR	ICR	ICR	ICR
UN-1100-6	Soil Ingestion	2E-05	3E-05		
	Fugitive Dust Inhalation	2E-08	3E-08		
	Dermal Exposure	2E-06	3E-06		
				2E-05	3E-05
Ephemeral Pool	Soil Ingestion	9E-06	3E-05		
	Fugitive Dust Inhalation	3E-08	8E-08		
	Dermal Exposure	1E-05	3E-05		
				2E-05	6E-05
Horn Rapids Landfill	Soil Ingestion	2E-05	8E-05		
	Fugitive Dust Inhalation	2E-06	3E-05		
	Dermal Exposure	3E-05	8E-05		
				5E-05	2E-04

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HRL

Arsenic
 Chromium
 PCB's
 Nitrate
 Tetrachlorethene
 Trichloroethene
 1,1,1-Trichloroethane
 Lead

Ephemeral Pool

Chlordane
 PCB's

In addition to the above, beryllium was evaluated as a contaminant of potential concern at HRL because the Slope Factor was not available when the Phase I RI Report was prepared.

The contaminants were evaluated in a two step process to minimize statistical analyses and allow comparison of maximum value concentrations and 95-percent UCL concentrations. Also, due to the heterogeneous nature of HRL, it is not reasonable for a contaminant to be statistically spread across the entire soil column or aquifer.

The BRSRA evaluates pathways defined by EPA and focused on soil and water. The soil related pathways included ingestion of soil, dermal contact with soil, ingestion of garden produce, and inhalation of particulates. The air inhalation pathway assumes exposure to concentrations of dust directly from each subunit. The FDM is used to estimate concentrations of airborne particulate at a site based on conservative estimations of soil and climatic conditions. Region X default parameters for residential scenario are used. (See appendix K.) Chromium present in the soil at HRL is the only contaminant that may be associated with risks greater than 1E-06. However, all chromium is assumed to be chromium(VI), which is a conservative assumption.

The EPA specified exposure pathways for groundwater contaminants detected in the vicinity of HRL include: ingestion of groundwater, inhalation of volatiles from groundwater, ingestion of Columbia River fish, and dermal contact with Columbia River water during swimming.

Evaluation of the potential contaminants of concern using the maximum and 95-percent UCL identified the contaminants of concern for the individual subunits in the 1100-EM-1. Contaminants of concern for individual subunits as determined in the BRSRA are:

UN-1100-3

Arsenic

UN-1100-6

BEHP

Chlordane

Ephemeral Pool
 Chlordane
 PCB's

HRL
 Arsenic
 Beryllium
 Chromium
 Nitrate
 PCB's
 TCE

A summary of residential scenario risk assessment based on the 95-percent UCL for UN-1100-6, Ephemeral Pool, and HRL is presented in table 5-4.

5.3 SUMMARY OF ECOLOGICAL RISK ASSESSMENT FOR THE 1100-EM-1 OPERABLE UNIT

5.3.1 Purpose and Scope of the Ecological Risk Assessment

The objective of the Ecological Risk Assessment is to provide an evaluation of the site specific ecological risks. An Environmental Assessment was provided in the Phase I RI report (DOE/RL-90-18) for the 1100-EM-1 Operable Unit. Presentation of an ecological risk assessment for the Phase II RI/FS is a voluntary effort that includes Phase II RI data in a manner that follows guidelines outlined in the HSB RAM (DOE/RL-91-45).

This Ecological Risk Assessment includes a problem definition, analysis, and risk characterization. The problem definition identified stressor characteristics (*i.e.*, COPC), ecosystems potentially at risk and ecological effects. These discussions lead to the selection of assessment and measurement endpoints. Assessment endpoints are those "specific properties of each habitat of interest used to evaluate the state, or change in the state, of the ecological system" (DOE/RL-91-45). Measurement endpoints are "those used to approximate, represent or lead to an assessment endpoint" (DOE/RL-91-45). An analysis was performed by characterizing exposure and ecological effects. Risk characterization was performed by integrating exposure and toxicity, discussing uncertainty, and interpreting ecological risk.

5.3.2 Problem Definition

The problem definition involved identifying ecosystems potentially at risk, the stressor characteristics, ecological effects, and the selection of assessment and measurement endpoints. Potentially sensitive habitats chosen for the 1100-EM-1 site include habitats known to be frequented by designated or proposed, endangered or threatened species. In determining ecosystems potentially at risk at 1100 EM-1, only terrestrial organisms are

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Table 5-4. Comparison of the Baseline Residential Scenario Risk Assessment Results using the Maximum Contaminant Concentrations and 95-percent UCL for UN-1100-6, the Ephemeral Pool, and the Horn Rapids Landfill.

Subunit	Pathway	95% UCL Pathway Totals		Maximum Concentration Pathway Totals		95% UCL Subunit Totals		Maximum Concentration Subunit Totals	
		HI*	ICR [†]	HI*	ICR [†]	HI*	ICR [†]	HI*	ICR [†]
UN-1100-6	Soil Ingestion	3.0	4E-04	4.7	6E-04	18	2E-03	23	3E-03
	Fugitive Dust Inhalation	--	5E-08	--	7E-08				
	Dermal Exposure	0.5	5E-05	0.7	8E-05				
	Garden Produce	15	2E-03	18	2E-03				
Ephemeral Pool	Soil Ingestion	0.1	2E-04	0.2	5E-04	2.5	1E-03	3.6	3E-03
	Fugitive Dust Inhalation	--	6E-08	--	2E-07				
	Dermal Exposure	0.2	2E-04	0.2	7E-04				
	Garden Produce	2.2	8E-04	3.2	2E-03				
Horn Rapids Landfill	Soil Ingestion	0.08	5E-04	1	1E-03	1.2	3E-03	5.6	7E-03
	Fugitive Dust Inhalation	--	4E-08	--	6E-05				
	Dermal Exposure	0.001	6E-04	0.02	2E-03				
	Garden Produce	0.3	2E-03	3.6	4E-03				
	Groundwater Ingestion	0.8	1E-05	1	1E-05				
	Inhalation of Volatiles from Groundwater	--	2E-05	--	3E-05				
*Hazard Index †Lifetime Incremental Cancer Risk UCL Upper Confidence Limit -- Indicates not applicable									

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considered. Aquatic species are not addressed, since it has been demonstrated through groundwater modeling that contaminants in the groundwater will not likely reach the river above drinking water standards.

The dominant plant species within the 1100 Area are sagebrush-bitterbrush and cheatgrass. The sandwort is designated a monitor species (DNR, 1990). Table L-1 (appendix L) is a list of mammals, birds, reptiles and insects that may inhabit the 1100 Area. Of the birds listed, the peregrine falcon and ferruginous hawk are endangered and threatened, respectively. The swainson's hawk, golden eagle, and prairie falcon are candidate species and the long-billed curlew is a monitored species. No threatened or endangered species of mammals, reptiles, or insects are known to inhabit the 1100 Area. However, the grasshopper mouse and sagebrush vole are monitored, and the pocket gopher and striped whipsnake are candidate species.

No toxicological studies were performed on species inhabiting 1100-EM-1 during the Phase I or Phase II RIs. The toxicological effects on species exposed to the COPC are assumed to be those addressed in the derivation of parameters such as the No Observed Adverse Effect Level (NOAEL). These parameters are used in the analysis and characterization sections.

Phase I field observations of the ecology of 1100-EM-1 (DOE/RL-91-45) showed that there was no evidence of adverse impacts from the COPC to the flora and fauna inhabiting any of the subunits, except for the UN-1100-6. Except for a single clump of grass, there is no vegetation growing in the depression of the UN-1100-6 subunit. The only evidence of ecological damage at the operable unit is this apparent lack of vegetative growth at this subunit.

As noted above, assessment endpoints are the properties of habitats of potential concern that are used to assess the state of an ecosystem. These endpoints "must be of ecological importance and of direct management relevance..." (DOE/RL-91-45). Terrestrial organisms have been designated as having habitats of potential concern for this site and the ferruginous hawk and peregrine falcon are threatened and endangered, respectively. From these considerations, adverse effects on these raptors have been chosen as assessment endpoints in this risk assessment. Without better data, it isn't possible to be more specific about the assessment endpoints (*i.e.*, to specify, for example, abundance, mortality, or ecosystem productive capability).

A measurement endpoint is defined "to approximate, represent or lead to an assessment endpoint" (DOE/RL-91-45). For this risk assessment, adverse effects on the swainson's hawk and long-billed curlew were used as measurement endpoints. These birds were chosen since they can be considered analog species. They were designated as candidate and monitored species (swainson's hawk and long-billed curlew, respectively) and data used for the exposure assessments were readily available.

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5.3.3 Analysis

The analysis involved performing an exposure and toxicity assessment. This involved first identifying the exposure pathways and secondly, calculating intake rates for the receptor population (swainson's hawk and long-billed curlew).

COPC uptake calculation for the swainson's hawk and long-billed curlew were performed according to Risk Assessment Guidance for Superfund (EPA, 1989). In appendix L, table L-2 lists maximum contaminant concentrations and plant and small mammal uptake factors used in uptake calculations. Similarly, the results of the uptake calculations are reported in table L-3. Appropriate parameters were not always available, so conservative estimations, taken from previously conducted studies, were made whenever necessary.

Intake rates for the analog species (swainson's hawk and long-billed curlew) were compared to toxicological values in appendix L, table L-4. Values for birds were used whenever possible. When these rates were not available, values for small mammals were reported. The most conservative parameters were used where available [e.g., NOAEL as opposed to the Lowest Observed Adverse Effect Level (LOAEL)].

5.3.4 Risk Characterization

Given the uncertainty in information available, it was not practical to perform risk calculations for this evaluation. Ecological risk was estimated by comparing exposure to the contaminant toxicity.

None of the uptake rates in table L-2 exceed the toxicologic values in table L-3. For the swainson's hawk, uptake rates for zinc, BEHP, beta-HCH, DDT and PCB were between 10 and 80 times lower than the corresponding toxicity value. Uptake rates for copper, thallium, and chlordane were between 2,000 and 20,000 times lower, and the remaining uptake rates were more than 300,000 times below toxicity values. For the long-billed curlew, arsenic, barium, nickel, vanadium, zinc, and BEHP had uptake rates 20 to 100 times less than toxicity values. The other contaminants were more than 100 times less than toxicity values.

5.3.5 Uncertainty Analysis

There were many sources of uncertainty in the exposure assessment and risk characterization for the ecological evaluation of 1100-EM-1. All information regarding the presence and behavior of species at the site, the exposure to contaminants, and toxicity of contaminants was estimated and extrapolated from information available from previous studies. Limited ecological data were taken from the site, therefore, the most conservative and simple models were used to determine the ecological impact. Thus, the exposure assessment represents the worst case scenario and the comparison of toxicity to exposure was highly conservative.

Since limited field observations were made, a search was performed to identify all terrestrial organisms expected to inhabit the Hanford site. Of these, organisms that seemed likely to exist at 1100-EM-1 were reported in table L-1. This list excluded organisms, such as amphibians, not likely to be found at 1100-EM-1. It is probable that many of the organisms listed in table L-1 do not actually inhabit the site, but they were addressed in order to ensure that important species were identified.

Stressor characteristics chosen for the site are also a source of uncertainty. COPC from the BISRA were used. This is expected to be a highly conservative assumption, since these contaminants were chosen by performing conservative risk-based screening that used exposure parameters for humans. Offsite sources of stressors are not addressed for this assessment. Since organisms do not necessarily inhabit the 1100 Area alone, they would be exposed to offsite contamination. It was not in the scope of this assessment to address these offsite exposures. It is possible, however, that the contamination outside the 1100 Area would probably be more significant than that identified at 1100-EM-1.

When selecting assessment endpoints, it is preferable to chose specific cases (such as reduced population size). However, with the lack of data regarding the effects of contaminants at the site on organisms known to inhabit the site, this was not possible. Therefore, adverse effects that generate the toxicological parameters (NOAEL, *etc.*) on important species (*i.e.*, the ferruginous hawk and peregrine falcon) were considered assessment endpoints. It would be preferable to use effects on these species as measurement endpoints, but data for the analog species (swainson's hawk and long-billed curlew) was more readily available.

The simplified exposure routes introduce uncertainty that may underestimate exposure. Only ingestion of contaminated food is addressed, where other sources of contamination, such as soil ingestion, would contribute to exposure. The use of uptake factors (UF) for plants, insects, and small mammals are also a source of uncertainty. Wherever possible the most appropriate values were used. For example, when available, UF's reported for rats were used as UF's for small mammals. All parameters for the exposure calculations were taken from previously conducted studies or conservatively estimated values were used. For example, it was assumed that the swainson's hawk and long-billed curlew consumed 100 percent of their contaminated diet from the HRL.

Toxicological parameters reported in table L-2 are a source of uncertainty. Only two values were derived from studies on swainson's hawks. Values for small mammals were chosen if values for birds were not available, however, the most conservative data available are presented. For example NOAEL is used over LOAEL, and Toxic Dose Low (TDLo) is used over Lethal Dose-50 (LD50).

5.3.6 Ecological Implications

Using highly conservative assumptions and models, no uptake rates for the long-billed curlew or the swainson's hawk exceeded toxicity values. Therefore, it is unlikely that contaminants of potential concern at 1100-EM-1 would have an impact on these birds that

was distinguishable from background conditions. Even though there are significant uncertainties in this assessment, there has been little evidence of ecological damage at the site.

Contaminants with uptake rates that were closest to toxicity values were zinc for the hawk and BEHP for the long-billed curlew, which were approximately 10 and 20 times less than toxicity values, respectively. Adverse impacts on these organisms would not like be due to zinc at HRL , or BEHP at UN-1100-6.

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6.0 CONTAMINANT FATE AND TRANSPORT

6.1 INTRODUCTION

This chapter is organized as follows. Contaminants of concern identified in the previous chapters will be briefly discussed. Then, the description of the physical characteristics and the delineation of the extent of contamination at the 1100-EM-1 Operable Unit are combined to analyze the fate and transport of contaminants. The body of field data for the 1100-EM-1 Area has been provided in previous sections and in other reports cited. Specific models appropriate to the physical parameters identified at the site have been designated by the EPA, DOE, and Ecology to assist in predicting the movement and the fate of contaminants within the environment. A summary of the vadose zone unsaturated flow model is provided. The unsaturated flow model was used to validate assumptions used in the groundwater flow model concerning the rate of groundwater recharge from infiltration originating as precipitation. Finally, the groundwater flow and contaminant transport model will be described. Contaminant fate and transport analysis are discussed in greater detail in the Phase I RI Report for the Hanford Site 1100-EM-1 Operable Unit (DOE/RL-90-18).

6.2 CONTAMINANTS OF CONCERN

Contaminants of concern for the 1100-EM-1 Operable Unit, as described in section 5.0, are BEHP in the soils at the UN-1100-6, Discolored Soil Site subunit, PCB's in the soils of the Ephemeral Pool subunit, PCB's and chromium in soils of the HRL subunit, and TCE and nitrate in the groundwater of the HRL subunit. A brief discussion of each contaminant of concern will be presented in the following paragraphs.

6.2.1 BEHP

Bis(2-ethylhexyl)phthalate (BEHP) is a compound used to render plastics more flexible. This substance and other phthalate-ester plasticizers have been found to be general contaminants in virtually all soil and water ecosystems. BEHP is relatively immobile due to strong soil sorption, low water solubility, and low vapor pressure. Thus, migration to groundwater through the vadose zone is not expected. The high potential for bioaccumulation would be the most likely pathway of importance.

Biodegradation of BEHP under aerobic aqueous conditions has been observed to be fairly rapid, and following bacterial acclimation, a half-life of 2 to 3 weeks has been measured. Under experimental conditions, aerobic biodegradation has been observed in soil with a degradation half-life of about 14 days.

6.2.2 Chlordane

Chlordane is expected to be fairly immobile in the soil/groundwater system due to strong soil sorption and moderate volatilization. Data on degradation are limited; the contaminants expected to be moderately persistent. Risk of groundwater contamination is moderate. Contamination of surface waters from surface runoff over chlordane-contaminated soils has been reported. Pathways of concern from the soil/groundwater system are migration into groundwater drinking supplies, uptake by crops from contaminated soils, and bioaccumulation by aquatic organisms or domestic animals.

Chlordane is not expected to undergo significant hydrolysis, oxidation, or direct photolysis. Little is known about biodegradation, but such a process would be expected to be slow. Volatilization is insignificant, but chlordane vapors in the atmosphere are known to react with photochemically produced hydroxyl radicals. The estimated half-life of these vapors is 6.2 hours.

6.2.3 PCB's

Polychlorinated biphenyls (PCB's) are very inert, thermally and chemically stable compounds having dielectric properties. PCB's are expected to be highly immobile in the soil/groundwater system due to rapid and strong soil sorption. In the absence of organic solvents, leaching is minimal. Being strongly sorbed to soils, migration to the groundwater is not expected. In the atmosphere, transformation takes place in a vapor-phase reaction with photochemically produced hydroxyl radicals. In general, the higher chlorinated biphenyls are less mobile and more persistent than the lower chlorinated species. The potential for PCB bioaccumulation is high.

6.2.4 Chromium

Elemental chromium does not exist naturally in the environment, but is found primarily as a constituent of chromite ore. In compounds, this element exists in one of three valence states, +2, +3, or +6. The trivalent form is an essential human micronutrient involved in carbohydrate metabolism. Adverse effects have not been associated with the trivalent form. The hexavalent form has been associated with serious toxicities. Hexavalent chromium is mobile in soil. Under aerobic and acidic conditions, it is reduced to trivalent chromium that readily precipitates with carbonates, hydroxides, and sulfides in the soil. Hexavalent chromium does not bioaccumulate in significant amounts.

6.2.5 Arsenic

Arsenic is a common element found in the earth's crust, usually in the form of arsenic-bearing minerals. It is difficult to characterize as a single element because of its very

complex chemistry. In the soil, arsenic compounds revert to arsenates that are held by clay soils and are not readily available for plant uptake.

6.2.6 TCE

Trichloroethene (TCE) is a widely used industrial solvent. It is relatively mobile in the soil/groundwater system, particularly in soils having a low organic content. Volatilization may be significant for TCE near the surface or in the soil-air phase. Biodegradation may be the most important transformation process. The biodegradation byproducts of TCE are dichloroethene and vinyl chloride. A contaminant degradation study performed on samples obtained from the 1100-EM-1 Operable Unit suggests that rapid biodegradation does not appear to occur (Golder, 1992). Transformation processes such as hydrolysis, oxidation, and photolysis are not expected to be important in natural soils. The primary pathway of concern in a soil/water system is the migration of TCE into groundwater drinking water supplies.

6.2.7 Nitrate

Ammonia released from SPC has degraded and results in elevated concentrations of nitrate at HRL. The nitrate form of nitrogen is very water soluble and is highly mobile in water and soil, contributing to concern over the presence of these compounds in the environment.

6.3 VADOSE ZONE MODELING

UNSAT-HTM is a one-dimensional computer code developed by Pacific Northwest Laboratory to model water flow through unsaturated media (Fayer and Jones, 1990). The purpose of the model is to assess water dynamics of near-surface waste disposal sites located on the Hanford Site. It is primarily used to predict deep drainage as a function of environmental conditions such as climate, soil type, and vegetation. The model is mechanistic in that it is based on Richards' equation for liquid water flow in unsaturated media (Richards, 1931), Fick's law of diffusion for vapor flow and evaporation (Hillel, 1980), and Fourier's law of heat conduction for soil heat flow (Campbell, 1985). In the present study, the UNSAT-HTM model is used to determine groundwater recharge from surface infiltration of rainwater for the 1100-EM-1 Operable Unit. Values derived will be compared with recharge amounts input to the groundwater model to confirm their applicability.

The original UNSAT-HTM code was written for execution on a VAXTM computer system. The code was submitted to modeling specialists from the Hydraulics and Environmental Laboratories at the U.S. Army Corps of Engineers, Waterways Experiment Station in Vicksburg, Mississippi, who performed necessary modifications to allow model

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runs on IBM-compatible personal computers. The modified code was verified by comparing output to model output published in the UNSAT-H™ User's Manual. No significant differences in results were noted.

6.3.1 Model Input

The following paragraphs will describe the inputs used to initialize UNSAT-H model runs. Actual data will be provided where practicable and the rationale for their use will be presented.

6.3.1.1 Soil Data. Soil properties used as model input were obtained from boring logs developed during the installation of groundwater monitoring wells. Gradation curves of soil components obtained during analyses for physical properties during the Phase I RI were recomputed and reconstructed to eliminate particle sizes greater than 2.0 millimeters. Particle sizes greater than 2.0 mm (0.08 in) have minimal impact on unsaturated flow parameters (Schroeder, 1992). The curves were then compared to soil gradation curves included in Smoot *et. al.*, 1989. During this study of vadose zone moisture flow at a location within the Hanford Site 200 Area, unsaturated flow parameters were determined from laboratory analyses of soil samples. The unsaturated flow parameters listed for soils in this project were assigned to 1100 Area soils based on the closest match of the gradation curves. Parameters assigned to the 1100 Area soils included soil conductivity at laboratory saturation, and the van Genuchten curve fitting parameters α , n , and m . Laboratory testing to determine soil unsaturated flow parameters was not performed during either the Phase I or Phase II investigations of the 1100-EM-1 Operable Unit.

Bulk density (γ) values were estimated based on classification of the 1100 Area soils and typical values tabulated in table 3.5 of Hunt, 1986. In situ bulk density measurements were not obtained during either the Phase I or Phase II investigations due to difficulties in obtaining undisturbed samples of gravelly, cobbly soils.

Specific gravities (SpG) were measured for 1100 Area soils by laboratory testing, in some instances. Where no specific gravity analysis was performed, the SpG value of similarly classified soils based on particle size gradation were assigned to the untested samples, *i.e.*, if a sandy silt had a measured SpG of 2.63, all untested sandy silts were assigned an SpG of 2.63. Where a range of SpG values were measured for similarly classified soils, the values were averaged and the average value was assigned to all untested soils having the same classification.

The in situ moisture content of the soil was measured during laboratory analysis of samples collected during the installation of Phase I monitoring wells on a weight percent (WT%) basis. Values were converted to a volumetric basis (cubic centimeters of water per cubic centimeter of soil [Θ]) using the formula:

$$\Theta = ((\gamma \times \text{WT}\%) / 0.998) / 100$$

(Jury *et. al.*, 1991)

A soil residual moisture content (Θ_r) of zero was assigned to all vadose zone soils based on the generally coarse texture of Operable Unit soils (Fayer, 1992). Saturated moisture content (Θ_s) was taken to be equal to the porosity of the soil. Soil porosity was calculated based on the formula:

$$\Theta_s = (1 - (\gamma / \text{SpG}))$$

(Hunt, 1986).

Soil matric potential (h) was calculated based on the van Genuchten formula:

$$h = (((((\Theta - \Theta_r) / (\Theta_s - \Theta_r))^{(1/m)} - 1)^{(1/n)}) / \alpha$$

(Fayer and Jones, 1990).

Initial runs of the UNSAT-HTM model were only marginally successful. The code was experiencing computational difficulties given the very low measured soil-moisture values and the use of the van Genuchten/Mualem model option. The Brooks-Corey/Mualem model option was implemented after van Genuchten curve fitting parameters were converted to the appropriate Brooks-Corey parameters using the formulas:

$$h_c = 1 / \alpha$$

$$b = 1 / (n - 1)$$

(Fayer, 1992). The Brooks-Corey matric potential was then computed using the formula:

$$h = h_c / (\Theta / \Theta_s)^b$$

(Fayer and Jones, 1990). Tables 6-1 and 6-2 present a compilation of computed parameters for the van Genuchten/Mualem and Brooks-Corey/Mualem computational models, respectively.

Computed soil parameters, laboratory measured soil properties, and soil classifications derived from field logs were compared. Monitoring well boring MW-15, located in the east-central portion of HRL was selected as being most representative of the Operable Unit vadose zone, and was used for all subsequent unsaturated flow model runs. The log was not excessively detailed so the soil column could be effectively represented by the model without resulting in extremes for computer computational time or memory usage. All UNSAT-HTM model runs were accomplished on a DELL 433DE[®] personal computer having a 80486 processor.

6.3.1.2 Climatic Data. Climatic data was derived from U.S. Department of Agriculture synthetic weather generating models WGENTM and CLIGENTM (Richardson and Wright, 1984, and U.S. Department of Agriculture). Weather data generated by these models was then compared to historic climatic records gathered at the Hanford Meteorological Station to ensure the synthetic data was reasonable. A 100-year interval was simulated using both the CLIGENTM and WGENTM models. Richland N.E. weather station data was used to generate weather data with CLIGENTM. The Richland N.E. station is located at the Richland Airport, approximately 1.6 km (1 mile) south of the 1100-EM-1 Operable Unit. Maximum, minimum, and dew point temperatures, average wind speed, cloud cover, and inches of precipitation were generated on a daily basis by the model. CLIGENTM computed precipitation values were extracted from the output file and input into the WGENTM portion of the Hydrologic Evaluation of Landfill Performance (HELP) Model (Schroeder, *et. al.*, 1992) to generate solar radiation values (Langleys). WGENTM generated solar radiation units were substituted for CLIGENTM data because WGENTM simulates radiation based on rainfall occurrence, a more reasonable estimation than the CLIGENTM based values. Data values generated by both weather models were combined by use of various computer routines written to place the output into a form suitable for direct entry into the UNSAT-HTM code.

Initially, climatic data having 17.018 cm (6.700 in) of yearly precipitation was run over a simulation period of 500 years, the period of time required for steady-state base drainage (recharge) conditions to develop. Head values for model node points within the unsaturated zone were input as elevation heads in centimeters above the water table. A water table depth of 853 cm (28 ft) was used as an average for HRL vicinity. Head values, node point depths, and soil type distributions modeled are included in table 6-3. Table 6-4 presents inputs for other UNSAT-HTM model variables employed for unsaturated flow simulations. Steady-state head values for model node points were then used to initiate a 100-year simulation period with yearly data generated by the weather models used to more accurately reflect groundwater recharge within the 1100-EM-1 Operable Unit. Table 6-5 lists yearly precipitation values used for the 100-year simulation. Daily cloud cover values generated by the weather models were input to UNSAT-HTM. However, an UNSAT-HTM program switch was set allowing the code to independently compute cloud cover based on input solar radiation values.

6.3.1.3 Vegetation Data. Vegetation input was limited to data on cheatgrass cover as outlined in the UNSAT-HTM user's manual (Fayer and Jones, 1990). Deeper rooted vegetation such as sagebrush was ignored for the purposes of the model simulation due to uncertainties related to cover percentage versus the time of the year. The resulting model outputs will, therefore, provide conservative (*i.e.*, overpredict) flux rates at the top of the groundwater table.

Vegetation cover was estimated to be 30 percent, based on a ground surface survey of the 1100-EM-1 sub-units performed in mid-May, 1992. Root distribution with depth was set within the UNSAT-HTM code to the logarithmic option. Cheatgrass germination date and the date when vegetation transpiration ceases were set at days 275 and 180 (day 1 equates to January 1), respectively. Root growth rate and depth of root penetration were input based on cheatgrass data outlined in the UNSAT-HTM manual. Table 6-3 includes a listing of the day

of the year when root growth reaches various model nodes (model variable "NTROOT(n)"). Roots were not assumed to extend beyond node number 23; a depth of 181 cm (71.26 in).

6.3.1.4 Initial Conditions. After steady-state drainage conditions were realized utilizing a uniform precipitation value of 17.018 cm/yr (6.700 in/yr), steady-state head values for modeled node points were extracted and used to restart a 100-year model period with new weather model-generated values inserted for each yearly interval encompassing the 100-year timeframe. The 17.018 cm/yr (6.7 in) precipitation amount was selected to use in reaching steady-state conditions because it was very close to the model computed average value of 19.316 cm/yr (7.605 in/yr); and slightly on the dry side. Tables 6-6 and 6-7 present steady-state head values for modeled node points used to begin the 100-year runs with the plant option set on and off, respectively.

6.3.2 Model Results - Plants Modeled

Yearly output for the 100-year model run with the UNSAT-HTM code plant option enabled and a 30-percent cheatgrass cover assumed is presented in table 6-8. Model results indicate an average groundwater recharge rate of 1.04 cm/yr (0.41 in/yr). This rate can be considered a conservative value (higher recharge rates will be computed) because deeper rooted shrubbery present within all 1100-EM-1 subunits was not included in the model for lack of reliable input values. Model output is graphically illustrated in figures 6-1 through 6-6.

6.3.3 Model Results - Plants Not Modeled

Yearly output for the 100-year run with the UNSAT-H code plant option set off to simulate an unvegetated site is presented in table 6-9. Model results indicate an average groundwater recharge rate of 3.46 cm/yr (1.36 in/yr). This is considered an appropriate value to assume for the Ephemeral Pool subunit for precipitation falling directly onto the existing ground surface. Runoff entering the site from the adjacent asphalt-paved parking area must be added to this amount. The no-plants recharge rate would also be appropriate to assume for short periods immediately following ground-disturbing activities such as excavations, and natural disasters such as range fires, which would reduce or completely remove the ground vegetative cover. Model output for unsaturated flow in unvegetated areas is graphically illustrated in figures 6-7 through 6-11.

6.3.4 Conclusions

Model results indicating a groundwater recharge rate of 1.04 cm/yr (0.41 in/yr) for a vegetated site is comparable to results obtained from actual on-the-ground lysimeter studies conducted elsewhere on the Hanford Site (see paragraph 2.4.3.1). The recharge rate of 3.46 cm/yr (1.36 in/yr) is within the published range for recharge below an unvegetated area recorded during lysimeter studies on the Hanford Site; although on the dry end of most reported limits. Differences between modeled and measured results arise from difficulties in

both study methods. Various modeling input parameters are difficult to determine due to complex laboratory procedures, difficult sampling procedures, long periods required to perform reliable test procedures, and lack of sufficient previous work in the various fields of interest in the modeling of unsaturated flow. Lysimeter studies suffer from difficulties in constructing accurate representations of natural soil conditions within the measuring devices. At the present stage of the technology, results from both modeling and field measurements should be used to determine the approximate magnitude of recharge to be anticipated; not actual amounts.

9 3 1 2 8 6 2 0 4 2 0

Table 6-1: VADOSE ZONE MODELING PARAMETERS
VAN GENUCHTEN MODEL

Operable Subunit Background	Borehole Number	Sample Number	Sample Depth		Soil Gradations LAB			Conductivity at Lab Saturation (cm/s)	Residual Moisture (THETA r)	Moisture Values In-Situ Moisture Content (THETA)	Moisture Weight % Measured	Bulk Density	Estimated Soil Porosity = Saturated Moisture Content (THETA s)	van Genuchten Parameters			Calculated Matric Potential (cm) (h)	Wentworth Soil Classification	
			From	To	% G	% S	% M							a	n	m			
BAP-2		A0202	5.5	5.5	58	33	9												
		A0203	8.3	9.6	60	27	13	5.77E-04	0.00	0.0346	1.80	1.92	0.29	2.69	0.09123	1.28327	0.22074	19,923.99	Silty Sandy GRAVEL
		A0208	19.5	21.0	58	33	9	2.82E-04	0.00	0.0385	2.00	1.92	0.29	2.69	0.25119	1.60079	0.37531	114.39	Silty Sandy GRAVEL
		A0210	34.4	35.4	78	15	7	5.77E-04	0.00	0.0423	2.20	1.92	0.29	2.69	0.09123	1.28327	0.22074	9,800.96	Silty Sandy GRAVEL
HRL-1		A0302	7.0	8.0	68	22	10	5.77E-04	0.00	0.0327	1.70	1.92	0.29	2.69	0.09123	1.28327	0.22074	24,319.71	Silty Sandy GRAVEL
		A0307	15.0	16.0	7	83	10	2.99E-04	0.00	0.0602	3.60	1.67	0.38	2.71	0.17633	1.36246	0.26603	914.21	Slightly Silty Slightly Gravelly SAND
DP-7		A0101	0.7	2.0	54	36	10	1.38E-05	0.00	0.0462	2.40	1.92	0.29	2.69	0.15633	1.39591	0.28362	661.43	Silty Sandy GRAVEL
		A0105	16.5	18.0	70	23	7	2.82E-04	0.00	0.0308	1.60	1.92	0.29	2.69	0.25119	1.60079	0.37531	166.05	Silty Sandy GRAVEL
		A0109	28.4	30.0	25	62	13	2.82E-04	0.00	0.0593	3.70	1.60	0.41	2.73	0.25119	1.60079	0.37531	99.11	Slightly Silty Gravelly SAND
1100-1	BAP-1	A1002S	2.2	4.2	26	55	19	1.38E-05	0.00	0.1427	8.90	1.60	0.40	2.68	0.15633	1.39591	0.28362	84.78	Gravelly Silty SAND
		A1006S	6.1	6.8	54	27	19	8.88E-04	0.00	0.0904	4.70	1.92	0.29	2.69	0.54741	1.28139	0.21960	401.13	Silty Sandy GRAVEL
		A1009S	7.8	8.8	42	37	21	5.77E-04	0.00	0.0558	2.90	1.92	0.29	2.69	0.09123	1.28327	0.22074	3,665.25	Silty Sandy GRAVEL
		A1013S	13.4	13.9	44	43	13	5.77E-04	0.00	0.0616	3.20	1.92	0.29	2.69	0.09123	1.28327	0.22074	2,598.65	Silty Sandy GRAVEL
		A1015S	16.3	17.5	65	28	7	1.21E-03	0.00	0.0442	2.30	1.92	0.29	2.69	0.39456	1.34559	0.25683	585.72	Silty Sandy GRAVEL
1100-2	DP-4	A0402S	0.8	1.4	34	55	11	1.78E-04	0.00	0.0154	0.80	1.92	0.29	2.69	0.20954	1.34125	0.25443	25,976.92	Silty Sandy GRAVEL
		A0404S	1.9	3.1	31	51	18	2.99E-04	0.00	0.0616	3.20	1.92	0.29	2.69	0.17633	1.36246	0.26603	406.45	Silty Sandy GRAVEL
		A0406S	3.3	5.1															
		A0410S	10.7	12.4	64	28	8	1.78E-04	0.00	0.0481	2.50	1.92	0.29	2.69	0.20954	1.34125	0.25443	922.32	Silty Sandy GRAVEL
		A0412S	16.0	17.0	60	32	8	1.38E-05	0.00	0.0519	2.70	1.92	0.29	2.69	0.15633	1.39591	0.28362	492.74	Silty Sandy GRAVEL
DP-5		A0503S	2.6	3.6	48	39	13	8.88E-04	0.00	0.0558	2.90	1.92	0.29	2.69	0.54741	1.28139	0.21960	2,235.70	Silty Sandy GRAVEL
		A0505S	6.6	7.1	35	48	17	2.24E-04	0.00	0.1039	5.40	1.92	0.29	2.69	0.48677	1.29968	0.23058	62.56	Silty Sandy GRAVEL
		A0509S	10.0	11.0	48	45	7	5.73E-04	0.00	0.0846	4.40	1.92	0.29	2.69	0.08632	1.31349	0.23867	587.04	Silty Sandy GRAVEL
		A0512S	15.0	15.7	33	60	7	1.21E-03	0.00	0.0923	4.80	1.92	0.29	2.69	0.39456	1.34559	0.25683	69.00	Silty Sandy GRAVEL
		A0513S	16.2	18.0	4	93	3	2.99E-04	0.00	0.0703	4.20	1.67	0.37	2.65	0.17633	1.36246	0.26603	553.28	SAND
DP-6		A0603S	0.5	2.0	42	45	13	5.77E-04	0.00	0.0231	1.20	1.92	0.29	2.69	0.09123	1.28327	0.22074	82,948.31	Silty Sandy GRAVEL
		A0604S	2.5	3.7	36	42	22	5.77E-04	0.00	0.0308	1.60	1.92	0.29	2.69	0.09123	1.28327	0.22074	30,042.61	Silty Sandy GRAVEL
		A0607S	4.2	5.7	39	41	20	1.38E-05	0.00	0.0827	4.30	1.92	0.29	2.69	0.15633	1.39591	0.28362	150.84	Silty Sandy GRAVEL
		A0609S	7.9	9.0	54	38	8	1.21E-03	0.00	0.0442	2.30	1.92	0.29	2.69	0.39456	1.34559	0.25683	585.72	Silty Sandy GRAVEL
		A0611S	12.8	13.8	32	61	7	1.21E-03	0.00	0.0616	3.20	1.92	0.29	2.69	0.39456	1.34559	0.25683	223.87	Silty Sandy GRAVEL
		A0614S	16.3	17.3	14	79	7	5.73E-04	0.00	0.0535	3.20	1.67	0.37	2.66	0.08632	1.31349	0.23867	5,531.07	Gravelly SAND
DP-9		A1102S	2.6	3.6	43	40	17	1.38E-05	0.00	0.0500	2.60	1.92	0.29	2.69	0.15633	1.39591	0.28362	541.53	Silty Sandy GRAVEL
		A1104S	6.75	7.1	51	34	15	5.77E-04	0.00	0.1154	7.20	1.60	0.41	2.69	0.09123	1.28327	0.22074	960.36	Silty Sandy GRAVEL
		A1108S	9.0	9.2	23	69	8	1.21E-03	0.00	0.0731	3.80	1.92	0.30	2.73	0.39456	1.34559	0.25683	150.29	Slightly Silty Gravelly SAND
		A1109S	9.2	11.5	25	70	5	2.99E-04	0.00	0.0653	3.90	1.67	0.37	2.66	0.17633	1.36246	0.26603	678.42	Gravelly SAND
		A1110S	9.2	11.5	21	72	7	2.99E-04	0.00	0.1807	10.80	1.67	0.37	2.66	0.17633	1.36246	0.26603	33.91	Gravelly SAND
		A1112S	13.5	14.5	18	76	6	2.99E-04	0.00	0.0885	4.60	1.92	0.28	2.66	0.17633	1.36246	0.26603	134.75	Gravelly SAND
		A1113S	15.5	16.5	26	66	8	5.73E-04	0.00	0.0641	4.00	1.60	0.41	2.73	0.08632	1.31349	0.23867	4,310.85	Slightly Silty Gravelly SAND
		A1117S	21.8	22.1	45	49	6	2.82E-04	0.00	0.0577	3.00	1.92	0.29	2.69	0.25119	1.60079	0.37531	58.00	Silty Sandy GRAVEL
		A1120S	25.0	26.0	69	24	7	1.21E-03	0.00	0.0519	2.70	1.92	0.29	2.69	0.39456	1.34559	0.25683	367.87	Silty Sandy GRAVEL
		A1122S	31.1	32.1	62	28	10	2.82E-04	0.00	0.0481	2.50	1.92	0.29	2.69	0.25119	1.60079	0.37531	78.78	Silty Sandy GRAVEL
		A1124S	35.5	36.8	60	29	11	5.77E-04	0.00	0.0712	3.70	1.92	0.29	2.69	0.09123	1.28327	0.22074	643.69	Silty Sandy GRAVEL
		1100-3	DP-1	A0902S	4.0	5.1	46	42	12	1.21E-03	0.00	0.0481	2.50	1.92	0.29	2.69	0.39456	1.34559	0.25683
A0905S	6.9			7.9	48	42	10	1.78E-04	0.00	0.0462	2.40	1.92	0.29	2.69	0.20954	1.34125	0.25443	1,038.04	Silty Sandy GRAVEL
A0908S	11.9			12.9	15	73	12	1.38E-05	0.00	0.0830	4.90	1.69	0.38	2.73	0.15633	1.39591	0.28362	297.39	Slightly Silty Gravelly SAND
A0911S	15.5			16.5	2	91	7	5.73E-04	0.00	0.0971	5.80	1.67	0.37	2.65	0.08632	1.31349	0.23867	824.02	SAND
DP-2		A0802S	2.0	3.5	39	51	10	1.21E-03	0.00	0.0250	1.30	1.92	0.29	2.69	0.39456	1.34559	0.25683	3,047.90	Silty Sandy GRAVEL
		A0804S	6.5	8.0	54	36	10	2.82E-04	0.00	0.0519	2.70	1.92	0.29	2.69	0.25119	1.60079	0.37531	69.34	Silty Sandy GRAVEL
		A0806S	8.5	10.2	9	86	5	1.78E-04	0.00	0.0647	3.80	1.70	0.37	2.71	0.20954	1.34125	0.25443	789.86	Slightly Gravelly SAND
		A0807S	12.5	14.3	10	82	8	5.73E-04	0.00	0.0664	3.90	1.70	0.37	2.71	0.08632	1.31349	0.23867	2,775.90	Slightly Gravelly SAND
		A0809S	15.0	16.0	40	47	13	2.82E-04	0.00	0.0539	2.80	1.92	0.29	2.69	0.25119	1.60079	0.37531	65.06	Silty Sandy GRAVEL
		A0811S	17.6	20.0	14	79	7	1.21E-03	0.00	0.0602	3.60	1.67	0.37	2.66	0.39456	1.34559	0.25683	484.77	Gravelly SAND

9 3 1 2 8 5 2 0 4 2 2

Table 6-1: VADOSE ZONE MODELING PARAMETERS
(continued)

Operable Subunit	Borehole Number	Sample Number	Sample Depth		Soil Gradations LAB			Conductivity at Lab Saturation (cm/s)	Residual Moisture (THETA r)	Moisture Values In-Situ Moisture Content (THETA)	Moisture Weight % Measured	Bulk Density	Estimated Soil Porosity = Saturated Moisture Content (THETA s)	van Genuchten Parameters			Calculated Matrix Potential (cm) (h)	Wentworth Soil Classification	
			From	To	% G	% S	% M							a	n	m			
DP-3	A0703S	2.3	3.3	41	40	19	8.88E-04	0.00	0.0289	1.50	1.92	0.29	2.69	0.08632	1.31349	0.23867	18,135.96	Silty Sandy GRAVEL	
	A0705S	7.1	8.1	60	35	5	3.64E-03	0.00	0.0481	2.50	1.92	0.29	2.69	0.10074	1.40147	0.28646	870.41	Silty Sandy GRAVEL	
	A0707S	10.1	10.8	14	81	5	2.99E-04	0.00	0.0736	4.40	1.67	0.37	2.66	0.17633	1.36246	0.26603	487.37	Gravelly SAND	
	A0710S	13.2	14.3	3	94	3	2.99E-04	0.00	0.0619	3.70	1.67	0.37	2.65	0.17633	1.36246	0.26603	786.42	SAND	
	A0711S	15.2	16.0	5	93	2	2.99E-04	0.00	0.0645	3.90	1.65	0.39	2.71	0.17633	1.36246	0.26603	811.80	Slightly Gravelly SAND	
DP-8	A1202S	2.5	3.7	41	47	12	3.64E-03	0.00	0.0289	1.50	1.92	0.29	2.69	0.10074	1.40147	0.28646	3,099.65	Silty Sandy GRAVEL	
	A1207S	7.7	8.9	42	49	9	5.73E-04	0.00	0.0404	2.10	1.92	0.29	2.69	0.08632	1.31349	0.23867	6,228.73	Silty Sandy GRAVEL	
	A1212S	15.1	16.1	54	40	6	2.82E-04	0.00	0.0385	2.00	1.92	0.29	2.69	0.25119	1.60079	0.37531	114.39	Silty Sandy GRAVEL	
	A1214S	18.3	18.7	34	56	10	2.82E-04	0.00	0.0404	2.10	1.92	0.29	2.69	0.25119	1.60079	0.37531	105.53	Silty Sandy GRAVEL	
	A1215S	20.5	22.2	17	73	10	1.21E-03	0.00	0.0423	2.50	1.69	0.38	2.73	0.39456	1.34559	0.25683	1,454.54	Slightly Silty Gravelly SAND	
	A1216S	23.7	26.4	19	73	8	1.21E-03	0.00	0.0502	3.00	1.67	0.37	2.66	0.39456	1.34559	0.25683	820.28	Gravelly SAND	
	A1218S	26.4	27.4	54	33	13	5.77E-04	0.00	0.0385	2.00	1.92	0.29	2.69	0.09123	1.28327	0.22074	5,647.53	Silty Sandy GRAVEL	
	A1220S	30.2	31.4	54	39	7	2.82E-04	0.00	0.0442	2.30	1.92	0.29	2.69	0.25119	1.60079	0.37531	90.79	Silty Sandy GRAVEL	
HRL	HRL-2	A1803S	3.4	4.8	51	35	14	5.77E-04	0.00	0.0596	3.10	1.92	0.29	2.69	0.09123	1.28327	0.22074	1,206.84	Silty Sandy GRAVEL
	A1806S	8.0	8.9	36	54	10	2.82E-04	0.00	0.0346	1.80	1.92	0.29	2.69	0.25119	1.60079	0.37531	136.74	Silty Sandy GRAVEL	
	A1809S	12.5	13.5	54	34	12	5.77E-04	0.00	0.0327	1.70	1.92	0.29	2.69	0.09123	1.28327	0.22074	10,051.31	Silty Sandy GRAVEL	
	A1811S	16.5	17.6	58	29	13	5.77E-04	0.00	0.0327	1.70	1.92	0.29	2.69	0.09123	1.28327	0.22074	10,051.31	Silty Sandy GRAVEL	
	A1813S	20.0	21.7	48	35	17	5.77E-04	0.00	0.0442	2.30	1.92	0.29	2.69	0.09123	1.28327	0.22074	3,468.57	Silty Sandy GRAVEL	
HRL-3	A2003S	2.8	4.4	54	34	12	2.82E-04	0.00	0.0544	2.83	1.92	0.29	2.69	0.25119	1.60079	0.37531	64.06	Silty Sandy GRAVEL	
	A2006S	8.0	9.3	68	24	8	5.77E-04	0.00	0.0577	3.00	1.92	0.29	2.69	0.09123	1.28327	0.22074	1,353.19	Silty Sandy GRAVEL	
	A2008S	13.3	14.5	47	45	8	2.82E-04	0.00	0.1083	5.63	1.92	0.29	2.69	0.25119	1.60079	0.37531	19.57	Silty Sandy GRAVEL	
	A2011S	17.6	18.8	61	29	10	5.77E-04	0.00	0.0558	2.90	1.92	0.29	2.69	0.09123	1.28327	0.22074	1,523.08	Silty Sandy GRAVEL	
	A2013S	22.0	23.2	68	25	7	5.77E-04	0.00	0.0687	3.57	1.92	0.29	2.69	0.09123	1.28327	0.22074	730.40	Silty Sandy GRAVEL	
HRL-4	A2203S	3.2	4.6	56	34	10	3.64E-03	0.00	0.0654	3.40	1.92	0.29	2.69	0.10074	1.40147	0.28646	403.86	Silty Sandy GRAVEL	
	A2206S	8.2	9.7	66	24	10	5.77E-04	0.00	0.0462	2.40	1.92	0.29	2.69	0.09123	1.28327	0.22074	2,966.78	Silty Sandy GRAVEL	
	A2209S	13.6	14.4	37	48	15	2.82E-04	0.00	0.0616	3.20	1.92	0.29	2.69	0.25119	1.60079	0.37531	51.94	Silty Sandy GRAVEL	
	A2211S	17.4	18.9	59	28	13	5.77E-04	0.00	0.0414	2.15	1.92	0.29	2.69	0.09123	1.28327	0.22074	4,370.21	Silty Sandy GRAVEL	
	A2213S	21.5	23.5	71	22	7	5.77E-04	0.00	0.0604	3.14	1.92	0.29	2.69	0.09123	1.28327	0.22074	1,151.31	Silty Sandy GRAVEL	
HRL-5	A1503S	3.8	6.0	60	35	5	1.78E-04	0.00	0.1347	7.00	1.92	0.29	2.69	0.20954	1.34125	0.25443	43.48	Silty Sandy GRAVEL	
	A1505S	8.6	9.4	53	37	10	3.64E-03	0.00	0.0712	3.70	1.92	0.29	2.69	0.10074	1.40147	0.28646	326.38	Silty Sandy GRAVEL	
	A1508S	11.8	13.1	59	28	13	5.77E-04	0.00	0.0414	2.15	1.92	0.29	2.69	0.09123	1.28327	0.22074	4,370.21	Silty Sandy GRAVEL	
	A1511S	15.5	16.0	51	30	19	5.77E-04	0.00	0.0304	1.58	1.92	0.29	2.69	0.09123	1.28327	0.22074	13,002.79	Silty Sandy GRAVEL	
	A1514S	21.9	22.8	48	32	20	5.77E-04	0.00	0.0308	1.60	1.92	0.29	2.69	0.09123	1.28327	0.22074	12,416.36	Silty Sandy GRAVEL	
HRL-6	A1604S	7.1	9.4	65	39	2	1.78E-04	0.00	0.3174	16.50	1.92	0.29	2.70	0.20954	1.34125	0.25443	(-1.135.139)	Sandy GRAVEL	
	A1606S	9.4	11.6	75	21	4	2.82E-04	0.00	0.1010	5.25	1.92	0.29	2.69	0.25119	1.60079	0.37531	22.16	Silty Sandy GRAVEL	
	A1609S	16.2	18.5	80	18	2	2.82E-04	0.00	0.1731	9.00	1.92	0.29	2.70	0.25119	1.60079	0.37531	7.83	Sandy GRAVEL	
	A1610S	18.5	20.8	80	18	2	2.82E-04	0.00	0.1731	9.00	1.92	0.29	2.70	0.25119	1.60079	0.37531	7.83	Sandy GRAVEL	
	A1611S	21.5	23.0	51	35	14	5.77E-04	0.00	0.0481	2.50	1.92	0.29	2.69	0.09123	1.28327	0.22074	2,573.23	Silty Sandy GRAVEL	
	A1614S	24.2	25.0	32	41	27	5.77E-04	0.00	0.0292	1.52	1.92	0.29	2.69	0.09123	1.28327	0.22074	14,989.41	Silty Sandy GRAVEL	
	A1615S	25.0	25.2	36	38	26	8.88E-04	0.00	0.0281	1.46	1.92	0.29	2.69	0.05474	1.28139	0.21960	73,128.95	Silty Sandy GRAVEL	
	A1616S	25.8	27.8	74	20	6	5.77E-04	0.00	0.0641	3.33	1.92	0.29	2.69	0.09123	1.28327	0.22074	933.15	Silty Sandy GRAVEL	
HRL-7	A2302S	2.7	4.3	70	23	7	3.64E-03	0.00	0.0633	3.29	1.92	0.29	2.69	0.10074	1.40147	0.28646	438.25	Silty Sandy GRAVEL	
	A2305S	7.3	8.4	58	30	12	5.77E-04	0.00	0.0481	2.50	1.92	0.29	2.69	0.09123	1.28327	0.22074	2,573.23	Silty Sandy GRAVEL	
	A2309S	11.2	12.2	58	30	12	3.64E-03	0.00	0.0481	2.50	1.92	0.29	2.69	0.10074	1.40147	0.28646	870.41	Silty Sandy GRAVEL	
	A2311S	15.3	16.5	64	23	13	5.77E-04	0.00	0.0341	1.77	1.92	0.29	2.69	0.09123	1.28327	0.22074	8,668.39	Silty Sandy GRAVEL	
	A2313S	19.0	20.0	56	29	15	5.77E-04	0.00	0.0371	1.93	1.92	0.29	2.69	0.09123	1.28327	0.22074	6,436.56	Silty Sandy GRAVEL	
HRL-8	A1403S	2.5	4.4	79	16	5	5.77E-04	0.00	0.0616	3.20	1.92	0.29	2.69	0.09123	1.28327	0.22074	1,074.00	Silty Sandy GRAVEL	
	A1405S	7.5	8.2	24	54	22	1.38E-05	0.00	0.0471	2.45	1.92	0.28	2.58	0.15633	1.39591	0.28362	576.40	Gravelly Silty SAND	
	A1408S	10.9	12.8	64	21	15	8.88E-04	0.00	0.0269	1.40	1.92	0.29	2.69	0.54741	1.28139	0.21960	29,902.75	Silty Sandy GRAVEL	
	A1410S	17.6	18.8	66	24	10	1.38E-05	0.00	0.0462	2.40	1.92	0.29	2.69	0.15633	1.39591	0.28362	661.43	Silty Sandy GRAVEL	
	A1413S	22.6	23.1	48	29	23	5.77E-04	0.00	0.0242	1.26	1.92	0.29	2.69	0.09123	1.28327	0.22074	29,089.82	Silty Sandy GRAVEL	

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Table 6-1
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Table 6-1: VADOSE ZONE MODELING PARAMETERS
(continued)

Operable Subunit HRL	Borehole Number HRL-9	Sample Number	Sample Depth		Soil Gradations LAB			Conductivity at Lab Saturation (cm/s)	Residual Moisture (THETA r)	Moisture Values In-Situ Moisture Content (THETA s)	Moisture Weight % Measured	Bulk Density	Estimated Soil Porosity = Saturated Moisture Content (THETA s)	van Genuchten Parameters			Calculated Matric Potential (cm)	Wertworth Soil Classification	
			From	To	% G	% S	% M							SpG	a	n			m
		A1703S	2.8	3.7	58	32	10	2.82E-04	0.00	0.0616	3.20	1.92	0.29	2.69	0.25119	1.60079	0.37531	51.94	Silty Sandy GRAVEL
		A1705S	5.0	5.8	51	31	18	5.77E-04	0.00	0.0331	1.72	1.92	0.29	2.69	0.09123	1.28327	0.22074	9,628.84	Silty Sandy GRAVEL
		A1708S	9.4	10.4	65	25	10	5.77E-04	0.00	0.0481	2.50	1.92	0.29	2.69	0.09123	1.28327	0.22074	2,573.23	Silty Sandy GRAVEL
		A1711S	14.2	15.2	69	21	10	5.77E-04	0.00	0.0404	2.10	1.92	0.29	2.69	0.09123	1.28327	0.22074	4,764.26	Silty Sandy GRAVEL
		A1713S	20.4	21.7	74	19	7	2.82E-04	0.00	0.0521	2.71	1.92	0.29	2.69	0.25119	1.60079	0.37531	68.89	Silty Sandy GRAVEL
	HRL-10	A1907S	9.1	11.4	73	21	6	2.82E-04	0.00	0.0481	2.50	1.92	0.29	2.69	0.25119	1.60079	0.37531	78.78	Silty Sandy GRAVEL
		A1908S	11.4	13.7	54	37	9	2.82E-04	0.00	0.0423	2.20	1.92	0.29	2.69	0.25119	1.60079	0.37531	97.72	Silty Sandy GRAVEL
		A1910S	16.9	17.8	32	51	17	5.77E-04	0.00	0.0712	3.70	1.92	0.29	2.69	0.09123	1.28327	0.22074	643.69	Silty Sandy GRAVEL
		A1911S	17.8	20.1	63	30	7	2.82E-04	0.00	0.0577	3.00	1.92	0.29	2.69	0.25119	1.60079	0.37531	58.00	Silty Sandy GRAVEL
		A1913S	27.9	30.3	81	17	2	3.64E-03	0.00	0.0693	3.60	1.92	0.29	2.69	0.10074	1.40147	0.28646	349.29	Silty Sandy GRAVEL
Monitoring Wells	MW-1	1	10.5	12.1	73	22	5	5.77E-04	0.00	0.0242	1.26	1.92	0.29	2.69	0.09123	1.28327	0.22074	29,089.82	Silty Sandy GRAVEL
		2	21.0	22.0	63	33	4	2.28E-04	0.00	0.0731	3.80	1.92	0.29	2.69	0.25119	1.60079	0.37531	38.83	Silty Sandy GRAVEL
		3	29.3	31.3	60	35	5	2.28E-04	0.00	0.0525	2.73	1.92	0.29	2.69	0.25119	1.60079	0.37531	68.01	Silty Sandy GRAVEL
		4	34.0	35.0	86	13	1	1.78E-04	0.00	0.0346	1.77	1.95	0.26	2.72	0.20954	1.34125	0.25443	2,186.04	GRAVEL
		5	40.0	41.7	32	64	4	5.73E-04	0.00	0.0806	4.19	1.92	0.29	2.70	0.08632	1.31349	0.23867	685.67	Sandy GRAVEL
	MW-2	1	11.5	12.8	58	36	6	1.21E-03	0.00	0.0419	2.18	1.92	0.29	2.69	0.39456	1.34559	0.25683	683.73	Silty Sandy GRAVEL
		2	19.0	20.0	60	33	7	1.21E-03	0.00	0.0339	1.76	1.92	0.29	2.69	0.39456	1.34559	0.25683	1,262.52	Silty Sandy GRAVEL
	MW-3	A2403	2.5	4.1	14	63	23	8.88E-04	0.00	0.0871	5.43	1.60	0.40	2.65	0.54741	1.28139	0.21960	1,439.99	Gravelly Silty SAND
		A2406	7.4	8.8	65	27	8	1.38E-05	0.00	0.0498	2.59	1.92	0.28	2.65	0.15633	1.39591	0.28362	500.55	Silty Sandy GRAVEL
		A2408	15.1	16.9	77	18	5	2.82E-04	0.00	0.0477	2.48	1.92	0.28	2.65	0.25119	1.60079	0.37531	75.32	Silty Sandy GRAVEL
		A2410	23.2	24.8	45	45	10	5.73E-04	0.00	0.0523	2.72	1.92	0.28	2.65	0.08632	1.31349	0.23867	2,443.02	Silty Sandy GRAVEL
		A2412	35.3	37.0	68	24	8	2.82E-04	0.00	0.0687	3.57	1.92	0.28	2.65	0.25119	1.60079	0.37531	40.66	Silty Sandy GRAVEL
		A2414	36.6	39.2	60	23	17	5.77E-04	0.00	0.0810	4.21	1.92	0.28	2.65	0.09123	1.28327	0.22074	360.18	Silty Sandy GRAVEL
	MW-4	1	8.5	9.5	48	46	6	1.21E-03	0.00	0.0385	2.00	1.92	0.29	2.69	0.39456	1.34456	0.25626	873.55	Silty Sandy GRAVEL
		2	16.0	17.0	40	55	5	2.82E-04	0.00	0.0577	3.00	1.92	0.29	2.70	0.25119	1.60079	0.37531	58.00	Sandy GRAVEL
		3	31.0	32.0	65	32	3	1.21E-03	0.00	0.0416	2.16	1.92	0.29	2.70	0.39456	1.34559	0.25683	698.11	Sandy GRAVEL
	MW-5	1	2.4	2.5	2	94	4	5.73E-04	0.00	0.0403	2.41	1.67	0.37	2.65	0.08632	1.31349	0.23867	13,658.10	SAND
		2	5.8	6.0	54	41	5	2.99E-04	0.00	0.0464	2.41	1.92	0.29	2.69	0.17633	1.36246	0.26603	889.51	Silty Sandy GRAVEL
		4	18.5	19.0	39	57	4	2.82E-04	0.00	0.0406	2.11	1.92	0.29	2.70	0.25119	1.60079	0.37531	104.66	Sandy GRAVEL
		5	34.5	35.0	75	22	3	2.82E-04	0.00	0.0283	1.47	1.92	0.29	2.69	0.25119	1.60079	0.37531	191.24	Silty Sandy GRAVEL
		6	48.0	48.5	72	22	6	5.77E-04	0.00	0.0877	4.56	1.92	0.29	2.69	0.09123	1.28327	0.22074	307.75	Silty Sandy GRAVEL
	MW-6	1	24.0	25.0	55	33	12	5.77E-04	0.00	0.0400	2.08	1.92	0.32	2.81	0.09123	1.28327	0.22074	6,985.41	Silty Sandy GRAVEL
		2	43.0	44.4	80	19	1	5.73E-04	0.00	0.0800	4.16	1.92	0.29	2.70	0.08632	1.31349	0.23867	702.29	Sandy GRAVEL
	MW-8	1	3.5	4.0	58	37	5	2.82E-04	0.00	0.0352	1.83	1.92	0.29	2.69	0.25119	1.60079	0.37531	132.87	Silty Sandy GRAVEL
	MW-9	1	4.6	5.2	51	36	13	5.77E-04	0.00	0.0587	3.05	1.92	0.29	2.69	0.09123	1.28327	0.22074	1,803.05	Silty Sandy GRAVEL
		2			59	33	8	2.41E-05	0.00	0.0317	1.65	1.92	0.29	2.69	0.15208	1.22993	0.18695	99,731.66	Silty Sandy GRAVEL
		3	14.1	15.2	23	73	4	2.99E-04	0.00	0.0474	2.83	1.67	0.37	2.66	0.17633	1.36246	0.26603	1,943.22	Gravelly SAND
	MW-10	1	9.5	10.5	22	73	5	2.99E-04	0.00	0.0413	2.47	1.67	0.37	2.66	0.17633	1.36246	0.26603	2,403.34	Gravelly SAND
		2	14.5	15.0	65	26	9	5.77E-04	0.00	0.0358	1.86	1.92	0.29	2.69	0.09123	1.28327	0.22074	10,334.21	Silty Sandy GRAVEL
		3	18.6	19.0	68	26	6	1.78E-04	0.00	0.0435	2.26	1.92	0.29	2.69	0.20954	1.34125	0.25443	1,238.51	Silty Sandy GRAVEL
	MW-11	1	8.6	9.4	51	46	3	2.99E-04	0.00	0.0314	1.63	1.92	0.29	2.70	0.17633	1.36246	0.26603	2,613.90	Sandy GRAVEL
	MW-12	1	1.0	1.5	0	98	2	5.77E-04	0.00	0.0686	4.10	1.67	0.37	2.65	0.08632	1.31349	0.23867	2,501.57	SAND
		2	3.5	4.0	9	68	23	8.88E-04	0.00	0.1068	6.66	1.60	0.41	2.70	0.54741	1.28139	0.21960	760.95	Slightly Gravelly Silty SAND
		3	5.5	6.0	9	82	9	1.80E-03	0.00	0.0336	2.03	1.65	0.39	2.71	0.07607	1.38880	0.27995	7,198.01	Slightly Gravelly SAND
		4	6.5	7.0	52	42	6	1.80E-03	0.00	0.0371	1.93	1.92	0.29	2.69	0.07607	1.38880	0.27995	2,603.09	Silty Sandy GRAVEL
		5	7.0	7.5	26	71	3	2.41E-05	0.00	0.0348	2.08	1.92	0.38	2.70	0.15208	1.22993	0.18695	215,341.03	Gravelly SAND
		6	10.0	10.5	61	33	6	2.82E-04	0.00	0.0552	2.87	1.92	0.29	2.69	0.25119	1.60079	0.37531	62.50	Silty Sandy GRAVEL
		7	11.5	12.0	46	50	4	1.78E-04	0.00	0.0487	2.53	1.92	0.29	2.70	0.20954	1.34125	0.25443	889.39	Sandy GRAVEL
		8	16.5	17.0	66	27	7	1.38E-05	0.00	0.0660	3.43	1.92	0.29	2.69	0.15633	1.39591	0.28362	267.93	Silty Sandy GRAVEL
		9	26.5	27.0	72	23	5	1.80E-03	0.00	0.0527	2.74	1.92	0.29	2.69	0.07607	1.38880	0.27995	1,054.16	Silty Sandy GRAVEL
		10	33.5	34.0	73	22	5	1.38E-05	0.00	0.0868	4.51	1.92	0.29	2.69	0.15633	1.39591	0.28362	133.27	Silty Sandy GRAVEL

Table 6-1: VADOSE ZONE MODELING PARAMETERS
(continued)

Operable Subunit Monitoring Wells	Borehole Number	Sample Number	Sample Depth		Soil Gradations LAB			Conductivity at Lab Saturation (cm/s)	Residual Moisture (THETA r)	Moisture Values In-Situ Moisture Content (THETA)	Moisture Weight % Measured	Bulk Density	Estimated Soil Porosity = Saturated Moisture Content (THETA s)	SpG	van Genuchten Parameters			Calculated Matric Potential (cm) (h)	Wentworth Soil Classification
			From	To	% G	% S	% M								a	n	m		
MW-13	1	9.5	10.0	62	35	3	1.78E-04	0.00	0.0535	2.78	1.92	0.29	2.70	0.20954	1.34125	0.25443	675.04	Sandy GRAVEL	
	2	13.0	13.5	47	51	2	5.73E-04	0.00	0.0448	2.33	1.92	0.29	2.70	0.08632	1.31349	0.23867	4,478.56	Sandy GRAVEL	
	3	14.0	14.5	63	30	7	2.82E-04	0.00	0.0446	2.32	1.92	0.29	2.69	0.25119	1.60079	0.37531	89.43	Silty Sandy GRAVEL	
	4	17.5	18.0	86	12	2	2.82E-04	0.00	0.0574	2.94	1.95	0.28	2.72	0.25119	1.60079	0.37531	55.15	GRAVEL	
	5	25.5	26.0	77	19	4	1.38E-05	0.00	0.0210	1.09	1.92	0.29	2.69	0.15633	1.39591	0.28362	4,851.06	Silty Sandy GRAVEL	
MW-14	1	7.6	8.8	53	39	8	1.38E-05	0.00	0.0866	4.50	1.92	0.29	2.69	0.15633	1.39591	0.28362	134.06	Silty Sandy GRAVEL	
	2	10.8	11.5	50	44	6	2.82E-04	0.00	0.0535	2.78	1.92	0.29	2.69	0.25119	1.60079	0.37531	62.10	Silty Sandy GRAVEL	
	3	20.5	21.0	82	16	2	2.82E-04	0.00	0.0467	2.39	1.95	0.28	2.72	0.25119	1.60079	0.37531	78.05	GRAVEL	
	4	21.5	22.0	58	31	11	1.38E-05	0.00	0.0265	1.38	1.92	0.29	2.69	0.15633	1.39591	0.28362	2,695.39	Silty Sandy GRAVEL	
MW-15	1	5.0	7.0	54	38	8	1.78E-04	0.00	0.0350	1.82	1.92	0.29	2.69	0.20954	1.34125	0.25443	2,342.59	Silty Sandy GRAVEL	
	2	9.0	10.0	55	40	5	2.82E-04	0.00	0.0402	2.09	1.92	0.29	2.69	0.25119	1.60079	0.37531	106.41	Silty Sandy GRAVEL	
	3	14.5	15.0	73	22	5	1.80E-03	0.00	0.0454	2.36	1.92	0.29	2.69	0.07607	1.38880	0.27995	1,547.94	Silty Sandy GRAVEL	
	4	19.5	20.0	72	24	4	1.80E-03	0.00	0.0352	1.83	1.92	0.29	2.69	0.07607	1.38880	0.27995	2,980.21	Silty Sandy GRAVEL	
	5	24.7	25.2	68	22	10	5.77E-04	0.00	0.0256	1.33	1.92	0.28	2.67	0.09123	1.28327	0.22074	21,072.42	Silty Sandy GRAVEL	
MW-17	2	15.0	16.0	72	23	5	2.82E-04	0.00	0.0335	1.74	1.92	0.29	2.69	0.25119	1.60079	0.37531	144.32	Silty Sandy GRAVEL	
	5	30.0	31.0	0	88	12	2.41E-05	0.00	0.1341	6.97	1.92	0.30	2.74	0.15208	1.22993	0.18695	215.76	Slightly Silty SAND	
	6	35.0	36.0	28	65	7	2.82E-04	0.00	0.0512	3.06	1.67	0.37	2.66	0.25119	1.60079	0.37531	106.72	Gravelly SAND	
	7	37.0	38.0	52	41	7	2.82E-04	0.00	0.1401	7.28	1.92	0.26	2.59	0.25119	1.60079	0.37531	9.75	Silty Sandy GRAVEL	
Sum						*****	1.07E-01	0.00	9.89	534.54	319.13	51.32	457.12	32.43114	236.42282	46.88822	984,584.76		
n						168	168	168	168	168	168	168	168	168	168	168	168	168	
Average						50	42	9	6.38E-04	0.00	0.06	3.18	1.90	0.31	2.72	0.19304	1.40728	0.27910	5,860.62

- NOTES:
- Bulk density values estimated from table 3.5, Geotechnical Engineering Analysis and Design, R.E. Hunt.
 - Specific gravity values from lab testing were used for all similarly classified soils; the average of measured Silty Sandy Gravel specific gravity analyses were used in the similar soil type where no testing was performed; all other values were estimated.
 - Soil porosity calculated from $(1 - (\text{bulk density} / \text{specific gravity}))$. Soil porosity is assumed equal to the saturated moisture content.
 - Soil in-situ moisture calculated from $((\text{bulk density} * \text{weight \% measured}) / 0.998) / 100$. Units in cubic cm./cubic cm. 0.998 = grams water per cubic cm.
 - Soil residual moisture value of zero was the recommended value for sands and gravels per Mr. Michael Fayer, PNL.
 - Van Genuchten parameters derived from first converting lab gradations to exclude particle sizes >2mm diameter. Second, the converted gradation curves were visually compared to curves for soils listed in the document, Simulations of Infiltration of Meteoric Water and Contaminant Plume Movement in the Vadose Zone at Single-Shell Tank 241-T-106 at the Hanford Site*, WHC-EP-0332. Finally, values listed in the publication for the van Genuchten parameters were assigned to 1100-EM-1 soils having the closest gradation curve match.
 - Soil Conductivity at Lab Saturation was obtained in the same method as the van Genuchten parameters (see note 6).
 - Calculated matric potential was obtained using an HP28S calculator and the formula:

$$\frac{((\text{in-situ moisture} - \text{residual moisture}) / (\text{saturated moisture} - \text{residual moisture}))^{(1/m)} - 1}{(1/n)/a}$$
 - Shaded rows indicate questionably high in-situ moisture values. Not intended for use.
 - Wentworth Soil Classification entries based on laboratory particle size gradations, NOT on field log gradations.

Table 6-2: VADOSE ZONE MODELING PARAMETERS
BROOKS-COREY MODEL

Borehole Number	Sample Number	Sample Depth		Soil Gradations LAB			Soil Conductivity at Lab Saturation Ks(cm/s)	In-Situ Soil Conduct. KI(cm/sec)	Residual Moisture (THETA r)	Moisture Values In-Situ Moisture Content (THETA)	Moisture Weight % Measured	Bulk Density	Estimated Soil Porosity = Saturated Moisture Content (THETA s)	Brooks-Corey Parameters			Calculated Matric Potential (cm) (h)	Wentworth Soil Classification	
		From	To	% G	% S	% M								he	b	b'			
BAP-2	A0202	5.5	6.5	58	33	9												Silty Sandy GRAVEL	
	A0203	8.3	9.6	60	27	13	5.77E-04	3.41E-13	0.00	0.0346	1.80	1.92	0.29	2.69	10.96131	3.53020	3.00000	18,971.38	Silty Sandy GRAVEL
	A0208	19.5	21.0	58	33	9	2.82E-04	8.60E-10	0.00	0.0385	2.00	1.92	0.29	2.69	3.98105	1.66448	3.00000	112.37	Silty Sandy GRAVEL
	A0210	34.4	35.4	78	15	7	5.77E-04	2.57E-12	0.00	0.0423	2.20	1.92	0.29	2.69	10.96131	3.53020	3.00000	9,342.03	Silty Sandy GRAVEL
HRL-1	A0302	7.0	8.0	68	22	10	5.77E-04	1.92E-13	0.00	0.0327	1.70	1.92	0.29	2.69	10.96131	3.53020	3.00000	23,212.99	Silty Sandy GRAVEL
	A0307	15.0	16.0	7	83	10	2.99E-04	4.22E-11	0.00	0.0602	3.60	1.67	0.38	2.71	5.67118	2.75893	3.00000	938.28	Slightly Silty Slightly Gravelly SAND
DP-7	A0101	0.7	2.0	54	36	10	1.38E-05	5.76E-12	0.00	0.0462	2.40	1.92	0.29	2.69	6.39672	2.52583	3.00000	641.67	Silty Sandy GRAVEL
	A0105	16.5	18.0	70	23	7	2.82E-04	2.09E-10	0.00	0.0308	1.60	1.92	0.29	2.69	3.98105	1.66448	3.00000	162.91	Silty Sandy GRAVEL
	A0109	28.4	30.0	25	62	13	2.82E-04	1.29E-09	0.00	0.0593	3.70	1.60	0.41	2.73	3.98105	1.66448	3.00000	101.01	Slightly Silty Gravelly SAND
BAP-1	A1002S	2.2	4.2	26	55	19	1.38E-05	3.23E-09	0.00	0.1427	8.90	1.60	0.40	2.68	6.39672	2.52583	3.00000	88.08	Gravelly Silty SAND
	A1006S	6.1	6.8	54	27	19	8.88E-04	7.76E-09	0.00	0.0904	4.70	1.92	0.29	2.69	1.82678	3.55379	3.00000	109.71	Silty Sandy GRAVEL
	A1009S	7.8	8.6	42	37	21	5.77E-04	4.14E-11	0.00	0.0558	2.90	1.92	0.29	2.69	10.96131	3.53020	3.00000	3,522.93	Silty Sandy GRAVEL
	A1013S	13.4	13.9	44	43	13	5.77E-04	1.11E-10	0.00	0.0616	3.20	1.92	0.29	2.69	10.96131	3.53020	3.00000	2,488.75	Silty Sandy GRAVEL
	A1015S	16.3	17.5	65	28	7	1.21E-03	9.07E-11	0.00	0.0442	2.30	1.92	0.29	2.69	2.53447	2.89360	3.00000	562.52	Silty Sandy GRAVEL
DP-4	A0402S	0.8	1.4	34	55	11	1.78E-04	1.00E-15	0.00	0.0154	0.80	1.92	0.29	2.69	4.77236	2.93040	3.00000	25,050.39	Silty Sandy GRAVEL
	A0404S	1.9	3.1	31	51	18	2.99E-04	6.18E-10	0.00	0.0616	3.20	1.92	0.29	2.69	5.67118	2.75893	3.00000	393.58	Silty Sandy GRAVEL
	A0406S	3.3	5.1																
	A0410S	10.7	12.4	64	28	8	1.78E-04	2.44E-11	0.00	0.0481	2.50	1.92	0.29	2.69	4.77236	2.93040	3.00000	888.60	Silty Sandy GRAVEL
	A0412S	16.0	17.0	60	32	8	1.38E-05	1.49E-11	0.00	0.0519	2.70	1.92	0.29	2.69	6.39672	2.52583	3.00000	476.55	Silty Sandy GRAVEL
DP-5	A0503S	2.6	3.6	48	39	13	8.88E-04	5.89E-11	0.00	0.0558	2.90	1.92	0.29	2.69	1.82678	3.55379	3.00000	610.21	Silty Sandy GRAVEL
	A0505S	6.6	7.1	35	48	17	2.24E-04	1.24E-08	0.00	0.1039	5.40	1.92	0.29	2.69	2.05436	3.33689	3.00000	60.46	Silty Sandy GRAVEL
	A0509S	10.0	11.0	48	45	7	5.73E-04	6.24E-09	0.00	0.0846	4.40	1.92	0.29	2.69	11.58480	3.18989	3.00000	564.56	Silty Sandy GRAVEL
	A0512S	15.0	15.7	33	60	7	1.21E-03	5.83E-08	0.00	0.0923	4.80	1.92	0.29	2.69	2.53447	2.89360	3.00000	66.93	Silty Sandy GRAVEL
	A0513S	16.2	18.0	4	93	3	2.99E-04	2.15E-10	0.00	0.0703	4.20	1.67	0.37	2.65	5.67118	2.75893	3.00000	553.68	SAND
DP-6	A0603S	0.5	2.0	42	45	13	5.77E-04	5.77E-15	0.00	0.0231	1.20	1.92	0.29	2.69	10.96131	3.53020	3.00000	79,384.61	Silty Sandy GRAVEL
	A0604S	2.5	3.7	36	42	22	5.77E-04	1.04E-13	0.00	0.0308	1.60	1.92	0.29	2.69	10.96131	3.53020	3.00000	28,752.63	Silty Sandy GRAVEL
	A0607S	4.2	5.7	39	41	20	1.38E-05	6.30E-10	0.00	0.0827	4.30	1.92	0.29	2.69	6.39672	2.52583	3.00000	147.11	Silty Sandy GRAVEL
	A0609S	7.9	9.0	54	38	8	1.21E-03	9.07E-11	0.00	0.0442	2.30	1.92	0.29	2.69	2.53447	2.89360	3.00000	562.52	Silty Sandy GRAVEL
	A0611S	12.8	13.8	32	61	7	1.21E-03	1.65E-09	0.00	0.0616	3.20	1.92	0.29	2.69	2.53447	2.89360	3.00000	216.34	Silty Sandy GRAVEL
	A0614S	16.3	17.3	14	79	7	5.73E-04	7.25E-12	0.00	0.0535	3.20	1.67	0.37	2.66	11.58480	3.18989	3.00000	5,621.29	Gravelly SAND
DP-9	A1102S	2.6	3.6	43	40	17	1.38E-05	1.10E-11	0.00	0.0500	2.60	1.92	0.29	2.69	6.39672	2.52583	3.00000	524.22	Silty Sandy GRAVEL
	A1104S	6.75	7.1	51	34	15	5.77E-04	1.88E-09	0.00	0.1154	7.20	1.60	0.41	2.69	10.96131	3.53020	3.00000	922.71	Silty Sandy GRAVEL
	A1108S	9.0	9.2	23	69	8	1.21E-03	5.46E-09	0.00	0.0731	3.80	1.92	0.30	2.73	2.53447	2.89360	3.00000	145.97	Slightly Silty Gravelly SAND
	A1109S	9.2	11.5	25	70	5	2.99E-04	1.08E-10	0.00	0.0653	3.90	1.67	0.37	2.66	5.67118	2.75893	3.00000	631.36	Gravelly SAND
	A1110S	9.2	11.5	21	72	7	2.99E-04	6.36E-07	0.00	0.1807	10.80	1.67	0.37	2.66	5.67118	2.75893	3.00000	41.62	Gravelly SAND
	A1112S	13.5	14.5	18	76	6	2.99E-04	1.73E-08	0.00	0.0885	4.60	1.92	0.28	2.66	5.67118	2.75893	3.00000	133.67	Gravelly SAND
	A1113S	15.5	16.5	26	66	8	5.73E-04	1.45E-11	0.00	0.0641	4.00	1.60	0.41	2.73	11.58480	3.18989	3.00000	4,438.91	Slightly Silty Gravelly SAND
	A1117S	21.8	22.1	45	49	6	2.82E-04	1.12E-08	0.00	0.0577	3.00	1.92	0.29	2.69	3.98105	1.66448	3.00000	57.22	Silty Sandy GRAVEL
	A1120S	25.0	26.0	69	24	7	1.21E-03	3.71E-10	0.00	0.0519	2.70	1.92	0.29	2.69	2.53447	2.89360	3.00000	353.70	Silty Sandy GRAVEL
	A1122S	31.1	32.1	62	28	10	2.82E-04	3.53E-09	0.00	0.0481	2.50	1.92	0.29	2.69	3.98105	1.66448	3.00000	77.51	Silty Sandy GRAVEL
	A1124S	35.5	36.8	60	29	11	5.77E-04	4.80E-10	0.00	0.0712	3.70	1.92	0.29	2.69	10.96131	3.53020	3.00000	1,490.72	Silty Sandy GRAVEL
DP-1	A0902S	4.0	5.1	46	42	12	1.21E-03	1.89E-10	0.00	0.0481	2.50	1.92	0.29	2.69	2.53447	2.89360	3.00000	441.93	Silty Sandy GRAVEL
	A0905S	6.9	7.9	48	42	10	1.78E-04	1.70E-11	0.00	0.0462	2.40	1.92	0.29	2.69	4.77236	2.93040	3.00000	1,001.51	Silty Sandy GRAVEL
	A0908S	11.9	12.9	15	73	12	1.38E-05	6.46E-11	0.00	0.0830	4.90	1.69	0.38	2.73	6.39672	2.52583	3.00000	300.50	Slightly Silty Gravelly SAND
	A0911S	15.5	16.5	2	91	7	5.73E-04	2.04E-09	0.00	0.0971	5.80	1.67	0.37	2.65	11.58480	3.18989	3.00000	826.25	SAND
DP-2	A0802S	2.0	3.5	39	51	10	1.21E-03	6.03E-13	0.00	0.0250	1.30	1.92	0.29	2.69	2.53447	2.89360	3.00000	2,931.74	Silty Sandy GRAVEL
	A0804S	6.5	8.0	54	36	10	2.82E-04	5.74E-09	0.00	0.0519	2.70	1.92	0.29	2.69	3.98105	1.66448	3.00000	68.19	Silty Sandy GRAVEL
	A0806S	8.5	10.2	9	86	5	1.78E-04	3.27E-11	0.00	0.0647	3.80	1.70	0.37	2.71	4.77236	2.93040	3.00000	806.44	Slightly Gravelly SAND
	A0807S	12.6	14.3	10	82	8	5.73E-04	5.41E-11	0.00	0.0664	3.90	1.70	0.37	2.71	11.58480	3.18989	3.00000	2,836.06	Slightly Gravelly SAND
	A0809S	15.0	16.0	40	47	13	2.82E-04	7.23E-09	0.00	0.0539	2.80	1.92	0.29	2.69	3.98105	1.66448	3.00000	64.18	Silty Sandy GRAVEL
	A0811S	17.6	20.0	14	79	7	1.21E-03	1.36E-10	0.00	0.0602	3.60	1.67	0.37	2.66	2.53447	2.89360	3.00000	492.42	Gravelly SAND

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Table 6-2: VADOSE ZONE MODELING PARAMETERS
(continued)

Borehole Number	Sample Number	Sample Depth From	Sample Depth To	Soil Gradations			Soil Conductivity		In-Situ Soil Conduct.		Residual Moisture (THETA r)	Moisture Values In-Situ		Bulk Density	SpG	Brooks-Corey Parameters			Calculated Metric Potential (cm)	Soil Classification	Wetworth Soil
				% G	% S	% M	Ks (cm/s)	Kl (cm/sec)	Moisture Content (THETA)	Moisture Weight % Measured		he	b			b'					
DP-3	A0703S	2.3	3.3	41	40	19	8.88E-04	4.00E-13	0.00	0.0289	1.50	1.92	0.29	2.69	11.58460	3.18989	3.00000	17,480.08	Silty Sandy GRAVEL		
	A0705S	7.1	8.1	60	35	5	3.64E-03	2.39E-09	0.00	0.0481	2.50	1.92	0.29	2.69	9.92654	2.49085	3.00000	843.87	Silty Sandy GRAVEL		
	A0707S	10.1	10.8	14	81	5	2.99E-04	3.03E-10	0.00	0.0736	4.40	1.67	0.37	2.66	5.67118	2.75893	3.00000	495.64	Gravelly SAND		
	A0710S	13.2	14.3	3	94	3	2.99E-04	7.31E-11	0.00	0.0619	3.70	1.67	0.37	2.65	5.67118	2.75893	3.00000	785.47	SAND		
	A0710S	15.2	16.0	5	93	2	2.99E-04	6.41E-11	0.00	0.0645	3.90	1.65	0.39	2.71	5.67118	2.75893	3.00000	819.76	Silty Gravelly SAND		
	A1202S	2.5	3.7	41	47	12	3.64E-03	4.05E-11	0.00	0.0289	1.50	1.92	0.29	2.69	9.92654	2.49085	3.00000	3,012.09	Silty Sandy GRAVEL		
	A1207S	7.7	8.9	42	49	9	5.73E-04	6.05E-12	0.00	0.0404	2.10	1.92	0.29	2.69	11.58460	3.18989	3.00000	5,976.00	Silty Sandy GRAVEL		
HRL-2	A1212S	15.1	16.1	54	40	6	2.82E-04	8.60E-10	0.00	0.0385	2.00	1.92	0.29	2.69	9.98105	1.66448	3.00000	112.37	Silty Sandy GRAVEL		
	A1214S	18.3	18.7	34	56	10	2.82E-04	1.17E-09	0.00	0.0404	2.10	1.92	0.29	2.69	3.98105	1.66448	3.00000	103.61	Silty Sandy GRAVEL		
	A1215S	20.5	22.2	17	73	10	1.21E-03	4.99E-12	0.00	0.0423	2.50	1.59	0.38	2.73	2.53447	2.89360	3.00000	1,461.80	Silty Gravelly SAND		
	A1216S	23.7	26.4	19	73	8	1.21E-03	2.74E-11	0.00	0.0502	3.00	1.67	0.37	2.66	2.53447	2.89360	3.00000	834.56	Gravelly SAND		
	A1218S	26.4	27.4	54	33	13	5.77E-04	9.84E-13	0.00	0.0385	2.00	1.92	0.29	2.69	10.96131	3.53020	3.00000	13,078.73	Silty Sandy GRAVEL		
	A1220S	30.2	31.4	54	39	7	2.82E-04	2.08E-09	0.00	0.0442	2.30	1.92	0.29	2.69	3.98105	1.66448	3.00000	89.05	Silty Sandy GRAVEL		
	A1803S	3.4	4.8	51	35	14	5.77E-04	8.09E-11	0.00	0.0596	3.10	1.92	0.29	2.69	10.96131	3.53020	3.00000	2,783.92	Silty Sandy GRAVEL		
	A1806S	8.0	9.9	36	54	10	2.82E-04	4.41E-10	0.00	0.0346	1.80	1.92	0.29	2.69	3.98105	1.66448	3.00000	133.91	Silty Sandy GRAVEL		
	A1809S	12.5	13.5	54	34	12	5.77E-04	1.92E-13	0.00	0.0327	1.70	1.92	0.29	2.69	10.96131	3.53020	3.00000	23,212.99	Silty Sandy GRAVEL		
	A1811S	16.5	17.6	58	29	13	5.77E-04	1.92E-13	0.00	0.0327	1.70	1.92	0.29	2.69	10.96131	3.53020	3.00000	23,212.99	Silty Sandy GRAVEL		
HRL-3	A1813S	20.0	21.7	48	35	17	5.77E-04	4.02E-12	0.00	0.0442	2.30	1.92	0.29	2.69	10.96131	3.53020	3.00000	7,985.28	Silty Sandy GRAVEL		
	A2003S	3.2	4.4	54	34	12	2.82E-04	7.73E-09	0.00	0.0544	2.83	1.92	0.29	2.69	9.92654	2.49085	3.00000	392.33	Silty Sandy GRAVEL		
	A2006S	8.0	9.3	68	24	8	5.77E-04	8.82E-11	0.00	0.0462	2.40	1.92	0.29	2.69	10.96131	3.53020	3.00000	6,871.32	Silty Sandy GRAVEL		
	A2008S	13.3	14.5	47	45	8	2.82E-04	6.01E-07	0.00	0.1083	5.63	1.92	0.29	2.69	3.98105	1.66448	3.00000	20.07	Silty Sandy GRAVEL		
	A2011S	17.6	18.8	61	29	10	5.77E-04	4.14E-11	0.00	0.0558	2.90	1.92	0.29	2.69	10.96131	3.53020	3.00000	3,529.93	Silty Sandy GRAVEL		
	A2013S	22.0	23.2	68	25	7	5.77E-04	3.35E-10	0.00	0.0687	3.57	1.92	0.29	2.69	10.96131	3.53020	3.00000	1,691.35	Silty Sandy GRAVEL		
	A2203S	3.2	4.6	56	34	10	3.64E-03	2.78E-08	0.00	0.0654	3.40	1.92	0.29	2.69	9.92654	2.49085	3.00000	392.33	Silty Sandy GRAVEL		
	A2206S	8.2	9.7	66	24	10	5.77E-04	6.16E-12	0.00	0.0462	2.40	1.92	0.29	2.69	10.96131	3.53020	3.00000	6,871.32	Silty Sandy GRAVEL		
	A2209S	13.6	14.4	37	48	15	2.82E-04	1.68E-08	0.00	0.0616	3.20	1.92	0.29	2.69	3.98105	1.66448	3.00000	51.39	Silty Sandy GRAVEL		
	A2211S	17.4	18.9	59	28	13	5.77E-04	2.04E-12	0.00	0.0414	2.15	1.92	0.29	2.69	10.96131	3.53020	3.00000	10,131.82	Silty Sandy GRAVEL		
HRL-4	A2213S	21.5	23.5	71	22	7	5.77E-04	9.20E-11	0.00	0.0604	3.14	1.92	0.29	2.69	10.96131	3.53020	3.00000	2,660.73	Silty Sandy GRAVEL		
	A1503S	3.8	6.0	60	35	5	1.78E-04	2.23E-07	0.00	0.1347	7.00	1.92	0.29	2.69	4.77236	2.93040	3.00000	43.49	Silty Sandy GRAVEL		
	A1505S	8.6	9.4	53	37	10	3.64E-03	5.46E-08	0.00	0.0712	3.70	1.92	0.29	2.69	9.92654	2.49085	3.00000	317.82	Silty Sandy GRAVEL		
	A1508S	11.8	13.1	59	28	13	5.77E-04	2.04E-12	0.00	0.0414	2.15	1.92	0.29	2.69	10.96131	3.53020	3.00000	10,131.82	Silty Sandy GRAVEL		
	A1511S	15.5	16.0	51	30	19	5.77E-04	9.19E-14	0.00	0.0304	1.58	1.92	0.29	2.69	10.96131	3.53020	3.00000	30,058.18	Silty Sandy GRAVEL		
	A1514S	21.9	22.8	48	32	20	5.77E-04	1.04E-13	0.00	0.0308	1.60	1.92	0.29	2.69	10.96131	3.53020	3.00000	28,752.63	Silty Sandy GRAVEL		
	A1604S	7.1	9.4	65	33	2	1.78E-04	4.10E-04	0.00	0.3174	10.50	1.92	0.29	2.70	4.77236	2.93040	3.00000	3.62	Sandy GRAVEL		
	A1606S	9.4	11.6	75	21	4	2.82E-04	3.86E-07	0.00	0.1010	5.25	1.92	0.29	2.69	3.98105	1.66448	3.00000	22.54	Silty Sandy GRAVEL		
	A1609S	16.2	18.5	80	18	2	2.82E-04	1.10E-05	0.00	0.1731	9.00	1.92	0.29	2.70	3.98105	1.66448	3.00000	9.33	Sandy GRAVEL		
	A1610S	18.5	20.8	80	18	2	2.82E-04	1.10E-05	0.00	0.1731	9.00	1.92	0.29	2.70	3.98105	1.66448	3.00000	9.33	Sandy GRAVEL		
HRL-5	A1611S	21.5	23.0	51	35	14	5.77E-04	9.29E-12	0.00	0.0481	2.50	1.92	0.29	2.69	10.96131	3.53020	3.00000	5,949.14	Silty Sandy GRAVEL		
	A1614S	24.2	25.0	32	41	27	5.77E-04	6.22E-14	0.00	0.0292	1.52	1.92	0.29	2.69	10.96131	3.53020	3.00000	34,460.19	Silty Sandy GRAVEL		
	A1615S	25.0	25.2	36	38	26	8.88E-04	5.73E-14	0.00	0.0281	1.46	1.92	0.29	2.69	18.26784	3.55379	3.00000	69,930.69	Silty Sandy GRAVEL		
	A1616S	25.8	27.8	74	20	6	5.77E-04	1.66E-10	0.00	0.0641	3.33	1.92	0.29	2.69	10.96131	3.53020	3.00000	2,162.96	Silty Sandy GRAVEL		
	A2302S	2.7	4.3	70	23	7	3.64E-03	2.14E-08	0.00	0.0633	3.29	1.92	0.29	2.69	9.92654	2.49085	3.00000	425.82	Silty Sandy GRAVEL		
	A2305S	7.3	8.4	58	30	12	5.77E-04	9.29E-12	0.00	0.0481	2.50	1.92	0.29	2.69	10.96131	3.53020	3.00000	5,949.14	Silty Sandy GRAVEL		
	A2309S	11.2	12.2	58	30	12	3.64E-03	2.39E-09	0.00	0.0481	2.50	1.92	0.29	2.69	9.92654	2.49085	3.00000	843.87	Silty Sandy GRAVEL		
	A2311S	15.3	16.5	64	23	13	5.77E-04	2.88E-13	0.00	0.0341	1.77	1.92	0.29	2.69	10.96131	3.53020	3.00000	20,131.06	Silty Sandy GRAVEL		
	A2313S	19.0	20.0	56	29	15	5.77E-04	6.86E-13	0.00	0.0371	1.93	1.92	0.29	2.69	10.96131	3.53020	3.00000	14,831.58	Silty Sandy GRAVEL		
	HRL-6	A1403S	2.5	4.4	79	16	5	5.77E-04	1.11E-10	0.00	0.0616	3.20	1.92	0.29	2.69	10.96131	3.53020	3.00000	2,488.75	Silty Sandy GRAVEL	
A1405S		7.5	8.2	24	54	22	1.38E-05	7.33E-12	0.00	0.0471	2.45	1.92	0.28	2.68	6.39672	2.52583	3.00000	594.90	Gravelly Silty SAND		
A1408S		10.9	12.8	64	21	15	8.88E-04	3.75E-14	0.00	0.0269	1.40	1.92	0.29	2.69	1.82678	3.55379	3.00000	6,117.74	Silty Sandy GRAVEL		
A1410S		17.6	18.8	66	24	10	1.38E-05	5.76E-12	0.00	0.0462	2.40	1.92	0.29	2.69	6.39672	2.52583	3.00000	641.67	Silty Sandy GRAVEL		
A1413S		22.6	23.1	48	29	23	5.77E-04	9.43E-15	0.00	0.0242	1.26	1.92	0.29	2.69	10.96131	3.53020	3.00000	65,824.21	Silty Sandy GRAVEL		

Table 6-2
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Table 6-2: VADOSE ZONE MODELING PARAMETERS
(continued)

Borehole Number	Sample Number	Sample Depth		Soil Gradations LAB			Soil Conductivity at Lab	In-Situ Soil Conduct.	Residual Moisture	Moisture Values In-Situ	Moisture Weight % Measured	Bulk Density	Estimated Soil Porosity = Saturated Moisture Content			Brooks-Corey Parameters			Calculated Matric Potential (cm) (h)	Wertworth Soil Classification
		From	To	% G	% S	% M	Ks(cm/s)	Kl(cm/sec)	(THETA r)	(THETA s)	(THETA s)		SpG	he	b	b'				
					2	3	4	5	6	7	8		9	10	11	12	13	14		
HRL-9	A1703S	2.8	3.7	58	32	10	2.82E-04	1.68E-08	0.00	0.0616	3.20	1.92	0.29	2.69	3.98105	1.66448	3.00000	51.39	Silty Sandy GRAVEL	
	A1705S	5.0	5.8	51	31	18	5.77E-04	2.16E-13	0.00	0.0331	1.72	1.92	0.29	2.69	10.96131	3.53020	3.00000	22,274.06	Silty Sandy GRAVEL	
	A1708S	9.4	10.4	65	25	10	5.77E-04	9.29E-12	0.00	0.0481	2.50	1.92	0.29	2.69	10.96131	3.53020	3.00000	5,949.14	Silty Sandy GRAVEL	
	A1711S	14.2	15.2	69	21	10	5.77E-04	1.61E-12	0.00	0.0404	2.10	1.92	0.29	2.69	10.96131	3.53020	3.00000	11,009.39	Silty Sandy GRAVEL	
	A1713S	20.4	21.7	74	19	7	2.82E-04	5.88E-09	0.00	0.0521	2.71	1.92	0.29	2.69	3.98105	1.66448	3.00000	67.77	Silty Sandy GRAVEL	
HRL-10	A1907S	9.1	11.4	73	21	6	2.82E-04	3.53E-09	0.00	0.0481	2.50	1.92	0.29	2.69	3.98105	1.66448	3.00000	77.51	Silty Sandy GRAVEL	
	A1908S	11.4	13.7	54	37	9	2.82E-04	1.57E-09	0.00	0.0423	2.20	1.92	0.29	2.69	3.98105	1.66448	3.00000	95.89	Silty Sandy GRAVEL	
	A1910S	16.9	17.8	32	51	17	5.77E-04	4.80E-10	0.00	0.0712	3.70	1.92	0.29	2.69	10.96131	3.53020	3.00000	1,490.72	Silty Sandy GRAVEL	
	A1911S	17.8	20.1	63	30	7	2.82E-04	1.12E-08	0.00	0.0577	3.00	1.92	0.29	2.69	3.98105	1.66448	3.00000	57.22	Silty Sandy GRAVEL	
	A1913S	27.9	30.3	81	17	2	3.64E-03	4.39E-08	0.00	0.0693	3.60	1.92	0.29	2.69	9.92554	2.49085	3.00000	340.27	Silty Sandy GRAVEL	
MW-1	1	10.5	12.1	73	22	5	5.77E-04	9.43E-15	0.00	0.0242	1.26	1.92	0.29	2.69	10.96131	3.53020	3.00000	66,824.21	Silty Sandy GRAVEL	
	2	21.0	22.0	63	33	4	2.28E-04	4.04E-08	0.00	0.0731	3.60	1.92	0.29	2.69	3.98105	1.66448	3.00000	38.61	Silty Sandy GRAVEL	
	3	29.3	31.3	60	35	5	2.28E-04	4.98E-09	0.00	0.0525	2.73	1.92	0.29	2.69	3.98105	1.66448	3.00000	66.95	Silty Sandy GRAVEL	
	4	34.0	35.0	86	13	1	1.78E-04	1.45E-12	0.00	0.0346	1.77	1.95	0.28	2.72	4.77236	2.93040	3.00000	2,261.11	GRAVEL	
	5	40.0	41.7	32	64	4	5.73E-04	3.62E-09	0.00	0.0806	4.19	1.92	0.29	2.70	11.58480	3.18989	3.00000	679.51	Sandy GRAVEL	
MW-2	1	11.5	12.8	58	36	6	1.21E-03	5.67E-11	0.00	0.0419	2.18	1.92	0.29	2.69	2.53447	2.89360	3.00000	656.86	Silty Sandy GRAVEL	
	2	19.0	20.0	60	33	7	1.21E-03	8.64E-12	0.00	0.0339	1.76	1.92	0.29	2.69	2.53447	2.89360	3.00000	1,220.16	Silty Sandy GRAVEL	
MW-3	A2403	2.5	4.1	14	63	23	8.88E-04	1.98E-10	0.00	0.0871	5.43	1.60	0.40	2.65	1.82678	3.55379	3.00000	398.68	Gravelly Silty SAND	
	A2406	7.4	8.8	65	27	8	1.38E-05	1.45E-11	0.00	0.0498	2.59	1.92	0.28	2.65	6.39672	2.52583	3.00000	480.46	Silty Sandy GRAVEL	
	A2408	15.1	16.9	77	18	5	2.82E-04	4.28E-09	0.00	0.0477	2.48	1.92	0.28	2.65	3.98105	1.66448	3.00000	73.69	Silty Sandy GRAVEL	
	A2410	23.2	24.8	45	45	10	5.73E-04	9.82E-11	0.00	0.0523	2.72	1.92	0.28	2.65	11.58480	3.18989	3.00000	2,316.75	Silty Sandy GRAVEL	
	A2412	35.3	37.0	68	24	8	2.82E-04	4.29E-08	0.00	0.0687	3.57	1.92	0.28	2.65	3.98105	1.66448	3.00000	40.19	Silty Sandy GRAVEL	
A2414	36.6	39.2	60	23	17	5.77E-04	2.59E-09	0.00	0.0810	4.21	1.92	0.28	2.65	10.96131	3.53020	3.00000	825.28	Silty Sandy GRAVEL		
MW-4	1	8.5	9.5	48	46	6	1.21E-03	2.57E-11	0.00	0.0385	2.00	1.92	0.29	2.69	2.53447	2.90226	3.00000	857.66	Silty Sandy GRAVEL	
	2	16.0	17.0	40	55	5	2.82E-04	1.06E-08	0.00	0.0577	3.00	1.92	0.29	2.70	3.98105	1.66448	3.00000	58.10	Sandy GRAVEL	
	3	31.0	32.0	65	32	3	1.21E-03	4.82E-11	0.00	0.0416	2.16	1.92	0.29	2.70	2.53447	2.89360	3.00000	692.80	Sandy GRAVEL	
MW-5	1	2.4	2.5	2	94	4	5.73E-04	5.39E-13	0.00	0.0403	2.41	1.67	0.37	2.65	11.58480	3.18989	3.00000	13,607.25	SAND	
	2	5.8	6.0	54	41	5	2.99E-04	5.52E-11	0.00	0.0464	2.41	1.92	0.29	2.69	5.67118	2.75893	3.00000	860.49	Silty Sandy GRAVEL	
	4	18.5	19.0	39	57	4	2.82E-04	1.14E-09	0.00	0.0406	2.11	1.92	0.29	2.70	3.98105	1.66448	3.00000	104.37	Sandy GRAVEL	
	5	34.5	35.0	75	22	3	2.82E-04	1.22E-10	0.00	0.0283	1.47	1.92	0.29	2.69	3.98105	1.66448	3.00000	187.59	Silty Sandy GRAVEL	
	6	48.0	48.5	72	22	6	5.77E-04	3.93E-09	0.00	0.0877	4.56	1.92	0.29	2.69	10.96131	3.53020	3.00000	712.83	Silty Sandy GRAVEL	
MW-6	1	24.0	25.0	55	33	12	5.77E-04	5.28E-13	0.00	0.0400	2.08	1.92	0.32	2.81	10.96131	3.53020	3.00000	16,276.84	Silty Sandy GRAVEL	
	2	43.0	44.4	80	19	1	5.73E-04	3.38E-09	0.00	0.0800	4.16	1.92	0.29	2.70	11.58480	3.18989	3.00000	695.26	Sandy GRAVEL	
MW-8	1	3.5	4.0	58	37	5	2.82E-04	4.90E-10	0.00	0.0352	1.83	1.92	0.29	2.69	3.98105	1.66448	3.00000	130.28	Silty Sandy GRAVEL	
MW-9	1	4.6	5.2	51	36	13	5.77E-04	6.87E-11	0.00	0.0587	3.05	1.92	0.29	2.69	10.96131	3.53020	3.00000	2,948.40	Silty Sandy GRAVEL	
	2			59	33	8	2.41E-05	1.62E-16	0.00	0.0317	1.65	1.92	0.29	2.69	6.57549	4.34915	3.00000	93,698.02	Silty Sandy GRAVEL	
	3	14.1	15.2	23	73	4	2.99E-04	7.06E-12	0.00	0.0474	2.83	1.67	0.37	2.66	5.67118	2.75893	3.00000	1,674.80	Gravelly SAND	
MW-10	1	9.5	10.5	22	73	5	2.99E-04	2.22E-12	0.00	0.0413	2.47	1.67	0.37	2.66	5.67118	2.75893	3.00000	2,437.74	Gravelly SAND	
	2	14.5	15.0	65	26	9	5.77E-04	4.74E-13	0.00	0.0358	1.86	1.92	0.29	2.69	10.96131	3.53020	3.00000	16,897.69	Silty Sandy GRAVEL	
	3	18.6	19.0	68	26	6	1.78E-04	9.96E-12	0.00	0.0435	2.26	1.92	0.29	2.69	4.77236	2.93040	3.00000	1,194.40	Silty Sandy GRAVEL	
MW-11	1	8.6	9.4	51	46	3	2.99E-04	1.83E-12	0.00	0.0314	1.63	1.92	0.29	2.70	5.67118	2.75893	3.00000	2,596.00	Sandy GRAVEL	
MW-12	1	1.0	1.5	0	98	2	5.77E-04	7.92E-11	0.00	0.0686	4.10	1.67	0.37	2.65	11.58480	3.18989	3.00000	2,498.32	SAND	
	2	3.5	4.0	9	68	23	8.88E-04	1.18E-09	0.00	0.1068	6.56	1.60	0.41	2.70	1.82678	3.55379	3.00000	213.03	Slightly Gravelly Silty SAND	
	3	5.5	6.0	9	82	9	1.80E-03	3.71E-12	0.00	0.0336	2.03	1.65	0.39	2.71	13.14579	2.57202	3.00000	7,274.60	Slightly Gravelly SAND	
	4	6.5	7.0	52	42	6	1.80E-03	1.08E-10	0.00	0.0371	1.93	1.92	0.29	2.69	13.14579	2.57202	3.00000	2,513.00	Silty Sandy GRAVEL	
	5	7.0	7.5	26	71	3	2.41E-05	1.65E-17	0.00	0.0348	2.08	1.67	0.38	2.70	6.57549	4.34915	3.00000	218,916.77	Gravelly SAND	
	6	10.0	10.5	61	33	6	2.82E-04	8.45E-09	0.00	0.0552	2.87	1.92	0.29	2.69	3.98105	1.66448	3.00000	61.60	Silty Sandy GRAVEL	
	7	11.5	12.0	46	50	4	1.78E-04	2.50E-11	0.00	0.0487	2.53	1.92	0.29	2.70	4.77236	2.93040	3.00000	881.50	Sandy GRAVEL	
	8	16.5	17.0	66	27	7	1.38E-05	1.02E-10	0.00	0.0660	3.43	1.92	0.29	2.69	6.39672	2.52583	3.00000	260.38	Silty Sandy GRAVEL	
	9	26.9	27.0	72	23	5	1.80E-03	1.87E-09	0.00	0.0527	2.74	1.92	0.29	2.69	13.14579	2.57202	3.00000	1,020.35	Silty Sandy GRAVEL	
	10	31.5	34.0	73	22	5	1.38E-05	9.25E-10	0.00	0.0868	4.51	1.92	0.29	2.69	6.39672	2.52583	3.00000	130.41	Silty Sandy GRAVEL	

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Table 6-2: VADOSE ZONE MODELING PARAMETERS
(continued)

Borehole Number	Sample Number	Sample Depth		Soil Gradations LAB			Soil Conductivity at Lab Saturation	In-Situ Soil Conduct.	Residual Moisture (THETA r)	Moisture Values In-Situ (THETA)	Moisture Weight % Measured	Bulk Density	Estimated Soil Porosity = Saturated Moisture Content (THETA s)	SpG	Brooks-Corey Parameters			Calculated Matric Potential (cm)	Wentworth Soil Classification	
		From	To	% G	% S	% M	Ks(cm/s)	Kl(cm/sec)	(THETA r)	(THETA)			he	b	b'	(h)				
MW-13	1	9.5	10.0	62	35	3	1.78E-04	5.75E-11	0.00	0.0535	2.78	1.92	0.29	2.70	4.77236	2.93040	3.00000	668.80	Sandy GRAVEL	
	2	13.0	13.5	47	51	2	5.73E-04	1.47E-11	0.00	0.0448	2.33	1.92	0.29	2.70	11.58480	3.18989	3.00000	4,417.38	Sandy GRAVEL	
	3	14.0	14.5	63	30	7	2.82E-04	2.20E-09	0.00	0.0446	2.32	1.92	0.29	2.69	3.98105	1.66448	3.00000	87.77	Silty Sandy GRAVEL	
	4	17.5	18.0	86	12	2	2.82E-04	1.17E-08	0.00	0.0574	2.94	1.95	0.28	2.72	3.98105	1.66448	3.00000	56.61	GRAVEL	
	5	25.5	26.0	77	19	4	1.38E-05	1.00E-14	0.00	0.0210	1.09	1.92	0.29	2.69	6.39672	2.52583	3.00000	4,711.16	Silty Sandy GRAVEL	
MW-14	1	7.5	8.8	53	39	8	1.38E-05	9.08E-10	0.00	0.0866	4.50	1.92	0.29	2.69	6.39672	2.52583	3.00000	131.15	Silty Sandy GRAVEL	
	2	10.8	11.5	50	44	6	2.82E-04	6.91E-09	0.00	0.0535	2.78	1.92	0.29	2.69	3.98105	1.66448	3.00000	64.95	Silty Sandy GRAVEL	
	3	20.5	21.0	82	16	2	2.82E-04	3.14E-09	0.00	0.0467	2.39	1.95	0.28	2.72	3.98105	1.66448	3.00000	79.92	GRAVEL	
	4	21.5	22.0	58	31	11	1.38E-05	6.68E-14	0.00	0.0265	1.38	1.92	0.29	2.69	6.39672	2.52583	3.00000	2,596.27	Silty Sandy GRAVEL	
MW-15	1	5.0	7.0	54	38	8	1.78E-04	1.46E-12	0.00	0.0350	1.82	1.92	0.29	2.69	4.77236	2.93040	3.00000	2,252.76	Silty Sandy GRAVEL	
	2	9.0	10.0	55	40	5	2.82E-04	1.14E-09	0.00	0.0402	2.09	1.92	0.29	2.69	3.98105	1.66448	3.00000	104.43	Silty Sandy GRAVEL	
	3	14.5	15.0	73	22	5	1.80E-03	5.53E-10	0.00	0.0454	2.36	1.92	0.29	2.69	13.14579	2.57202	3.00000	1,498.01	Silty Sandy GRAVEL	
	4	19.5	20.0	72	24	4	1.80E-03	6.97E-11	0.00	0.0352	1.83	1.92	0.29	2.69	13.14579	2.57202	3.00000	2,881.52	Silty Sandy GRAVEL	
	5	24.7	25.2	68	22	10	5.77E-04	1.96E-14	0.00	0.0256	1.33	1.92	0.28	2.67	10.96131	3.53020	3.00000	51,657.58	Silty Sandy GRAVEL	
MW-17	2	15.0	16.0	72	23	5	2.82E-04	3.56E-10	0.00	0.0335	1.74	1.92	0.29	2.69	3.98105	1.66448	3.00000	141.68	Silty Sandy GRAVEL	
	5	30.0	31.0	0	88	12	2.41E-05	2.01E-09	0.00	0.1341	6.97	1.92	0.30	2.74	6.57549	4.34915	3.00000	215.92	Slightly Silty SAND	
	6	35.0	36.0	28	65	7	2.82E-04	9.96E-10	0.00	0.0512	3.06	1.67	0.37	2.66	3.98105	1.66448	3.00000	108.11	Gravelly SAND	
	7	37.0	38.0	52	41	7	2.82E-04	5.80E-06	0.00	0.1401	7.28	1.92	0.26	2.59	3.98105	1.66448	3.00000	11.05	Silty Sandy GRAVEL	
Sum n						*****	1.07E-01	4.41E-04	0.00	9.89	534.54	319.13	51.32	457.12	1204.43	469.52938	507.00000	1234286.8		
Average						168 168 168	168	168	168	168	168	168	168	168	168	168	168	168	168	
						50 42 9	6.38E-04	2.62E-06	0.00	0.06	3.18	1.90	0.31	2.72	7.16921	2.79482	3.01786	7,346.95		

- NOTES:
- Bulk density values estimated from table 3.5, Geotechnical Engineering Analysis and Design, R.E. Hunt.
 - Specific gravity values from lab testing were used for all similarly classified soils; the average of measured Silty Sandy Gravel specific gravity analyses were used in the similar soil type where no testing was performed; all other values were estimated.
 - Soil porosity calculated from $(1 - (\text{bulk density} / \text{specific gravity}))$. Soil porosity is assumed equal to the saturated moisture content.
 - Soil in-situ moisture calculated from $(((\text{bulk density} * \text{weight \% measured}) / 0.998) / 100)$. Units in cubic cm./cubic cm. 0.998 = grams water per cubic cm.
 - Soil residual moisture value of zero was the recommended value for sands and gravels per Mr. Michael Fayer, PNL.
 - Brooks-Corey parameters were derived from converting Van Genuchten functions using the formulas:
 $h_e = 1/a$
 $b = 1/(n-1)$
 $b' = (1+l)$ where l is taken as 2.0 for the Burdine conductivity model.
 - Soil Conductivity at Lab Saturation was obtained in the same method as the van Genuchten parameters (see note 6).
 - Calculated matric potential was obtained using an HP28S calculator and the formula:
 $h = h_e / (\text{THETA} / \text{THETA } s)^b$
 - Shaded rows indicate questionably high in-situ moisture values. Not intended for use.
 - Wentworth Soil Classification entries based on laboratory particle size gradations, NOT on field log gradations.

TABLE 6-3: UNSAT-H MODEL CONSTRUCTION
 based on monitoring well MW-15 located at the Horn Rapids Landfill

Node Number	Node		Initial	Soil	Plant Root
	Depth (cm)	Node	Elevation Head (cm)	Type	Growth
	"Z(m)"	Depth (ft)	"H(m)"	"MAT(m)"	"NROOT(m)"
1	0.00	0.0000	853.00	1	1
2	0.10	0.0033	852.90	1	1
3	0.20	0.0066	852.80	1	1
4	0.30	0.0098	852.70	1	1
5	0.40	0.0131	852.60	1	1
6	0.50	0.0164	852.50	1	1
7	1.00	0.0328	852.00	1	1
8	3.00	0.0984	850.00	1	1
9	5.00	0.1640	848.00	1	1
10	15.00	0.4921	838.00	1	1
11	25.00	0.8202	828.00	1	1
12	40.00	1.3123	813.00	1	1
13	60.00	1.9685	793.00	1	1
14	80.00	2.6247	773.00	1	65
15	100.00	3.2808	753.00	1	90
16	120.00	3.9370	733.00	1	120
17	130.00	4.2651	723.00	1	135
18	150.00	4.9213	703.00	1	165
19	160.00	5.2493	693.00	1	243
20	170.00	5.5774	683.00	1	321
21	177.00	5.8071	676.00	1	362
22	179.00	5.8727	674.00	1	364
23	181.00	5.9383	672.00	1	365
24	182.50	5.9875	670.50	1	365
25	182.70	5.9941	670.30	1	365
26	182.90	6.0007	670.10	1	365
27	183.00	6.0039	670.00	2	365
28	183.10	6.0072	669.90	2	365
29	183.30	6.0138	669.70	2	365
30	183.50	6.0203	669.50	2	365
31	184.00	6.0367	669.00	2	365
32	186.00	6.1024	667.00	2	365
33	188.00	6.1680	665.00	2	365
34	195.00	6.3976	658.00	2	365
35	205.00	6.7257	648.00	2	365
36	220.00	7.2178	633.00	2	365
37	240.00	7.8740	613.00	2	365
38	260.00	8.5302	593.00	2	365
39	280.00	9.1864	573.00	2	365
40	300.00	9.8425	553.00	2	365
41	310.00	10.1706	543.00	2	365
42	320.00	10.4987	533.00	2	365
43	329.00	10.7940	524.00	2	365
44	331.00	10.8596	522.00	2	365
45	333.00	10.9252	520.00	2	365
46	334.50	10.9744	518.50	2	365
47	334.70	10.9810	518.30	2	365
48	334.90	10.9875	518.10	2	365
49	335.00	10.9908	518.00	3	365
50	335.10	10.9941	517.90	3	365
51	335.30	11.0007	517.70	3	365
52	335.50	11.0072	517.50	3	365
53	336.00	11.0236	517.00	3	365
54	338.00	11.0892	515.00	3	365
55	340.00	11.1549	513.00	3	365

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TABLE 6-3: UNSAT-H MODEL CONSTRUCTION
based on monitoring well MW-15 located at the Horn Rapids Landfill

Node Number	Node		Initial Elevation	Soil	Plant Root
	Depth (cm)	Node Depth (ft)	Head (cm)	Type	Growth
	Z(a)'		H(a)'	MAT(a)'	NITROOT(a)'
56	350.00	11.4829	503.00	3	365
57	360.00	11.8110	493.00	3	365
58	375.00	12.3032	478.00	3	365
59	395.00	12.9593	458.00	3	365
60	415.00	13.6155	438.00	3	365
61	455.00	14.9278	398.00	3	365
62	475.00	15.5840	378.00	3	365
63	510.00	16.7323	343.00	3	365
64	550.00	18.0446	303.00	3	365
65	585.00	19.1929	268.00	3	365
66	625.00	20.5053	228.00	3	365
67	655.00	21.4895	198.00	3	365
68	685.00	22.4738	168.00	3	365
69	705.00	23.1299	148.00	3	365
70	725.00	23.7861	128.00	3	365
71	740.00	24.2782	113.00	3	365
72	750.00	24.6063	103.00	3	365
73	757.00	24.8360	96.00	3	365
74	759.00	24.9016	94.00	3	365
75	761.00	24.9672	92.00	3	365
76	761.50	24.9836	91.50	3	365
77	761.70	24.9902	91.30	3	365
78	761.90	24.9967	91.10	3	365
79	762.00	25.0000	91.00	4	365
80	762.10	25.0033	90.90	4	365
81	762.30	25.0098	90.70	4	365
82	762.50	25.0164	90.50	4	365
83	763.00	25.0328	90.00	4	365
84	765.00	25.0984	88.00	4	365
85	767.00	25.1640	86.00	4	365
86	775.00	25.4265	78.00	4	365
87	785.00	25.7546	68.00	4	365
88	800.00	26.2467	53.00	4	365
89	810.00	26.5748	43.00	4	365
90	820.00	26.9029	33.00	4	365
91	830.00	27.2310	23.00	4	365
92	835.00	27.3950	18.00	4	365
93	840.00	27.5591	13.00	4	365
94	848.00	27.8215	5.00	4	365
95	850.00	27.8871	3.00	4	365
96	852.00	27.9528	1.00	4	365
97	852.50	27.9692	0.50	4	365
98	852.70	27.9757	0.30	4	365
99	852.90	27.9823	0.10	4	365
100	853.00	27.9856	0.00	4	365

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Table 6-4: UNSAT-H™ Input Listing (1 of 2)

<u>Parameter Description</u>	<u>Plants Modeled</u>	<u>Plants Not Modeled</u>
Code Run Options:		
Plant Option	On	Off
Lower Boundary Condition	----- Constant Head -----	-----
Profile Orientation	----- Vertical -----	-----
Heat Flow Option	Off	Off
Upper Boundary Condition	----- Calculated Heat Flux -----	-----
Lower Boundary Condition	----- Constant Heat Flux -----	-----
Simulation Years	100	100
Water Application	---- Values Provided as Input ----	----
Convective Heat Flow	Off	Off
Evaporation Option (No Plants)	---	On
Evapotranspiration Distribution	----- Generated by Model -----	-----
Surface Boundary Condition	Flux	Flux
Meteorological Condition	---- Values Provided as Input ----	----
Cloud Cover Condition	----- Generated by Model -----	-----
Soil Hydraulic Computation	----- Brooks-Corey -----	-----
Vapor Flow	On	On
Upper Surface Head Limit	---- Constant Upper Head Value ----	----
Maximum Soil Head	1.0E5	1.0E5
Minimum Soil Head	1.0E-4	1.0E-4
Tortuosity	0.66	0.66
Average Soil Temperature	288°K	288°K
Vapor Diffusion in Air	0.24cm ² /s	0.24cm ² /s
Number of Soil Types	4	4
Number of Analysis Nodes	100	100
Soil Property Description Options:		
Saturated Soil Water Content	0.29cm ³ /cm ³	0.29cm ³ /cm ³
Saturated Hydraulic Conductivity		
Soil #1	0.6408	0.6408
Soil #2	1.0152	1.0152
Soil #3	6.4800	6.4800
Soil #4	2.0772	2.0772
Residual Water Content	0.00	0.00
Conductivity Model	Mualem	Mualem
Initial Conditions:		
Initial Suction Heads	Table 6-6	Table 6-7

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Table 6-4: UNSAT-H™ Input Listing (2 of 2)

<u>Parameter Description</u>	<u>Plants Modeled</u>	<u>Plants Not Modeled</u>
Plant Information:		
Leaf Area Index	Off	----
Root Growth	exponential	----
PET Partitioning	cheatgrass data	----
Day of Year; Seed Germination	275	----
Day of Year Transpiration Ends	180	----
Coefficients for Root Growth Equation		
a.	1.163	----
b.	0.129	----
c.	0.020	----
Growth Day Roots Reach Each Node	Table 11-4	----
Wilting Head Value	30,000cm	----
Head Where Transpiration Starts Decreasing	3000cm	----
Transpiration Limiting Head	0.10cm	----
Percent of Bare Ground Surface	70%	100%
Boundary Conditions:		
Surface Albedo	0.25	0.25
Altitude of Study Site	103m	103m
Height of Wind Speed Measurement	3.0m	3.0m
Average Annual Atmospheric Pressure	929mb	929mb
Meteorological Data	----- Table 11-3 -----	

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Table 6-5: Precipitation Input for the UNSAT-H™ model

PRECIPITATION			PRECIPITATION			PRECIPITATION		
YEAR	(cm)	(in)	YEAR	(cm)	(in)	YEAR	(cm)	(in)
1	17.0002	6.6930	35	15.3213	6.0320	69	19.8780	7.8260
2	21.2065	8.3490	36	37.1145	14.6120	70	18.8011	7.4020
3	22.7508	8.9570	37	18.7401	7.3780	71	16.7437	6.5920
4	15.8496	6.2400	38	19.5885	7.7120	72	15.1384	5.9600
5	23.2308	9.1460	39	24.1986	9.5270	73	19.6621	7.7410
6	22.2783	8.7710	40	17.2187	6.7790	74	24.4069	9.6090
7	18.0848	7.1200	41	22.8321	8.9890	75	21.9913	8.6580
8	22.0269	8.6720	42	21.1023	8.3080	76	13.4772	5.3060
9	20.4318	8.0440	43	12.3139	4.8480	77	18.3515	7.2250
10	18.4785	7.2750	44	18.8519	7.4220	78	18.4734	7.2730
11	15.7886	6.2160	45	18.7350	7.3760	79	12.4714	4.9100
12	21.8135	8.5880	46	14.9581	5.8890	80	18.0442	7.1040
13	17.4244	6.8600	47	15.0825	5.9380	81	20.0279	7.8850
14	20.9601	8.2520	48	16.8707	6.6420	82	18.8773	7.4320
15	19.5377	7.6920	49	21.8084	8.5860	83	29.9034	11.7730
16	20.1879	7.9480	50	15.5702	6.1300	84	14.7523	5.8080
17	16.7691	6.6020	51	18.3388	7.2200	85	21.8516	8.6030
18	22.8879	9.0110	52	12.2885	4.8380	86	22.2809	8.7720
19	16.8148	6.6200	53	22.2428	8.7570	87	24.9580	9.8260
20	24.1402	9.5040	54	19.9873	7.8690	88	15.8394	6.2360
21	24.7955	9.7620	55	15.4102	6.0670	89	22.7533	8.9580
22	24.3230	9.5760	56	19.1135	7.5250	90	17.1323	6.7450
23	14.7396	5.8030	57	21.2065	8.3490	91	27.4701	10.8150
24	17.1933	6.7690	58	18.9941	7.4780	92	16.3449	6.4350
25	16.8935	6.6510	59	19.3700	7.6260	93	20.9525	8.2490
26	12.8143	5.0450	60	19.5885	7.7120	94	19.3116	7.6030
27	21.2776	8.3770	61	15.0520	5.9260	95	17.7571	6.9910
28	15.9741	6.2890	62	21.3563	8.4080	96	17.0028	6.6940
29	23.5255	9.2620	63	22.0777	8.6920	97	13.4925	5.3120
30	17.7292	6.9800	64	13.9065	5.4750	98	13.2842	5.2300
31	14.1351	5.5650	65	19.0678	7.5070	99	25.0515	9.8628
32	18.8493	7.4210	66	20.2971	7.9910	100	24.3434	9.5840
33	24.6380	9.7000	67	23.6626	9.3160			
34	15.3619	6.0480	68	14.6075	5.7510			

Average: 19.3161 7.6047
Maximum: 37.1145 14.6120
Minimum: 12.2885 4.8380

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Table 6-6: Initial Suction Heads, Plants Modeled

<u>NODE</u>	<u>HEAD (cm)</u>	<u>NODE</u>	<u>HEAD (cm)</u>	<u>NODE</u>	<u>HEAD (cm)</u>
1	131.326	35	176.474	69	147.981
2	124.583	36	178.828	70	127.987
3	118.683	37	183.623	71	112.990
4	113.484	38	191.465	72	102.992
5	108.792	39	205.044	73	95.9926
6	104.515	40	230.942	74	93.9928
7	87.8913	41	254.677	75	91.9930
8	58.0712	42	295.592	76	91.4931
9	46.0729	43	371.113	77	91.2931
10	55.1736	44	403.534	78	91.0931
11	72.8150	45	449.033	79	90.9931
12	99.7704	46	498.778	80	90.8932
13	159.293	47	507.116	81	90.6932
14	172.919	48	515.957	82	90.4933
15	170.134	49	515.860	83	89.9934
16	176.268	50	515.762	84	87.9940
17	180.922	51	515.565	85	85.9945
18	189.025	52	515.369	86	77.9962
19	188.727	53	514.877	87	67.9978
20	184.825	54	512.909	88	52.9991
21	180.273	55	510.942	89	42.9996
22	178.742	56	501.097	90	32.9998
23	177.117	57	491.244	91	23.0000
24	175.840	58	476.448	92	18.0000
25	175.666	59	456.691	93	13.0000
26	175.491	60	436.905	94	5.00000
27	175.414	61	397.251	95	3.00000
28	175.464	62	377.391	96	.999999
29	175.560	63	342.586	97	.500000
30	175.651	64	302.746	98	.300000
31	175.857	65	267.843	99	.099999
32	176.394	66	227.915	100	0.0000
33	176.630	67	197.949		
34	176.090	68	167.971		

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Table 6-7: Initial Suction Heads, Plants Not Modeled

<u>NODE HEAD (cm)</u>	<u>NODE HEAD (cm)</u>	<u>NODE HEAD (cm)</u>
1 118.943	35 43.0274	69 145.509
2 113.584	36 42.0997	70 126.314
3 108.787	37 41.2159	71 111.724
4 104.507	38 40.7483	72 101.924
5 100.600	39 40.8108	73 95.0348
6 97.0004	40 42.3209	74 93.0625
7 82.6371	41 44.5799	75 91.0886
8 55.4025	42 50.6674	76 90.5949
9 44.0472	43 68.4945	77 90.3973
10 48.5146	44 81.1530	78 90.1998
11 57.6727	45 109.521	79 90.1016
12 63.4112	46 183.126	80 90.0054
13 75.7525	47 231.953	81 89.8129
14 88.4700	48 365.349	82 89.6203
15 88.8131	49 365.411	83 89.1387
16 82.0681	50 365.392	84 87.2095
17 77.8838	51 365.355	85 85.2762
18 67.5820	52 365.317	86 77.5017
19 61.5698	53 365.223	87 67.7064
20 54.7590	54 364.840	88 52.8825
21 49.5207	55 364.449	89 42.9469
22 47.9576	56 362.327	90 32.9801
23 46.3623	57 360.094	91 22.9936
24 45.1452	58 356.288	92 17.9967
25 44.9816	59 350.478	93 12.9981
26 44.8177	60 343.825	94 4.99937
27 44.7478	61 327.739	95 2.99962
28 44.7389	62 318.401	96 .999875
29 44.7213	63 299.685	97 .499937
30 44.7037	64 274.599	98 .299962
31 44.6599	65 249.563	99 .099988
32 44.4870	66 217.566	100 0.0000
33 44.3178	67 191.644	
34 43.7553	68 164.314	

9 3 | 2 8) 2 0 4 3 5

Table 6-8: UNSAT-H Model Output (1 of 2)
Plant Option: ON

Year	Yearly Precipitation (inches)	Yearly Precipitation (inches)	Actual Transpiration	Actual Evaporation	Total Base Drainage	Final Moisture Storage	Mass Balance Error (%)
1	1.7000E+01	6.69	5.5034E+00	1.0894E+01	1.7133E-02	7.8551E+01	2.6424E-01
2	2.1206E+01	8.35	5.2294E+00	1.2227E+01	1.7134E-02	8.2212E+01	3.4341E-01
3	2.2751E+01	8.96	6.3698E+00	1.4701E+01	1.7135E-02	8.3806E+01	3.0005E-01
4	1.5850E+01	6.24	5.9101E+00	1.0293E+01	1.7135E-02	8.3375E+01	3.7879E-01
5	2.3231E+01	9.15	6.2967E+00	1.3954E+01	1.7182E-02	8.6291E+01	1.9821E-01
6	2.2278E+01	8.77	5.6090E+00	1.4077E+01	3.0914E-02	8.8784E+01	3.0930E-01
7	1.8085E+01	7.12	6.2240E+00	1.0394E+01	3.2955E-01	8.9842E+01	4.3641E-01
8	2.2027E+01	8.67	6.7875E+00	1.4322E+01	2.3259E+00	8.8358E+01	3.4296E-01
9	2.0432E+01	8.04	6.8586E+00	1.3619E+01	1.8671E+00	8.6358E+01	4.2318E-01
10	1.8479E+01	7.27	6.0740E+00	9.8763E+00	1.2894E+00	8.7561E+01	1.9328E-01
11	1.5789E+01	6.22	6.3602E+00	9.4854E+00	1.0013E+00	8.6439E+01	4.0607E-01
12	2.1814E+01	8.59	6.7858E+00	1.4282E+01	1.1447E+00	8.5966E+01	3.4261E-01
13	1.7424E+01	6.86	5.9963E+00	1.1588E+01	1.2008E+00	8.4528E+01	4.3953E-01
14	2.0960E+01	8.25	6.2020E+00	1.2776E+01	9.4858E-01	8.5487E+01	3.5723E-01
15	1.9538E+01	7.69	5.7601E+00	1.2180E+01	7.0901E-01	8.6317E+01	2.9977E-01
16	2.0188E+01	7.95	6.2563E+00	1.2591E+01	5.6848E-01	8.7032E+01	2.8546E-01
17	1.6769E+01	6.60	5.7681E+00	1.1306E+01	7.5907E-01	8.5904E+01	3.7672E-01
18	2.2888E+01	9.01	5.9465E+00	1.3461E+01	1.2282E+00	8.8070E+01	3.7868E-01
19	1.6815E+01	6.62	6.0374E+00	1.2709E+01	9.8328E-01	8.5081E+01	4.3764E-01
20	2.4140E+01	9.50	6.3302E+00	1.4229E+01	7.5047E-01	8.7867E+01	1.8527E-01
21	2.4796E+01	9.76	5.7994E+00	1.4092E+01	9.8082E-01	9.1749E+01	1.6509E-01
22	2.4323E+01	9.58	6.4987E+00	1.6034E+01	2.6833E+00	9.0775E+01	3.3409E-01
23	1.4740E+01	5.80	6.0042E+00	9.5139E+00	2.0995E+00	8.7840E+01	3.8657E-01
24	1.7193E+01	6.77	6.1821E+00	1.1288E+01	1.8132E+00	8.5690E+01	3.4651E-01
25	1.6893E+01	6.65	6.3317E+00	1.0617E+01	1.4011E+00	8.4154E+01	4.7314E-01
26	1.2814E+01	5.04	5.4150E+00	9.4406E+00	9.0448E-01	8.1145E+01	4.9566E-01
27	2.1278E+01	8.38	6.5871E+00	1.2432E+01	6.1420E-01	8.2796E+01	-3.5507E-02
28	1.5974E+01	6.29	5.5811E+00	8.1086E+00	4.4761E-01	8.4569E+01	3.9869E-01
29	2.3526E+01	9.26	6.2115E+00	1.3756E+01	3.4383E-01	8.7715E+01	2.9085E-01
30	1.7729E+01	6.98	5.8741E+00	1.1468E+01	2.7716E-01	8.7752E+01	4.0989E-01
31	1.4135E+01	5.56	5.3537E+00	9.4520E+00	8.8514E-01	8.6139E+01	4.0433E-01
32	1.8849E+01	7.42	6.1167E+00	1.0461E+01	1.5647E+00	8.6764E+01	4.3578E-01
33	2.4638E+01	9.70	6.3686E+00	1.5482E+01	1.2143E+00	8.8261E+01	3.0550E-01
34	1.5362E+01	6.05	6.0011E+00	1.1822E+01	8.5392E-01	8.4876E+01	4.5685E-01
35	1.5321E+01	6.03	5.4946E+00	9.3426E+00	7.9986E-01	8.4488E+01	4.6815E-01
36	3.7115E+01	14.61	6.4731E+00	1.5101E+01	2.2893E+00	9.8519E+01	-2.3919E+00
37	1.8740E+01	7.38	6.0179E+00	1.3422E+01	7.5592E+00	9.0193E+01	3.5204E-01
38	1.9588E+01	7.71	6.0527E+00	1.1159E+01	3.6490E+00	8.8841E+01	4.1079E-01
39	2.4199E+01	9.53	6.6423E+00	1.4088E+01	1.7811E+00	9.0484E+01	1.8401E-01
40	1.7219E+01	6.78	6.6067E+00	1.2386E+01	1.0645E+00	8.7571E+01	4.2929E-01
41	2.2832E+01	8.99	6.4998E+00	1.5704E+01	2.0124E+00	8.6096E+01	3.9544E-01
42	2.1102E+01	8.31	6.4595E+00	1.1834E+01	1.6392E+00	8.7187E+01	3.7261E-01
43	1.2314E+01	4.85	4.9165E+00	8.3683E+00	1.0113E+00	8.5162E+01	3.5159E-01
44	1.8852E+01	7.42	5.9074E+00	1.2435E+01	7.2821E-01	8.4881E+01	3.3174E-01
45	1.8735E+01	7.38	6.7438E+00	1.2525E+01	7.1631E-01	8.3556E+01	3.9649E-01
46	1.4958E+01	5.89	5.5111E+00	9.3724E+00	6.7995E-01	8.2876E+01	4.9881E-01
47	1.5082E+01	5.94	6.1161E+00	9.6692E+00	5.5173E-01	8.1549E+01	4.8692E-01
48	1.6871E+01	6.64	5.8231E+00	1.0368E+01	4.4509E-01	8.1703E+01	4.7180E-01
49	2.1808E+01	8.59	5.6192E+00	1.1574E+01	3.6607E-01	8.5894E+01	2.6666E-01
50	1.5570E+01	6.13	6.6800E+00	1.0296E+01	3.0320E-01	8.4119E+01	4.2672E-01
51	1.8339E+01	7.22	6.8106E+00	1.3054E+01	2.5212E-01	8.2266E+01	4.1252E-01

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Table 6-8: UNSAT-H Model Output (2 of 2)

Continued

Year	Yearly	Yearly	Actual	Actual	Total	Final	Mass
	Precipitation	Precipitation	Transpiration	Evaporation	Base	Moisture	Balance
	(inches)	(inches)			Drainage	Storage	Error (%)
52	1.2289E+01	4.84	5.4844E+00	7.6426E+00	2.2189E-01	8.1155E+01	3.7897E-01
53	2.2243E+01	6.68	6.6794E+00	1.3723E+01	2.5617E-01	8.2651E+01	3.9514E-01
54	1.9987E+01	7.87	6.2984E+00	1.4445E+01	3.1215E-01	8.1509E+01	3.6924E-01
55	1.5410E+01	6.07	5.1305E+00	9.3250E+00	3.1401E-01	8.2086E+01	4.1060E-01
56	1.9113E+01	7.52	5.7894E+00	1.1733E+01	2.8038E-01	8.3303E+01	4.9278E-01
57	2.1206E+01	8.35	6.6752E+00	1.2838E+01	2.4155E-01	8.4681E+01	3.5016E-01
58	1.8994E+01	7.48	6.0831E+00	1.1996E+01	2.0882E-01	8.5530E+01	-7.5555E-01
59	1.9370E+01	7.63	5.9592E+00	1.1404E+01	1.8401E-01	8.7289E+01	3.3241E-01
60	1.9588E+01	7.71	6.0903E+00	1.1265E+01	4.2682E-01	8.9022E+01	3.7325E-01
61	1.5052E+01	5.93	6.6265E+00	8.4625E+00	3.1197E+00	8.5802E+01	4.1874E-01
62	2.1356E+01	8.41	6.3187E+00	1.4688E+01	1.8587E+00	8.4230E+01	2.9557E-01
63	2.2078E+01	8.69	6.2100E+00	1.2646E+01	1.0366E+00	8.6322E+01	4.1757E-01
64	1.3906E+01	5.47	5.6450E+00	9.3472E+00	6.5556E-01	8.4519E+01	4.4394E-01
65	1.9068E+01	7.51	6.7436E+00	1.2166E+01	4.5904E-01	8.4132E+01	4.4940E-01
66	2.0297E+01	7.99	5.7370E+00	1.2454E+01	4.0939E-01	8.5778E+01	2.5297E-01
67	2.3663E+01	9.32	5.4965E+00	1.5779E+01	4.7852E-01	8.7600E+01	3.6569E-01
68	1.4607E+01	5.75	5.7592E+00	1.0364E+01	4.6068E-01	8.5556E+01	4.5864E-01
69	1.9878E+01	7.83	6.4090E+00	1.2541E+01	5.1946E-01	8.5899E+01	3.2847E-01
70	1.8801E+01	7.40	5.9344E+00	1.1646E+01	9.8392E-01	8.6069E+01	3.5728E-01
71	1.6744E+01	6.59	6.3216E+00	1.0380E+01	9.6472E-01	8.5081E+01	3.8910E-01
72	1.5138E+01	5.96	5.9209E+00	9.4352E+00	7.4325E-01	8.4052E+01	4.4992E-01
73	1.9662E+01	7.74	6.3435E+00	1.2658E+01	5.5659E-01	8.4087E+01	3.4927E-01
74	2.4407E+01	9.61	7.2304E+00	1.6169E+01	4.4845E-01	8.4566E+01	3.2811E-01
75	2.1991E+01	8.66	6.7086E+00	1.3604E+01	3.8900E-01	8.5784E+01	3.2791E-01
76	1.3477E+01	5.31	5.3000E+00	8.5329E+00	3.7167E-01	8.4987E+01	5.1200E-01
77	1.8352E+01	7.22	5.6968E+00	1.1313E+01	3.9909E-01	8.5872E+01	3.1727E-01
78	1.8473E+01	7.27	5.6911E+00	1.1347E+01	4.7868E-01	8.6780E+01	2.6506E-01
79	1.2471E+01	4.91	6.1848E+00	8.7382E+00	7.4234E-01	8.3523E+01	5.0543E-01
80	1.8044E+01	7.10	5.6368E+00	1.1342E+01	1.2573E+00	8.3249E+01	4.4921E-01
81	2.0028E+01	7.88	6.0285E+00	1.2770E+01	9.4937E-01	8.3453E+01	3.8022E-01
82	1.8877E+01	7.43	5.3753E+00	1.1460E+01	6.5030E-01	8.4812E+01	1.7687E-01
83	2.9903E+01	11.77	6.8305E+00	1.8305E+01	4.6225E-01	8.9145E+01	-9.4327E-02
84	1.4752E+01	5.81	5.9794E+00	8.6041E+00	5.8068E-01	8.8683E+01	3.4422E-01
85	2.1852E+01	8.60	6.2025E+00	1.2560E+01	2.9284E+00	8.8769E+01	3.4018E-01
86	2.2281E+01	8.77	5.9794E+00	1.4026E+01	1.7867E+00	8.9195E+01	2.8015E-01
87	2.4958E+01	9.83	6.6254E+00	1.3033E+01	1.2998E+00	9.3100E+01	3.8126E-01
88	1.5839E+01	6.24	5.7930E+00	9.8688E+00	1.6676E+00	9.1560E+01	3.1212E-01
89	2.2753E+01	8.96	6.4463E+00	1.3827E+01	3.1615E+00	9.0807E+01	3.1586E-01
90	1.7132E+01	6.74	6.0190E+00	1.1657E+01	2.6048E+00	8.7587E+01	4.1894E-01
91	2.7470E+01	10.81	6.1225E+00	1.6565E+01	1.7789E+00	9.0528E+01	2.2658E-01
92	1.6345E+01	6.43	6.0340E+00	1.1431E+01	1.3207E+00	8.8042E+01	2.7829E-01
93	2.0953E+01	8.25	6.3784E+00	1.3470E+01	2.3799E+00	8.6681E+01	4.0325E-01
94	1.9312E+01	7.60	5.6214E+00	1.2281E+01	1.7339E+00	8.6291E+01	3.3758E-01
95	1.7757E+01	6.99	6.2728E+00	1.1241E+01	1.0826E+00	8.5398E+01	2.9941E-01
96	1.7003E+01	6.69	6.0085E+00	9.5332E+00	7.7126E-01	8.6019E+01	4.1015E-01
97	1.3492E+01	5.31	5.4126E+00	8.6770E+00	6.9790E-01	8.4659E+01	4.8223E-01
98	1.3284E+01	5.23	5.8866E+00	9.2244E+00	6.5812E-01	8.2103E+01	5.3421E-01
99	2.1052E+01	8.29	5.8881E+00	1.3501E+01	5.5940E-01	8.3125E+01	3.8486E-01
100	2.4343E+01	9.58	6.0759E+00	1.5747E+01	4.7616E-01	8.5102E+01	2.7373E-01
Minimum	1.2289E+01	4.84	4.9165E+00	7.6426E+00	1.7133E-02	7.8551E+01	-2.3919E+00
Maximum	3.7115E+01	14.61	7.2304E+00	1.8305E+01	7.5592E+00	9.8519E+01	5.3421E-01
Average	1.9236E+01	7.55	6.0809E+00	1.1994E+01	1.0348E+00	8.5996E+01	3.1944E-01
Std. Dev.	3.9770E+00	1.56	4.4101E-01	2.1620E+00	1.0109E+00	2.9114E+00	3.1062E-01

NOTE: All units reported in centimeters unless otherwise noted.

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BORING MW-15

TRANSPIRATION

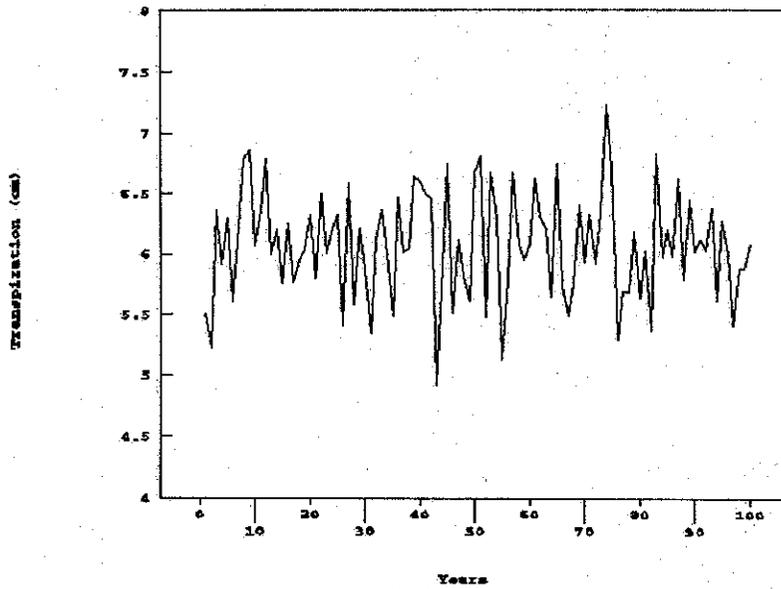


Figure 6-1: Actual Plant Transpiration as Computed by UNSAT-H (cm)

BORING MW-15

EVAPORATION

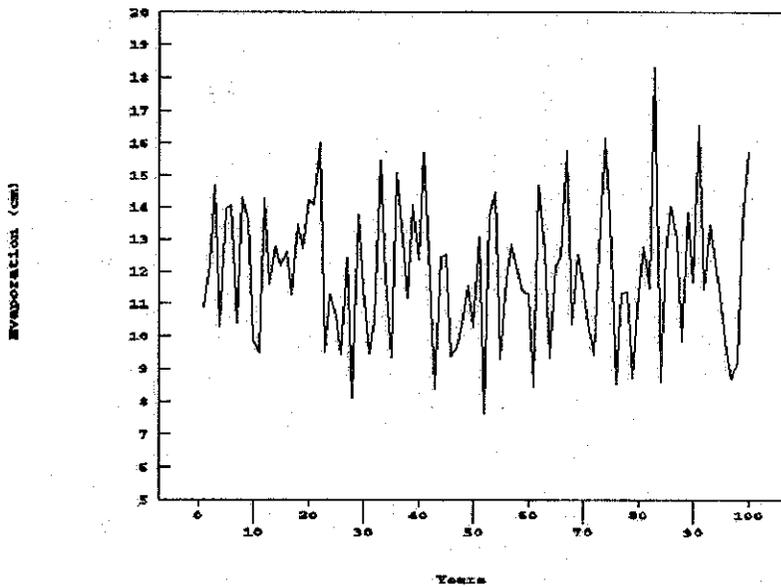


Figure 6-2: Actual Evaporation as Computed by UNSAT-H for a Vegetated Site (cm)

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BORING MW-15

PRECIPITATION

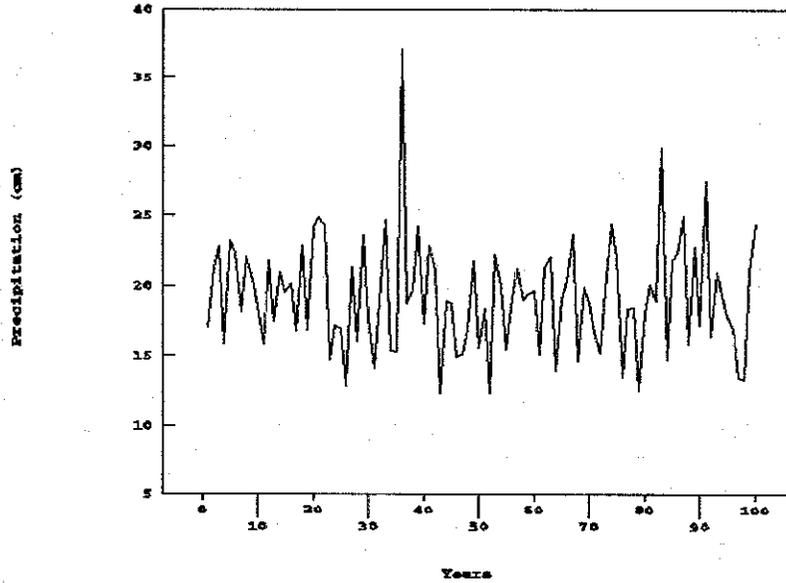


Figure 6-3: Precipitation Values Used in UNSAT-H Simulation (cm)

BORING MW-15

TOTAL BASE DRAINAGE

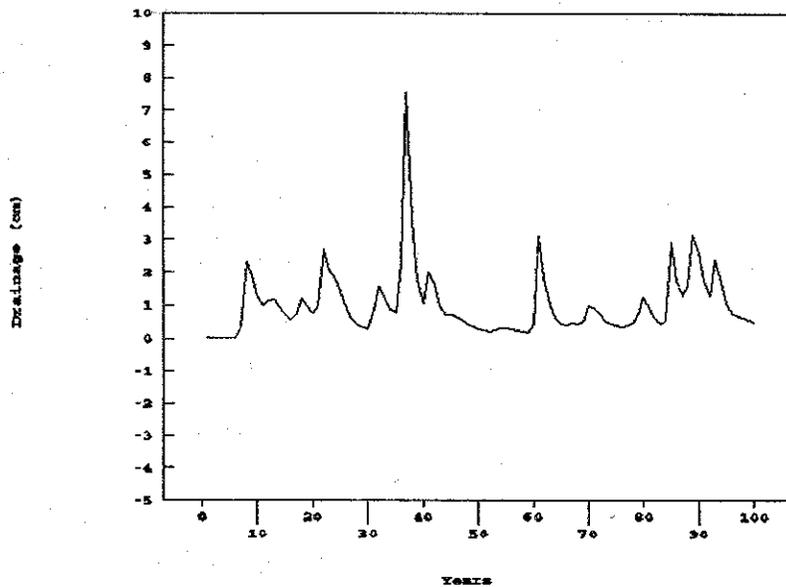


Figure 6-4: Total Soil Column Base Drainage (Recharge) to the Water Table for a Vegetated Site (cm)

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BORING MW-15
TOTAL SOIL COLUMN STORAGE

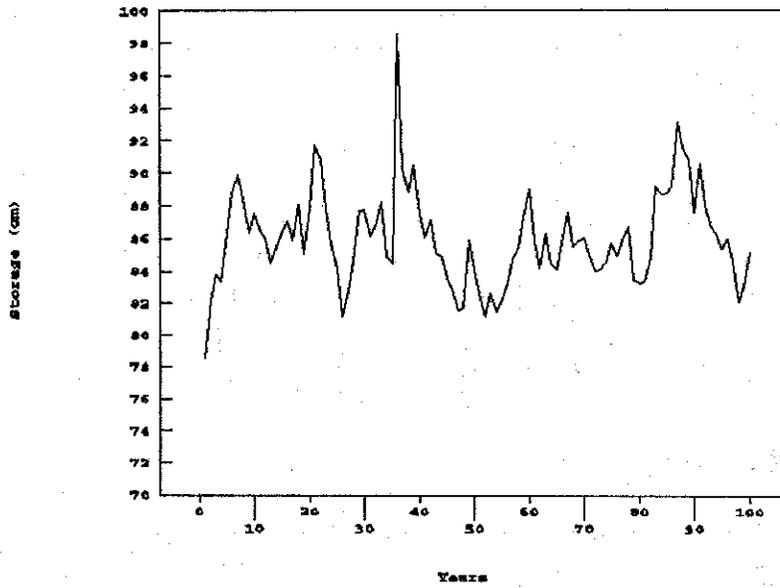


Figure 6-5: Final Yearly Soil Column Moisture Storage as Calculated By UNSAT-H (cm)

BORING MW-15
MASS BALANCE ERROR

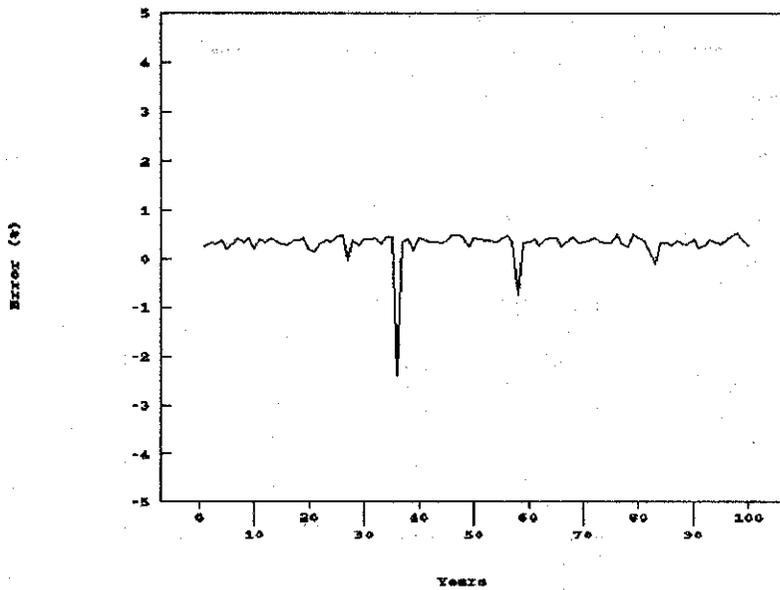


Figure 6-6: UNSAT-H Mass Balance Errors for Each Year of the Simulation (%)

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Table 6-9: UNSAT-H Model Output (1 of 2)
Plant Option: OFF

Year	Yearly Precipitation (inches)	Yearly Actual Evaporation	Total Base Drainage	Final Moisture Storage	Mass Balance Error (%)	
1	1.7000E+01	6.69	1.4100E+01	2.3140E+00	9.0940E+01	1.6947E-01
2	2.1206E+01	8.35	1.5284E+01	2.3867E+00	9.4427E+01	2.2921E-01
3	2.2751E+01	8.96	1.8455E+01	4.1297E+00	9.4536E+01	2.5305E-01
4	1.5850E+01	6.24	1.3654E+01	4.8522E+00	9.1839E+01	2.5226E-01
5	2.3231E+01	9.15	1.7690E+01	3.5775E+00	9.3777E+01	1.1171E-01
6	2.2278E+01	8.77	1.7293E+01	3.3099E+00	9.5430E+01	9.9536E-02
7	1.8085E+01	7.12	1.3934E+01	5.3738E+00	9.4152E+01	3.0879E-01
8	2.2027E+01	8.67	1.8572E+01	4.9329E+00	9.2604E+01	3.2052E-01
9	2.0432E+01	8.04	1.7916E+01	4.8986E+00	9.1705E+01	3.1460E-01
10	1.8479E+01	7.27	1.9263E+01	3.3537E+00	9.3436E+01	1.2889E-01
11	1.5789E+01	6.22	1.3407E+01	4.1015E+00	9.1675E+01	2.6653E-01
12	2.1814E+01	8.59	1.8624E+01	3.7954E+00	9.1021E+01	2.1611E-01
13	1.7424E+01	6.86	1.5465E+01	2.9600E+00	8.9967E+01	3.0791E-01
14	2.0960E+01	8.25	1.6650E+01	2.2742E+00	9.1948E+01	2.5861E-01
15	1.9538E+01	7.69	1.5532E+01	3.3130E+00	9.2774E+01	2.2525E-01
16	2.0188E+01	7.95	1.6328E+01	3.6498E+00	9.2945E+01	1.9201E-01
17	1.6769E+01	6.60	1.4778E+01	4.3436E+00	9.0544E+01	2.8993E-01
18	2.2888E+01	9.01	1.7086E+01	2.6799E+00	9.3594E+01	3.1260E-01
19	1.6815E+01	6.62	1.6371E+01	2.7545E+00	9.1228E+01	3.2725E-01
20	2.4140E+01	9.50	1.7958E+01	3.8552E+00	9.3526E+01	1.2343E-01
21	2.4796E+01	9.76	1.7493E+01	5.4322E+00	9.5375E+01	8.2499E-02
22	2.4323E+01	9.58	2.0046E+01	4.8815E+00	9.4709E+01	2.5124E-01
23	1.4740E+01	5.80	1.3003E+01	4.2071E+00	9.2201E+01	2.5503E-01
24	1.7193E+01	6.77	1.5106E+01	3.8502E+00	9.0392E+01	2.6986E-01
25	1.6893E+01	6.65	1.4675E+01	2.3214E+00	9.0233E+01	3.2995E-01
26	1.2814E+01	5.04	1.2624E+01	2.0886E+00	8.8291E+01	3.3775E-01
27	2.1278E+01	8.38	1.6603E+01	1.9660E+00	9.1123E+01	-5.7901E-01
28	1.5974E+01	6.29	1.1531E+01	2.6566E+00	9.2865E+01	2.7470E-01
29	2.3526E+01	9.26	1.7383E+01	2.6647E+00	9.6295E+01	2.0359E-01
30	1.7729E+01	6.98	1.4734E+01	5.5404E+00	9.3694E+01	3.1534E-01
31	1.4135E+01	5.56	1.2333E+01	4.8066E+00	9.0648E+01	2.9170E-01
32	1.8849E+01	7.42	1.4412E+01	3.4449E+00	9.1582E+01	3.1082E-01
33	2.4638E+01	9.70	1.9360E+01	2.3256E+00	9.4476E+01	2.3614E-01
34	1.5362E+01	6.05	1.5456E+01	2.1915E+00	8.9244E+01	3.4052E-01
35	1.5321E+01	6.03	1.2749E+01	2.4376E+00	8.9322E+01	3.6857E-01
36	3.7114E+01	14.61	1.8887E+01	6.9744E+00	1.0122E+02	-2.0422E+00
37	1.8740E+01	7.38	1.6926E+01	1.0286E+01	9.2696E+01	2.9620E-01
38	1.9588E+01	7.71	1.9305E+01	4.5449E+00	9.2831E+01	2.7350E-01
39	2.4199E+01	9.53	1.7930E+01	2.5356E+00	9.6550E+01	5.8396E-02
40	1.7219E+01	6.78	1.6411E+01	5.2689E+00	9.2041E+01	2.7770E-01
41	2.2832E+01	8.99	1.9829E+01	4.5821E+00	9.0416E+01	1.9928E-01
42	2.1102E+01	8.31	1.5766E+01	2.6268E+00	9.3069E+01	2.7434E-01
43	1.2314E+01	4.85	1.0926E+01	2.9651E+00	9.1429E+01	2.0911E-01
44	1.8852E+01	7.42	1.6096E+01	3.6108E+00	9.0531E+01	2.2797E-01
45	1.8735E+01	7.38	1.9216E+01	2.3039E+00	9.0196E+01	2.8932E-01
46	1.4958E+01	5.89	1.2667E+01	2.5143E+00	8.9919E+01	3.6098E-01
47	1.5082E+01	5.94	1.3618E+01	2.3864E+00	8.8945E+01	3.4383E-01
48	1.6871E+01	6.64	1.4069E+01	1.9429E+00	8.9746E+01	3.4288E-01
49	2.1808E+01	8.59	1.5014E+01	1.6922E+00	9.4814E+01	1.5607E-01
50	1.5570E+01	6.13	1.4299E+01	2.8331E+00	9.3206E+01	2.9822E-01
51	1.8339E+01	7.22	1.7520E+01	4.3258E+00	8.9643E+01	3.0444E-01

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Table 6-9: UNSAT-H Model Output (2 of 2)

Plant Option: OFF

Year	Yearly Precipitation	Yearly Precipitation (inches)	Actual Evaporation	Total Base Drainage	Final Moisture Storage	Mass Balance Error (%)
52	1.2289E+01	4.84	1.0889E+01	2.4969E+00	8.8521E+01	2.0357E-01
53	2.2243E+01	8.76	1.8234E+01	2.1104E+00	9.0358E+01	2.7249E-01
54	1.9987E+01	7.87	1.8471E+01	1.8470E+00	8.9977E+01	2.1110E-01
55	1.5410E+01	6.07	1.2301E+01	2.5034E+00	9.0541E+01	2.7381E-01
56	1.9113E+01	7.52	1.5327E+01	2.1185E+00	9.2137E+01	3.7856E-01
57	2.1206E+01	8.35	1.7083E+01	2.3608E+00	9.3845E+01	2.5353E-01
58	1.8994E+01	7.48	1.5537E+01	3.5684E+00	9.3915E+01	-9.5840E-01
59	1.9370E+01	7.63	1.4891E+01	3.9223E+00	9.4422E+01	2.6092E-01
60	1.9588E+01	7.71	1.4843E+01	6.5323E+00	9.2587E+01	2.4595E-01
61	1.5052E+01	5.93	1.2606E+01	5.1733E+00	8.9818E+01	2.7365E-01
62	2.1356E+01	8.41	1.8961E+01	2.4036E+00	8.9774E+01	1.6390E-01
63	2.2078E+01	8.69	1.6610E+01	1.7326E+00	9.3441E+01	3.0989E-01
64	1.3906E+01	5.47	1.2410E+01	2.5769E+00	9.2307E+01	3.7847E-01
65	1.9068E+01	7.51	1.5567E+01	1.1690E+00	9.0577E+01	3.2304E-01
66	2.0297E+01	7.99	1.5840E+01	2.3270E+00	9.2681E+01	1.2976E-01
67	2.3663E+01	9.32	1.8972E+01	2.2243E+00	9.5091E+01	2.4308E-01
68	1.4607E+01	5.75	1.3822E+01	4.0965E+00	9.1730E+01	3.3993E-01
69	1.9878E+01	7.83	1.6534E+01	4.0409E+00	9.0986E+01	2.3972E-01
70	1.8801E+01	7.40	1.5238E+01	3.0049E+00	9.1504E+01	2.1850E-01
71	1.6744E+01	6.59	1.4294E+01	2.2434E+00	9.1659E+01	3.0267E-01
72	1.5138E+01	5.96	1.9442E+01	2.6776E+00	9.0966E+01	3.3383E-01
73	1.9662E+01	7.74	1.6581E+01	2.4309E+00	9.1572E+01	2.2430E-01
74	2.4407E+01	9.61	2.0744E+01	3.0652E+00	9.2109E+01	2.4809E-01
75	2.1991E+01	8.66	1.7905E+01	2.9000E+00	9.3249E+01	2.1092E-01
76	1.3477E+01	5.31	1.1478E+01	3.5143E+00	9.1675E+01	4.3280E-01
77	1.8352E+01	7.22	1.4701E+01	2.8420E+00	9.2443E+01	2.2331E-01
78	1.8473E+01	7.27	1.4564E+01	3.4882E+00	9.2823E+01	2.2085E-01
79	1.2471E+01	4.91	1.2480E+01	4.4900E+00	8.8278E+01	3.6308E-01
80	1.8044E+01	7.10	1.5188E+01	2.4320E+00	8.8647E+01	3.0652E-01
81	2.0028E+01	7.88	1.6598E+01	1.7471E+00	9.0286E+01	2.2004E-01
82	1.8877E+01	7.43	1.4247E+01	1.7500E+00	9.3148E+01	9.6878E-02
83	2.9903E+01	11.77	2.1856E+01	4.3062E+00	9.7008E+01	-5.7736E-01
84	1.4752E+01	5.81	1.2113E+01	7.3835E+00	9.2234E+01	2.0065E-01
85	2.1852E+01	8.60	1.6514E+01	4.7895E+00	9.2724E+01	2.6415E-01
86	2.2280E+01	8.77	1.7333E+01	3.1070E+00	9.4516E+01	2.1940E-01
87	2.4958E+01	9.83	1.7105E+01	4.3458E+00	9.7954E+01	2.7685E-01
88	1.5839E+01	6.24	1.3184E+01	5.7420E+00	9.4837E+01	1.9279E-01
89	2.2753E+01	8.96	1.7830E+01	5.3473E+00	9.4360E+01	2.3241E-01
90	1.7132E+01	6.74	1.5328E+01	4.4587E+00	9.1658E+01	2.8250E-01
91	2.7470E+01	10.81	2.0270E+01	3.3054E+00	9.5508E+01	1.6170E-01
92	1.6345E+01	6.43	1.4903E+01	4.8473E+00	9.2072E+01	1.8747E-01
93	2.0953E+01	8.25	1.7426E+01	4.6474E+00	9.0891E+01	2.9271E-01
94	1.9312E+01	7.60	1.5662E+01	2.8783E+00	9.1612E+01	2.6001E-01
95	1.7757E+01	6.99	1.5074E+01	2.5934E+00	9.1660E+01	2.3118E-01
96	1.7003E+01	6.69	1.3121E+01	3.5143E+00	9.1972E+01	3.3324E-01
97	1.3492E+01	5.31	1.1658E+01	2.4817E+00	9.1277E+01	3.5020E-01
98	1.3284E+01	5.23	1.2851E+01	2.7938E+00	8.8864E+01	3.9685E-01
99	2.1052E+01	8.29	1.7351E+01	2.3034E+00	9.0202E+01	2.7905E-01
100	2.4343E+01	9.58	1.9383E+01	1.8211E+00	9.3306E+01	1.4874E-01
Minimum	1.2289E+01	4.84	1.0889E+01	1.1690E+00	8.8278E+01	-2.0422E+00
Maximum	3.7114E+01	14.61	2.1856E+01	1.0286E+01	1.0122E+02	4.3280E-01
Average	1.9236E+01	7.57	1.5857E+01	3.4552E+00	9.2235E+01	2.0544E-01
Std. Dev.	3.9770E+00	1.57	2.4336E+00	1.4250E+00	2.1940E+00	2.8994E-01

NOTE: All units reported in centimeters unless otherwi

BORING MW-15

EVAPORATION

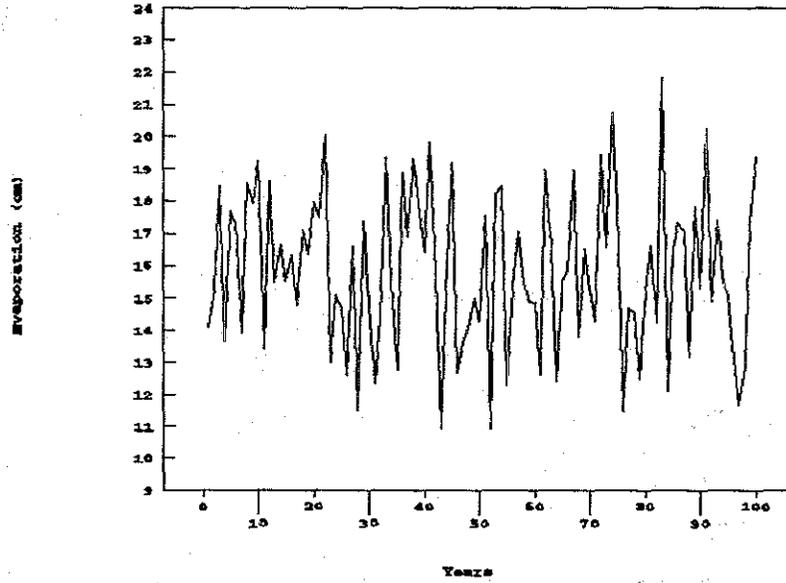


Figure 6-7: Actual Evaporation as Computed by UNSAT-H for an Unvegetated Site (cm)

BORING MW-15

PRECIPITATION

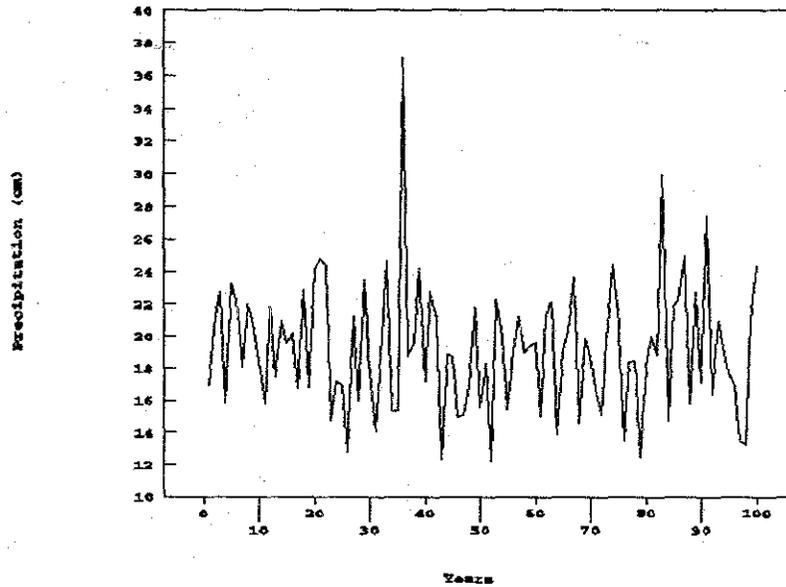


Figure 6-8: Precipitation Values Used in UNSAT-H Simulation (cm)

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BORING MW-15
TOTAL BASE DRAINAGE

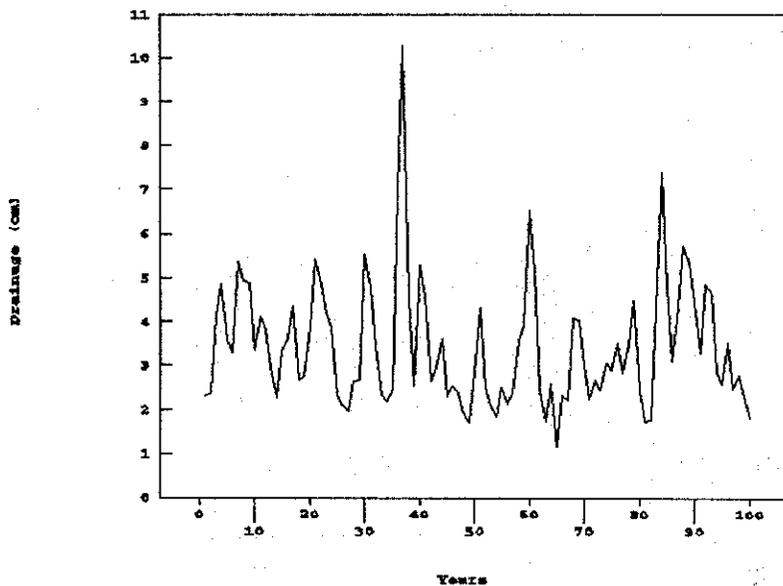


Figure 6-9: Total Soil Column Base Drainage (Recharge) to the Water Table for an Unvegetated Site (cm)

BORING MW-15
TOTAL SOIL COLUMN STORAGE

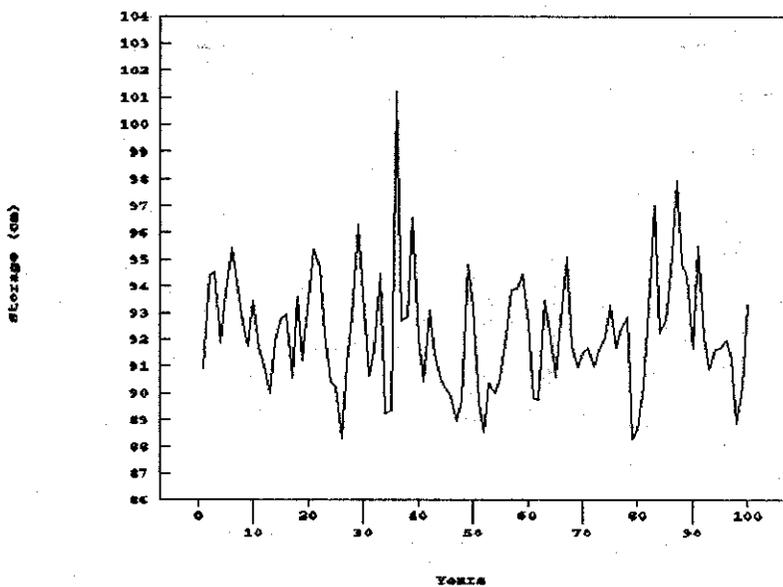


Figure 6-10: Final Soil Column Moisture Storage as Calculated by UNSAT-H for an Unvegetated Site (cm)

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BORING MW-15
MASS BALANCE ERROR

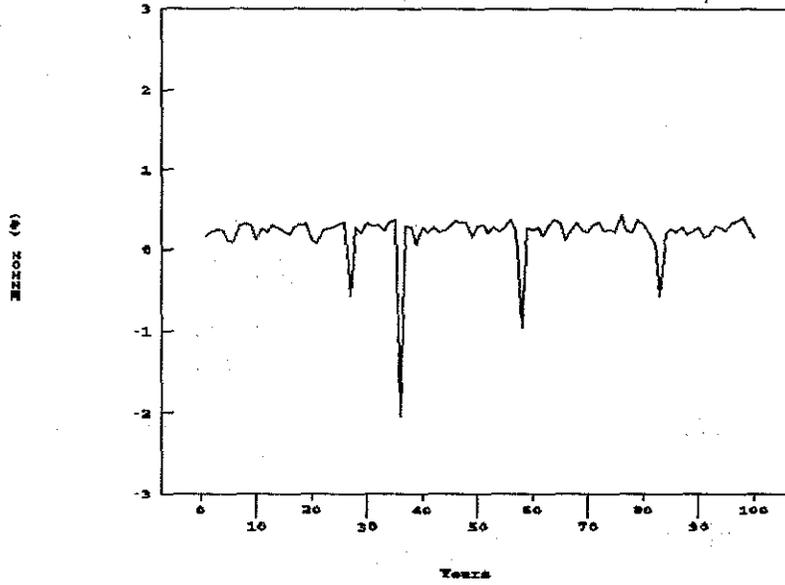


Figure 6-11: UNSAT-H Yearly Simulation Mass Balance Errors (%)

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6.4 SATURATED ZONE CONTAMINANT TRANSPORT MODELING

The purpose of modeling the groundwater flow and contaminant transport at the 1100-EM-1 Operable Unit was to determine the migration rate and persistence of the contaminants of concern for the baseline condition (*i.e.*, no active remediation) and to evaluate the effectiveness of selected remediation alternatives. The contaminants of concern are TCE and nitrate. Figure 6-12 shows the observed concentration levels and approximate plume delineations for March, 1992. The modeling analysis focused on TCE migration, because of its greater persistence, and provided predicted migration and attenuation rates for the baseline (natural) condition and selected extraction-treatment-infiltration (pump and treat) remediation scenarios. The modeling analysis also provided a better understanding of the origin of the TCE contaminant.

6.4.1 Conceptual Model

Groundwater flow and contaminant transport at the site were simulated for the area shown in figure 6-13. The model area boundaries were oriented to minimize hydraulic flux across the northern and southern boundaries and to avoid the possibility of computed contaminant plumes approaching the edges of the model grid. Prevailing groundwater flow enters the model area from the southwest and travels northeastward toward the Columbia River. The flow within the modeled boundary is generally uniform except for the increased velocities near the river. The North Richland well field and recharge area and the active agricultural area west of the SPC facility are not within the model boundaries. Observed levels in wells immediately adjacent to the river indicate vertical water table fluctuations of about 2.0 m (6.6 ft), which directly correlate to river stage fluctuations. Near the upgradient (western) boundary, data from well MW-8 show water table fluctuations of about 0.3 m (1 ft) caused mainly by seasonal increases in upgradient recharge. Numerical simulations included these fluctuations by calibrating the model to three different observed water table data sets representing the high, average, and low water table conditions.

The unconfined aquifer (upper aquifer), upper aquitard, and underlying confined to semi-confined aquifer (lower aquifer) form the basic hydrogeologic units. The model included the units underlying the silt aquitard to more accurately represent site flow, however, finer definition was emphasized for the unconfined aquifer because the contaminants of concern have been detected only there. The Hanford and Ringold Formation soils in the unconfined aquifer exhibit different hydraulic properties; the estimated horizontal hydraulic conductivities being 400 to 500 m/d (131 to 1,641 ft/d) and 10 to 72 m/d (33 to 236 ft/d), respectively. These units were differentiated in the model. Velocity estimates for flow in the unconfined aquifer are 0.1 to 0.3 m/d (0.3 to 1.0 ft/d) (Ringold Formation) and 0.4 to 1.0 m/d (1.3 to 3.3 ft/d) (Hanford formation). The site geology and hydrogeology are discussed in section 2.0.

Positive pressure head differences, occurring between the confined and unconfined aquifers, were observed in three areas (at MW-8 and MW-9 in the 1100 Area, and at 7a, b, and c and 399-1-17a, b, and c in the 300-FF-5 Area), indicating upward pressure head

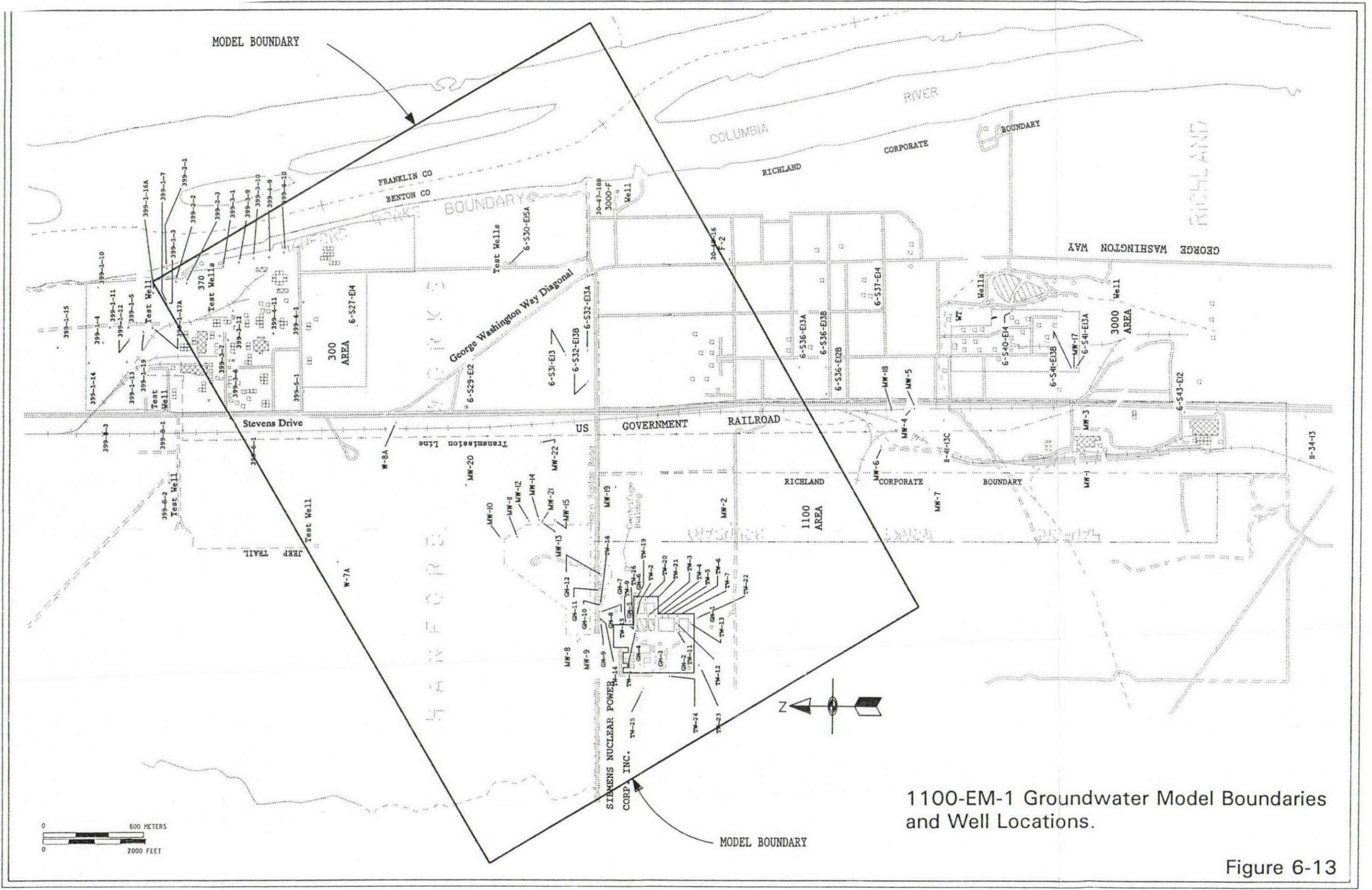
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9 3 1 2 8 6 2 0 4 5 0

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1100-EM-1 Groundwater Model Boundaries and Well Locations.

Figure 6-13

differences of 2.0 m (6.6 ft) upgradient of HRL, 0.3 m (1.0 ft) downgradient HRL, and less than 0.1 m near the river. This data is consistent with the observation of the upper silt layer becoming discontinuous and/or nonexistent in parts of the eastern portion of the modeled area, adjacent to the river.

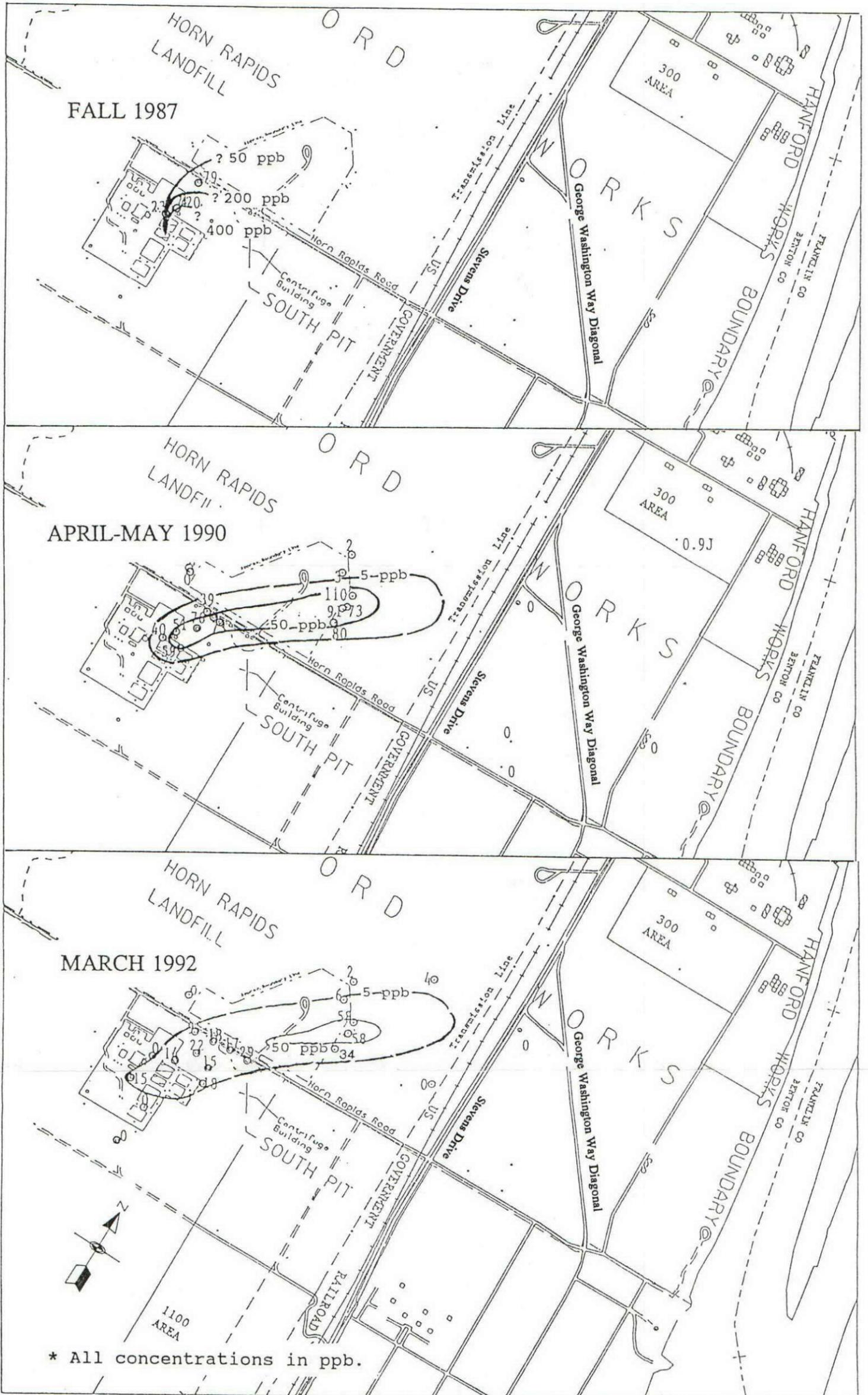
Groundwater flow into the modeled area included recharge from precipitation through the upper surface, upward seepage through the lower surface, and some horizontal flux inward through all horizontal boundaries except the river boundary, which has outward flux. The main source of horizontal flow for the unconfined aquifer is the Yakima River located nearly 3.2 km (2 mi) west of the area.

The analysis included contaminant transport of the TCE and nitrate plumes extending from the SPC plant area northeastward toward the Columbia River. Nitrate is considered a conservative solute (no significant reaction with the host soil) for purposes of this analysis. Migration of TCE can include processes of advection, retardation due to adsorption, dispersion, degradation, and volatilization. These processes were listed in their approximate order of influence on TCE migration rates for the site. Advective transport is proportional to the effective groundwater velocities, which are dependent on the hydraulic conductivity of the host material and the aquifer pressure gradient. Advective transport is, therefore, the most accurately defined of the transport processes because of the available hydraulic conductivity and water level observations at the site. Retardation due to the adsorption-desorption relationship between TCE and the host material is known to occur at the site. The details defining the exact relationship on the micro-scale were not available, and may not be useful, because of potential scale effects encountered when applying small scale measurements to a large scale analysis. Similar difficulties exist for determining dispersion, degradation, and volatilization effects on an aquifer-wide scale. The approach used in this analysis, as discussed further in the model calibration sections (paragraphs 6.4.5.1 and 6.4.5.2), was to determine estimates of the factors governing these processes from the observed history of the plume itself. In other words, the observed nature and extent of the plume, through time, was the best available indicator of the effects of retardation and dispersion processes. The effects of biodegradation and volatilization of TCE were not modeled, thus making the model results conservative (*i.e.*, the computed persistence of the TCE was overestimated because the actual losses due to biodegradation and volatilization were not included). Refer to chapter 5 of the Phase I RI report for a more complete discussion on basic subsurface transport.

The available TCE data for the earliest (fall, 1987), latest (March, 1992), and one intermediate (April through May, 1990) sampling rounds, determined the approximate extent of plume through time as shown in figure 6-14. Data indicates that in the 5-year period from 1987 to 1992, natural attenuation caused the maximum TCE concentration to reduce from 420 to 58 ppb. Nitrate levels have also attenuated from about 1,000 to 2,000 ppm (exact value is not known because only total nitrogen was measured) in 1977 at TW-2, to a maximum value of 52 ppm in 1992. These reductions indicate that the site hydrogeology allows for significant reductions in contaminant levels due to natural attenuation, which is, in turn, due to dispersion and the other processes discussed above. Section 4.0 provides additional contaminant characterization and plume description.

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TCE Data and Approximate Plume Delineations.

Figure 6-14

6.4.2 Comparison With The Phase I RI Model Analysis

During the Phase I RI, a PORFLOW™ model was constructed for the purpose of estimating contaminant migration at the site. This model was two-dimensional, homogeneous, and used assumed ranges of hydraulic and contaminant transport parameters. Results from this model provided rough, widely-banded estimates of TCE and nitrate plume migration but lacked the detail and capability to provide calibrated simulations of plume migration and remedial action scenarios. Subsequent to the Phase I RI, additional information on hydraulic parameters, site stratigraphy, and contaminant source data was gathered and a three-dimensional, heterogeneous model was constructed and calibrated to include variable river stages, recharge, vertical seepage, horizontal boundary flux, and more detailed hydraulic and contaminant transport parameters. Table 6-10 summarizes the differences between the Phase I RI model and this final RI/FS report model.

6.4.3 Numerical Model Description

Groundwater flow and contaminant transport were simulated numerically through use of the PORFLOW™ software package developed by Analytical & Computational Research, Inc. (ACRI), Los Angeles, California. Version 2.4 was used, which, for the scope used in this modeling study (*i.e.*, single phase, saturated flow), is computationally equivalent to earlier PORFLOW™ versions. Descriptions of PORFLOW™ capabilities, and reasons that it is included in the list of Hanford Site software, are found in DOE/RL-91-44. The PORFLOW™-based simulations were run on a DELL® 486 personal computer at the offices of the U.S. Army Corps of Engineers, Walla Walla District. Successful software installation was verified by comparing test file output provided by ACRI with test file output from runs made by the U.S. Army Corps of Engineers on April 14, 1992. No significant numerical differences were observed.

The analysis approach focused on predicting the transport and persistence of TCE for the following reasons. The current maximum nitrate levels (50 to 60 ppm) are closer to the nitrate MCL of 10 ppm than current maximum TCE levels (50 to 60 ppb) are to the TCE MCL of 5 ppb. Also, because of adsorption of TCE, its predicted persistence and difficulty of remediation were predicted to be much greater than that of nitrate. Only a rough analysis of nitrate transport was included, with the assumption being that nitrate will attenuate to below MCL prior to TCE for all scenarios considered.

The modeling analysis was accomplished in a manner that emphasized accuracy of groundwater flow velocities and contaminant transport in the areas of SPC and HRL and downgradient to the Columbia River. Refinement of peripheral issues, such as total water budget, seepage from the basalt aquifer, 300 Area groundwater contamination, *etc.*, were not emphasized as their significance to the simulation of the 1100 Area contaminant plume was minimal.

6.4.3.1 Model Grid Definition and Hydrofacie Zones. Figure 6-15 shows the horizontal grid definition and boundaries of the model. For numerical modeling purposes, the model

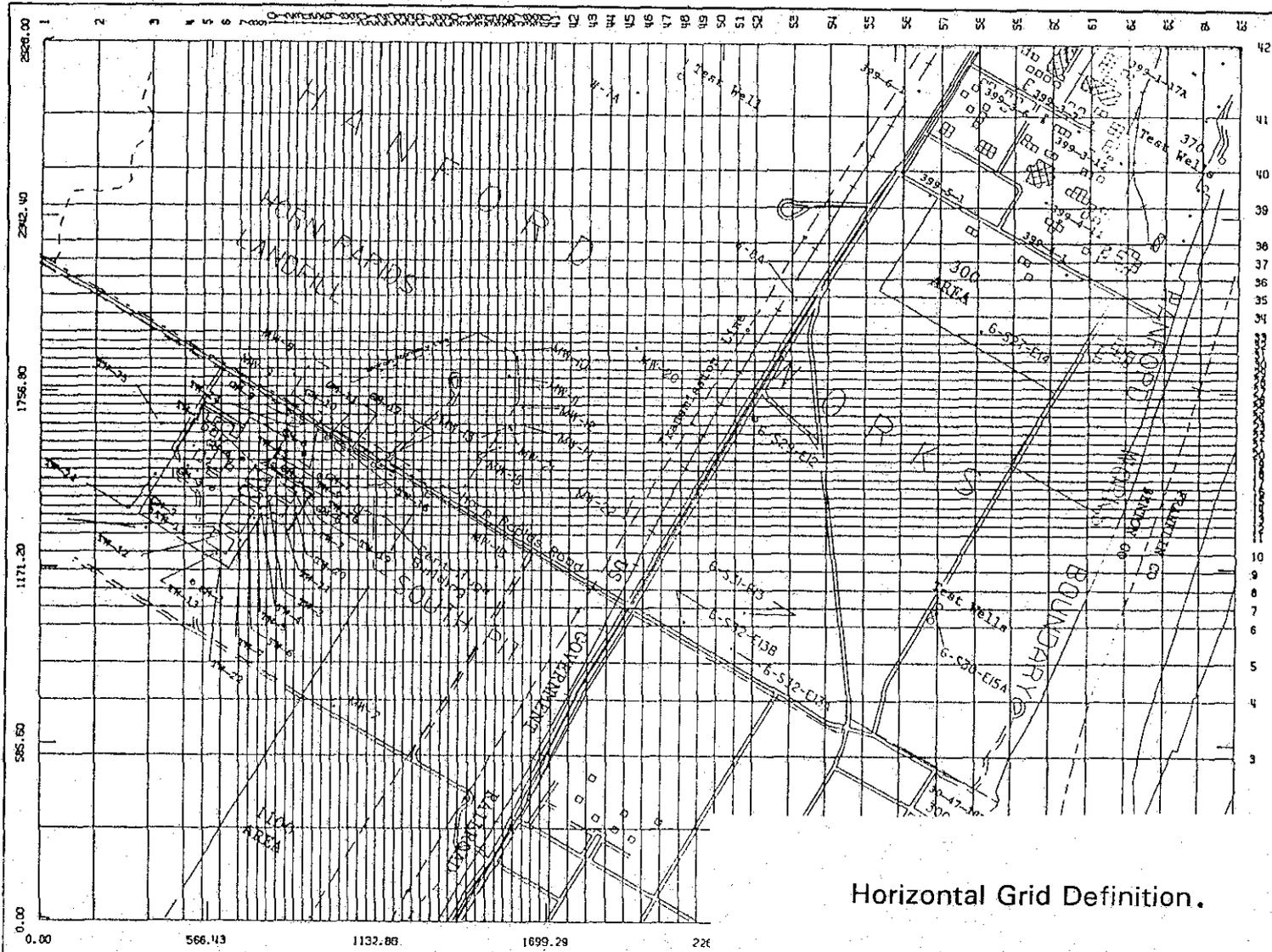
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9 3 1 2 8 6 2 0 4 5 6

Table 6-10. Comparison of Remedial Investigation and Feasibility Study Groundwater Models

<u>Remedial Investigation</u>	<u>Feasibility Study</u>
Used PORFLOW, v-1.0	Used PORFLOW, v-2.4
2-dimensional	3-dimensional
Constant grid with 61.0x61.0 meter node spacing	Variable grid with closest node spacing of 30.5x30.5 meters
Constant assumed boundaries	Variable and constant boundaries
Uncalibrated model	Calibrated model
Homogeneous soil	Heterogeneous soil
No recharge or seepage	Recharge and seepage
Assumed source range at HRL	Source correlates to TCE use



Horizontal Grid Definition.

Figure 6-15

6-48

area was divided into a 65 by 42 grid mesh with variable horizontal node spacing ranging from 30.5 by 30.5 to 122.0 by 305.0 m (100.1 by 100.1 by 400.3 ft). The longer axis of the modeled area is 3,965 m long (about 2.5 mi), the shorter axis is 2,928 m (about 1.8 mi), with a total area of 11.6 km² (about 4.5 mi²). Vertical model definition was accomplished using 15 layers, ranging in thickness from 1 to 33.5 m (3.3 to 109.9 ft) thick as shown in figure 6-16. The largest xy, xz, and yz aspect ratios were located near the grid boundary and were 1/10, 1/183, and 1/305 respectively. Differentiation between the distinct hydrogeological units (hydrofacies) was accomplished by dividing the three dimensional grid into zones that follow the prevailing site hydrogeologic boundaries. Figure 6-17 shows the hydrofacies zone designation for layer 12 and shows the delineation of the zones representing the Ringold Formation above the silt (Zone 4), the Hanford formation near HRL (Zone 8), and other zones for this model layer. The properties and hydrogeologic description associated with each zone are discussed further in paragraph 6.2.5 and are listed in table 6-15. Figures H-1 through H-15 in appendix H show the zone definition of all 15 grid layers. This discretized zone placement was developed from the isopach and formation contact maps provided in appendix C. These maps were based on drill logs and other data collected during well development.

6.4.3.2 Boundary Conditions. The model boundary conditions are listed in table 6-11. The western boundary (upgradient boundary) was represented by constant head nodes ranging in elevation from 108.7 to 109.2 m (356.6 to 358.3 ft) for the unconfined upper layers, and 110.7 m (363.2 ft) for the lower layers (below the silt aquitard). These values were taken from upgradient extrapolation of observations in wells in the HRL/SPC area. This extrapolation was not intended to predict groundwater elevations at the boundary, but was done to provide a starting point for the model to match the observed levels in the area of interest (*i.e.*, from the SPC area downgradient toward the Columbia River).

The eastern boundary (river boundary) was modeled with constant head nodes set at the appropriate levels for the high, average, and low river stage conditions. The nodes representing the unconfined layers varied from elevations 105.30 m to 105.65 m (high) (345.49 to 346.64 ft), 104.35 m to 104.70 m (average) (342.37 to 343.52 ft), and 103.65 m to 104.00 m (low) (340.08 to 341.22 ft). These values correspond to the observed water levels in wells near the river for the June 1990, February through March, 1990, and September, 1990, groundwater level data sets shown in figures 6-18 through 6-20. A statistical analysis of the levels in wells near the river showed that the water elevations were higher than 97 percent, 48 percent, and 7 percent of observed well levels from January, 1990, to January, 1992. Lower layers had constant nodes set 0.1 m (0.3 ft) higher than upper layer nodes as determined by observations in wells 399-1-16a and -b, and 399-1-17a and -b.

The northern boundary was set as a no-flow boundary except near the northeast corner where constant head elevations were set according to the river stage. The point where the boundary condition changed from no-flow to constant head ranged from grid column 56 to 59 for the three river-boundary conditions.

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Table 6-11. 1100-EM-1 Groundwater Model Boundary Conditions

<u>Location</u>	<u>Type</u>	<u>Range</u>
Southwest Horizontal (Upgradient Boundary)	Constant Head Nodes	108.7 to 109.2 ¹ (Upper) ² 110.7(Lower Layers)
Southeast Horizontal	Constant Flux Nodes	0 to 0.45 meters/day
Northeast Horizontal (River)	Constant Head Nodes	105.3 to 105.65(High) ³ 104.35 to 104.7(Avg.) 103.65 to 104.0(Low)
Northwest Horizontal	Constant Flux and Constant Head Nodes (Columns 56- 65)	Flux = 0 C.H. same as River
Lower Vertical	Constant Flux	0.0005 meters/day (Upward)
Upper Vertical	Constant Flux	0.0001 meters/day (Downward)

¹ Elevations in meters

² Upper and Lower refer to the model layers representing strata above and below the silt aquitard

³ High, Ave., and Low refer to the three representative river stages that were used for calibration.

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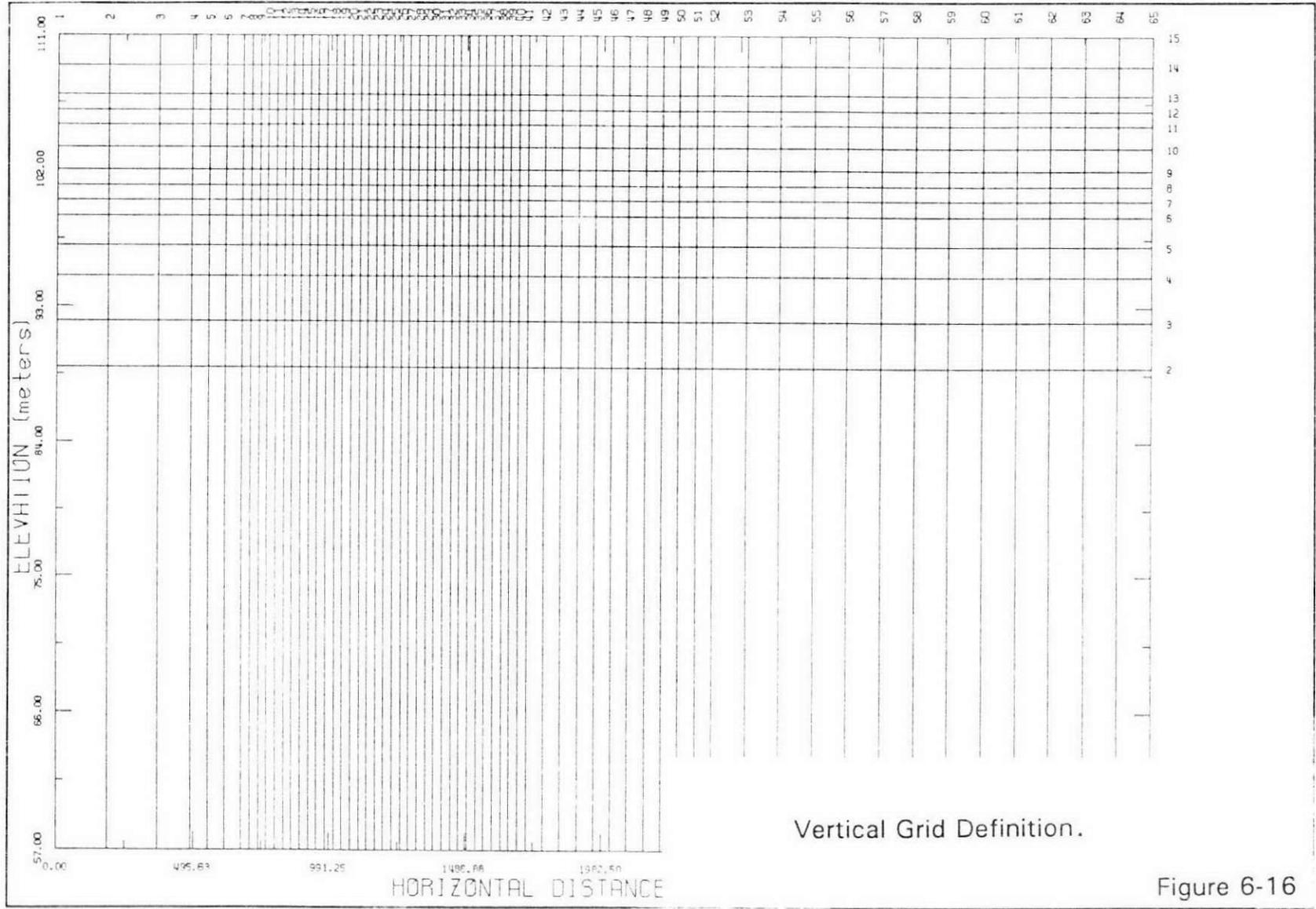
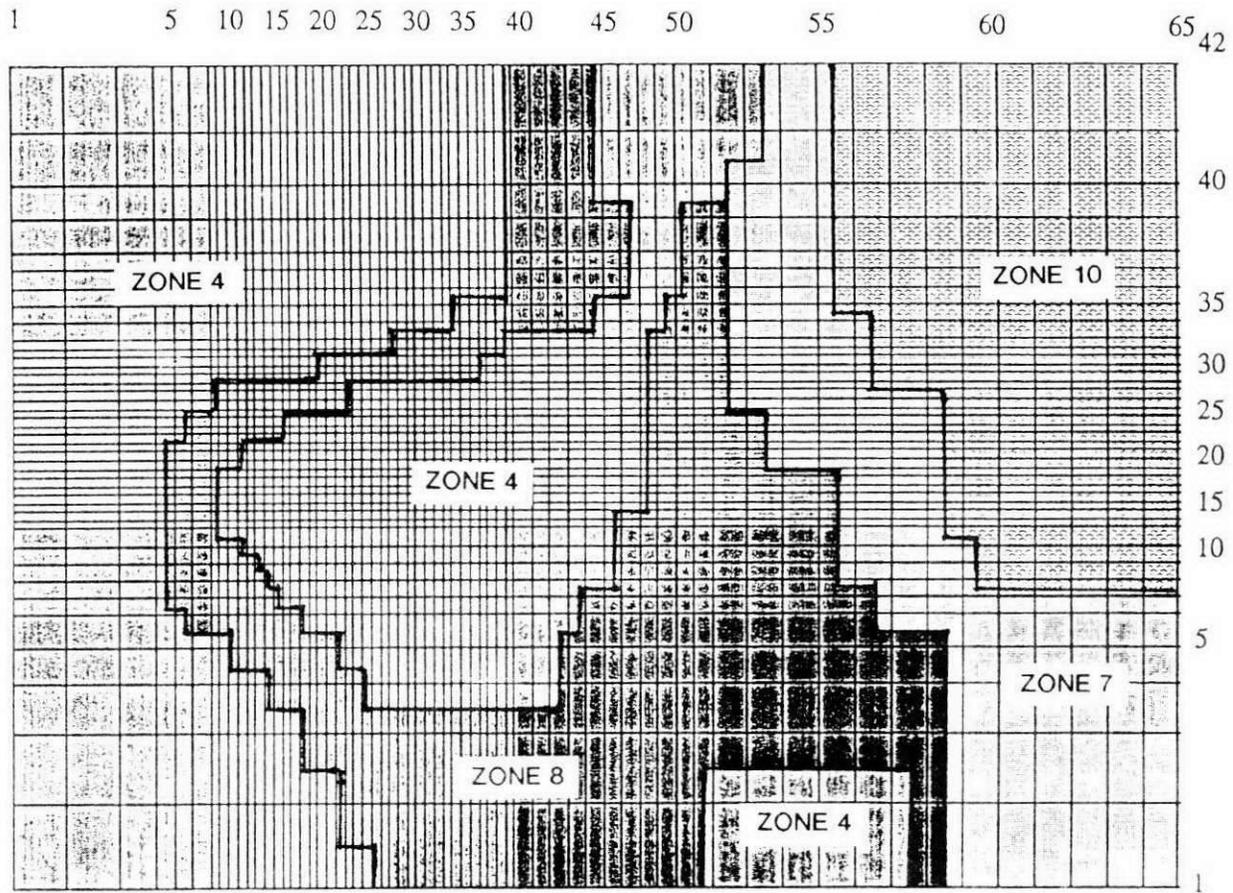


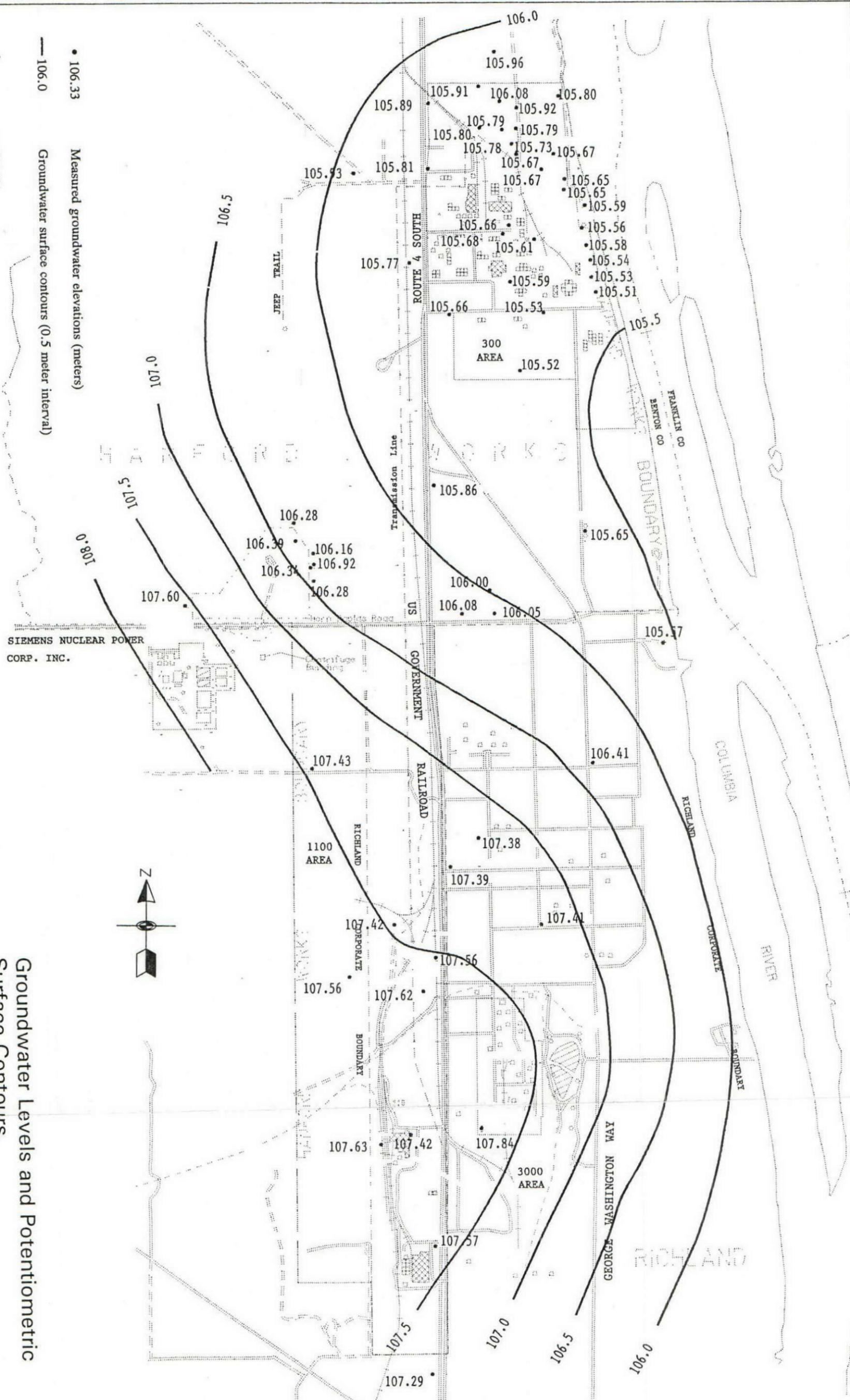
Figure 6-16

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Hydrofacies Zone Designation
Layer 12.

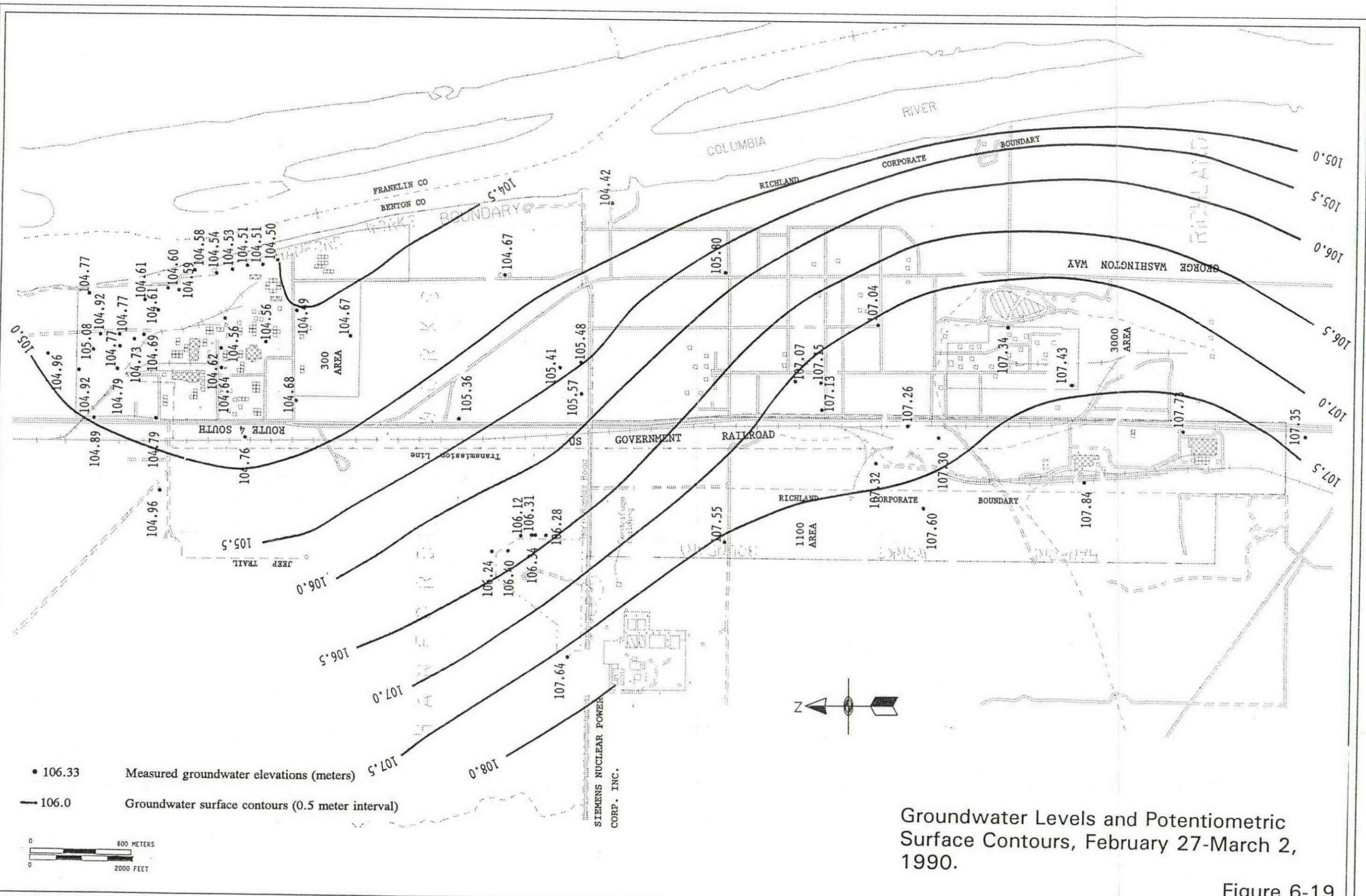
Figure 6-17



Groundwater Levels and Potentiometric Surface Contours, June 25-27, 1990.

Figure 6-18

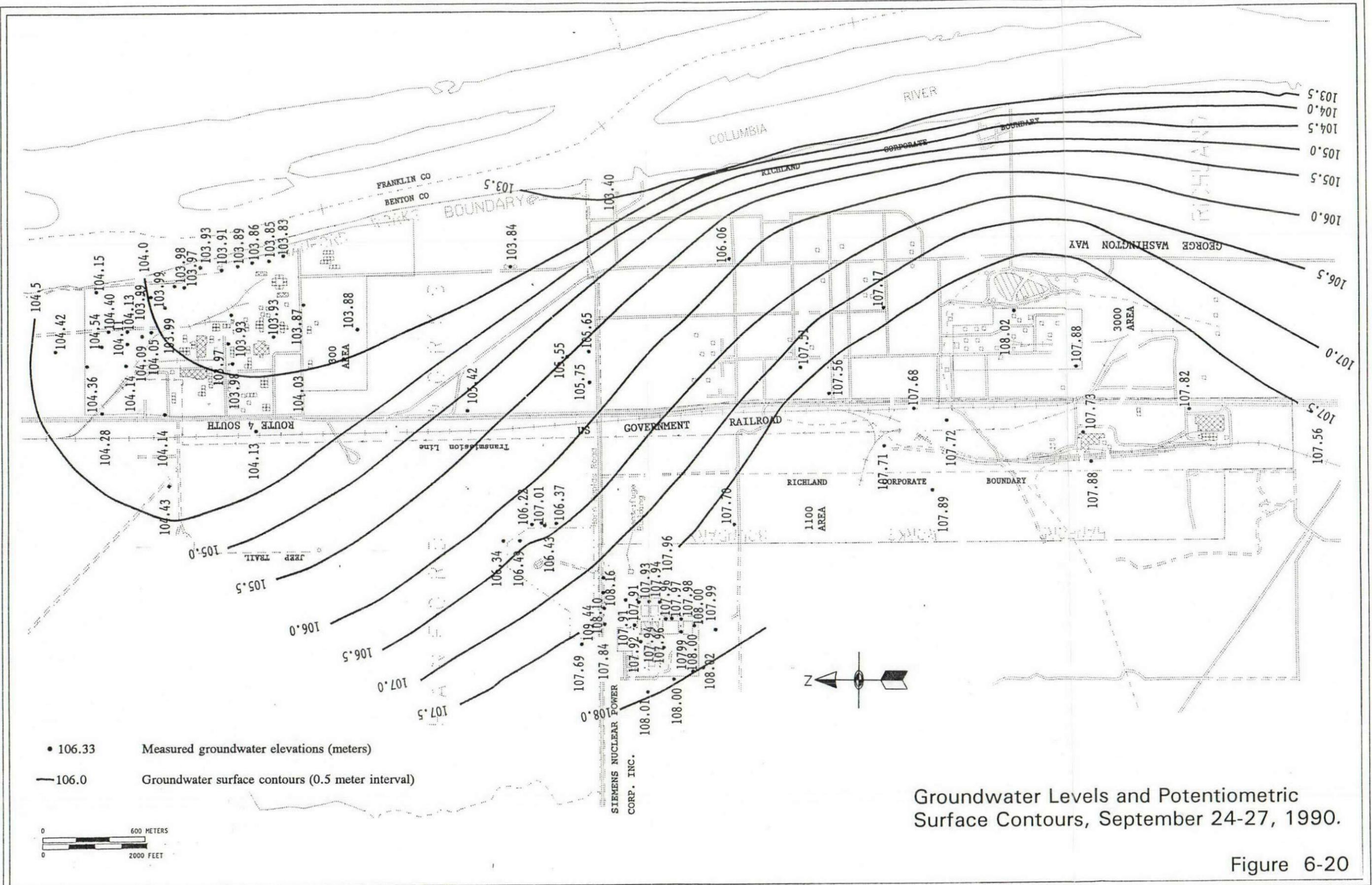
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Groundwater Levels and Potentiometric Surface Contours, February 27-March 2, 1990.

Figure 6-19

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Groundwater Levels and Potentiometric Surface Contours, September 24-27, 1990.

Figure 6-20

Table 6-13. Contaminant Transport Sensitivity Analysis

<u>Parameter Varied</u>	<u>1988 Max C (ppb)</u>	<u>1992 Max C (ppb)</u>	<u>2000 Max C (ppb)</u>
Base Case	180	80	30
R = 1.5	130	55	15
R = 4.0	180	80	30
SS = .1	180	80	30
SS = .4	180	80	30
$\eta_{eff} = .1$	110	30	3
$\eta_{eff} = .4$	220	130	75
$\eta_{tot} = .4$	180	80	30
$\eta_{diff} = .4$	180	85	30
$\alpha_{long} = 0$	180	80	30
$\alpha_{long} = 4$	160	76	28
$\alpha_{trans} = .001$	220	120	45
$\alpha_{trans} = .5$	20	5	0

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The southern boundary was initially set as a no-flow boundary but positive inward fluxes were added as determined in the calibration process as discussed in the calibration section (paragraph 6.4.5.1)

The upper model surface boundary was set as a uniform constant downward flux (vertical recharge) of $1.0E-4$ m/d (0.13 inches/year). This value was determined from initial vadose zone modeling runs (see sensitivity and calibration sections for further discussion on the relative importance of recharge). The PORFLOW™ software was not capable of treating this boundary as a free surface boundary but computed the entire 3-dimensional grid as saturated flow. Although the upper surface was chosen at an elevation near the actual water table, the area of the model near the river had higher than actual transmissivities because the groundwater surface slopes downward at this location. This was not a large concern for the analysis because the model was calibrated so that total pressure heads and hydraulic conductivities (and, as a result, computed groundwater velocities, the important factor in determining contaminant migration) matched the observed data. In other words, the model appropriately matched the groundwater velocities and, because of the software constraints, no attempt was made to match the total water budget. This approach is consistent with the stated model objectives.

The lower model surface was set with a uniform constant upward flux of $5.0E-4$ m/d ($16.4E-4$ ft/d). This value was determined in the calibration process and corresponds to values of 10 m (32.8 ft) of positive head differential across the lower silt aquitard (an observed value) and a vertical hydraulic conductivity value of about $5.0E-4$ m/d ($16.4E-4$ ft/d) for that unit.

6.4.3.3 Computational Parameters. Hydraulic flow simulations were run in steady-state (*i.e.*, although the boundary conditions for each of the calibrations, representing the high, average, and low water table conditions, are different, only one set of conditions was used at a time). The number of time steps required, until a steady-state simulation converged, varied depending on the starting condition; several thousand steps required for a simulation starting from rough initial conditions to several hundred for restart files that have initial conditions close to the convergence conditions. Steady-state runs were typically initialized from restart files and used 1,000 time steps. Contaminant transport simulations were run in the transient mode in order to simulate plume migration through time. Time steps used in the transient mode ranged from 1 to 200 days depending on the time period being modeled. A typical transient run incorporated approximately 1,200 time steps.

Default matrix and governing differential equation solvers were used. The grid Peclet number remained below two during simulations. No significant mass balance errors were observed. See appendix H for input and output files, and for additional information on the computational aspects of the PORFLOW simulations.

6.4.3.4 Contaminant Transport. The contaminant transport portion of the model used the calibrated hydraulic flow parameters, then added source terms and contaminant transport parameters to simulate plume progression through time. Specific source term and contaminant transport data were not available for input to the model. Information on the

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Table 6-12. Hydraulic Flow Sensitivity Analysis

		TOTAL PRESSURE HEAD DIFFERENCE IN METERS			
RUN	TESTED PARAMETER	Δ @C15R22	Δ @C36R22	Δ @C52R22	
0	1c60 Base	0	0	0	
1	1c61 $K_h' = K_h \times .50$ (all)	0.007	0.045	0.095	
2	1c62 $K_h' = K_h \times .25$ (all)	0.151	0.428	0.476	
3	1c63 $K_h' = K_h \times 2.0$ (all)	-0.245	-0.236	-0.109	
4	1c64 $K_h' = K_h \times 4.0$ (all)	-0.304	-0.297	-0.147	
5	1c65 $K_h' = K_h \times .50$ (all)	-0.189	-0.172	-0.042	
6	1c66 $K_h' = K_h \times .25$ (all)	-0.215	-0.197	-0.042	
7	1c67 $K_h' = K_h \times 2.0$ (all)	-0.117	-0.097	-0.038	
8	1c69 Up Surf. Rech.' = 0 in./yr	-0.206	-0.146	-0.027	
9	1c70 Up Surf. Rech.' = 4 in./yr	-0.134	-0.075	0.012	
10	1c71 Low Surf. Rech.' x .50	-0.169	-0.171	-0.074	
11	1c72 Low Surf. Rech.' x 2.0	-0.108	-0.048	0.075	
12	1c73 Low Surf. Rech.' x 1.5	-0.128	-0.089	0.025	
13	1c74 Low Surf. Rech.' x .25	-0.180	-0.192	-0.098	
14	1c75 Porosity' = Poros. x .25	-0.149	-0.130	-0.024	
15	1c76 Porosity' = Poros. x 4.0	-0.149	-0.130	-0.024	
16	1c77 $K_h' = K_h \times .25$ (Hanford)	0.109	0.213	0.387	
17	1c78 $K_h' = K_h \times .50$ (Hanford)	-0.037	0.016	0.123	
18	1c79 $K_h' = K_h \times 2.0$ (Hanford)	-0.245	-0.254	-0.144	
19	1c80 $K_h' = K_h \times 4.0$ (Hanford)	-0.323	-0.346	-0.209	
20	1c81 $K_h' = K_h \times .25$ (Up Ringd)	-0.151	-0.140	-0.044	
21	1c82 $K_h' = K_h \times .50$ (Up Ringd)	-0.154	-0.140	-0.039	
22	1c83 $K_h' = K_h \times 2.0$ (Up Ringd)	-0.158	-0.120	-0.008	
23	1c84 $K_h' = K_h \times 4.0$ (Up Ringd)	-0.189	-0.111	0.020	
24	1c85 $K_h' = K_h \times .25$ (Silt)	-0.146	-0.129	-0.023	
25	1c86 $K_h' = K_h \times 4.0$ (Silt)	-0.145	-0.127	-0.023	
26	1c87 $K_h' = K_h \times .25$ (Lo Ringd)	-0.112	-0.100	-0.044	
27	1c88 $K_h' = K_h \times 4.0$ (Lo Ringd)	-0.152	-0.112	0.041	

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TCE source was limited to a history of lagoon liner installation and repair at SPC (see source discussion in section 4.0). Quantities, timing, and location of the TCE source were determined, for use in the modeling analysis, by correlation with the lagoon liner history and matching plume progression with observed TCE groundwater concentrations. Because the exact source location is unknown, the simulated source area was not treated as a point source but as a volume 90 by 152 by 4 m (295 by 499 by 13 ft) located near SPC Lagoon No. 1. The best indicator of the contaminant transport parameters was the observed TCE plume and ranges of these parameters developed during the calibration process as discussed in paragraph 6.4.5.2. The observed nitrate data was not used for parameter estimation because the information did not allow for complete plume definition.

All simulations used retardation values directly, as discussed in paragraph 6.4.5.2, and were consistent with a linear adsorption-desorption assumption. This assumption is reasonable at low contaminant concentrations and is thus applicable at this site.

6.4.4 Sensitivity Analysis

Sensitivity analyses were performed on the flow and the contaminant transport portions of the model. The purpose of the sensitivity analyses was to determine the relative influence of the model input parameters on model results.

6.4.4.1 Hydraulic Flow Sensitivity. The hydraulics portion of the model was run repeatedly with the hydraulic parameters multiplied and divided by factors of 2 and 4 to determine model sensitivity. For recharge due to precipitation, the range was only varied from 0 to 4 inches per year. For each run, total pressure head deviations from the base case (calibrated average model) were determined at XY nodes (15,22), (36,22), and (52,22). Deviations are listed in table 6-12. This analysis showed the hydraulic model to be insensitive to changes in soil density and porosity. There was only slight sensitivity to recharge due to precipitation, horizontal flux across the southern boundary, vertical hydraulic conductivity, and seepage (positive flux) into the bottom of the model. The unconfined aquifer pressure heads were not very sensitive to flux into the model's lower boundary due to the intervening silt aquitard, which tends to dampen effects of changes in the lower aquifer. Unconfined aquifer total pressure heads were not very sensitive to upper surface recharge (precipitation recharge) because of the high hydraulic conductivities in the upper part of the unconfined aquifer and due to the small range of possible precipitation recharge. The model was most sensitive to changes in horizontal hydraulic conductivity. This is consistent with groundwater systems and groundwater models in general.

6.4.4.2 Contaminant Transport Sensitivity. A contaminant transport sensitivity analysis was performed in which pertinent parameters were varied within reasonable ranges. Table 6-13 shows predicted maximum TCE concentrations for years 1988, 1992, and 2000 as a result of simulations using the parameters listed in the first column. The analysis indicated the model was most sensitive to total and effective porosity values, significantly sensitive to retardation and dispersivity values, and minimally sensitive to storage and diffusive porosity values.

6.4.5 Calibration

The hydraulic flow and contaminant transport portions of the model were calibrated to observed site data. The purpose of the calibrations was to set model parameters consistent with site parameters so that model results better simulate actual site conditions. Without calibration, a model can produce results having little resemblance to what is observed in the field.

6.4.5.1 Hydraulic Flow Calibration. For the hydraulic flow portion of the model, calibration data was chosen from the observed groundwater levels reported in WHC, 1991b. Three data sets, June 25-27, February 27-March 2, and September 24 to 27, were chosen to represent the groundwater levels relating to the high-, average-, and low-river stage conditions. These calibrations were performed in the steady-state mode with boundary conditions and hydraulic conductivities adjusted until the model simulated the observed groundwater levels. Figures 6-21 through 6-23 show the observed and calibrated water surface contours superimposed. Table 6-14 lists the observed, computed, and the resulting difference for 22 wells in the area of interest. Maximum deviations of the computed from the observed elevations consistently occurs at well MW-13 which appears to be screened at a different depth or to have some other similar cause for its levels being consistently about 0.5 m (1.6 ft) higher than those of MW-14. Most other deviations are less than 0.1 m (0.3 ft) which indicates reasonably close calibrations.

The simulated river stages and inflowing flux values at the southern boundary were modified appropriately for each condition. The high-, average-, and low-river stages represent conditions where the river boundary was higher than 97, 48, and 7 percent of normally distributed river elevations. During the calibration process, horizontal and vertical hydraulic conductivities and boundary fluxes were adjusted until reasonable matches between observed and computed heads were obtained. Table 6-15 shows the calibrated hydraulic conductivities. The calibrated values for the Hanford formation and middle Ringold Formation correspond reasonably well to the pump test results [365 to 472 m/d (1,198 to 1,548 ft/d) at SPC and 37 to 50 m/d (121 to 164 ft/d) near the 300 Area].

6.4.5.2 Contaminant Transport Calibration. Contaminant transport parameters were calibrated by matching simulated plume concentrations with observed contaminant levels. The model was used to determine an approximate source term that corresponds with TCE use at the site. Discrete spike source terms, with release timing correlating to periods of most intense lagoon repair and installation activity, were input to the model that was run iteratively until dispersion and retardation values produced calculated plumes matching observed plumes. This process began with an attempt to match the observed plume in a simulation having only one source spike in the summer of 1987. This was tried as a starting point because the observed data begins with a maximum 1987 reading of 420 ppb as shown in figure 6-24. By comparing the simulated plumes, shown in figure 6-25, with those drawn from observed data shown in figure 6-14, the determination was made that it was not possible, even with unreasonable input values, to match the observed data with only one source term occurring in 1987 (the time-series graphs, such as figure 6-25, are 2-dimensional slices of the computed, 3-dimensional contaminant plumes taken at the layer where the plume

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extends the farthest). Because the simulation with one source spike did not match the observed data, one additional source spike was added in 1983, at the next earlier period of increased TCE use, with the result shown in figure 6-26. This simulation showed that additional, earlier, TCE introduction was still required for computed values to match the observed values. With one additional spike introduced in 1980 (12 shown in figure 6-27), near the earliest recorded use of TCE, the simulated values were able to produce a reasonable match to observed values as shown in figure 6-28. For this simulation, the TCE concentrations attenuate to below 5 ppb by the year 2007 with no concentrations above that level migrating across the George Washington Way Diagonal (and line extending straight therefrom as shown in figure 6-25).

The simulation discussed above is considered unconservative (the computed contaminant plume is less persistent than is actually the case) because, comparing the 1992 computed and observed plumes, the simulated concentrations in the source area appear to be dissipating faster than is occurring. The parameters used for this condition were: retardation factor (R) = 2.0, total porosity (η_{tot}) = 0.23, effective porosity (η_{eff}) = 0.20, and longitudinal and transverse dispersivity factors of 1.0 and 0.03, respectively. Porosity values are for sand and gravel zones, the silt zone had η_{tot} and a η_{eff} of 0.24 and 0.28 assigned throughout. A conservative simulation (contaminant plume attenuates slower than actual) was found through repeated model runs. Results are presented in figure 6-29. The parameters used for this condition were: retardation factor (R) = 2.55, total porosity (η_{tot}) = 0.32, effective porosity (η_{eff}) = 0.28, and longitudinal and transverse dispersivity factors of 0.3 and 0.01, respectively. For this simulation, the TCE concentrations attenuate to below 5 ppb by the year 2017 with no concentrations above that level migrating across the George Washington Diagonal area. Because these contaminant transport parameters were more conservative, the source terms (figure 6-30) were reduced so the simulation would match the 1987 to 1992 observed data (*i.e.*, the more conservative transport parameters cause the simulated plume to remain at higher concentrations longer; so as the parameters become increasingly conservative, the source must be reduced proportionately in order to match the observed data). This simulation was the most conservative one found that would match the observed data.

The modeled source term and an estimate of the actual source amount were compared. The model used source amounts of 33 and 24 gal (125 and 91 l) for the unconservative and conservative simulations, respectively. The amount of actual source material is not documented and is not evident from the observed concentrations in the plume because of losses due to adsorption, degradation, and dispersion of TCE in concentrations below detection limits. However, an estimate of the amount of TCE in the groundwater plume was made by multiplying TCE concentration levels with their corresponding plume volumes and found to be about 15 to 20 gallons.

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Table 6-14. Comparison of Observed Groundwater levels and Computed Total Pressure Heads for the High, Average, and Low River Stage Model Calibrations

WELL #	SEPTEMBER 24-27, 1990			FEB 27 - MARCH 2, 1990			JUNE 25 - 27, 1990		
	OBS meters	CALC meters	DIFF meters	OBS meters	CALC meters	DIFF meters	OBS meters	CALC meters	DIFF meters
399-1-17A	104.05	104.01	0.04	104.72	104.69	0.03	105.73	105.65	0.08
399-3-6	103.98	104.01	0.03	104.67	104.70	0.03	105.68	105.64	0.04
399-3-7	103.97	104.01	0.04	104.67	104.70	0.03	105.66	105.64	0.02
399-3-12	103.93	104.00	0.07	104.64	104.69	0.05	105.61	105.62	0.01
399-4-1	103.87	103.99	0.12	104.59	104.65	0.06	105.53	105.60	0.07
399-4-11	103.93	104.00	0.06	104.63	104.69	0.06	105.59	105.62	0.02
399-5-1	104.03	104.08	0.05	104.65	104.75	0.10	105.66	105.65	0.01
399-6-1	104.13	104.08	0.06	104.72	104.75	0.03	105.77	105.67	0.10
699-S27-E14	103.88	104.02	0.14	104.58	104.69	0.10	105.52	105.60	0.09
699-S29-E12	105.42	105.10	0.32	105.32	105.32	0.01	105.86	105.80	0.06
699-S30-E(MW-10)	106.34	106.26	0.08	106.22	106.31	0.09	106.28	106.51	0.23
699-S30-E(MW-11)	106.49	106.36	0.13	106.37	106.36	0.00	106.39	106.61	0.21
699-S30-E15A	103.84	104.09	0.25	104.80	104.74	0.06	105.65	105.57	0.09
699-S31-E(MW-08)	107.69	107.56	0.12	107.61	107.54	0.07	107.60	107.52	0.08
699-S31-E(MW-12)	106.22	106.29	0.07	106.09	106.32	0.23	106.16	106.53	0.37
699-S31-E(MW-14)	106.43	106.39	0.04	106.30	106.37	0.07	106.34	106.57	0.23
699-S31-E(MW-13)	107.01	106.39	0.62	106.88	106.42	0.45	106.92	106.62	0.30
699-S31-E(MW-15)	106.37	106.40	0.03	106.24	106.43	0.18	106.28	106.62	0.34
699-S31-E13	105.55	105.45	0.11	105.38	105.37	0.01	106.00	105.97	0.03
699-S32-E13A	105.65	105.45	0.21	105.47	105.63	0.16	106.05	106.03	0.02
699-S32-E13B	--	--	--	105.55	105.85	0.30	106.08	106.18	0.11
699-S34-E(MW-02)	107.70	107.72	0.01	107.40	107.46	0.06	107.43	107.48	0.04

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Table 6-15. Model Zone Properties

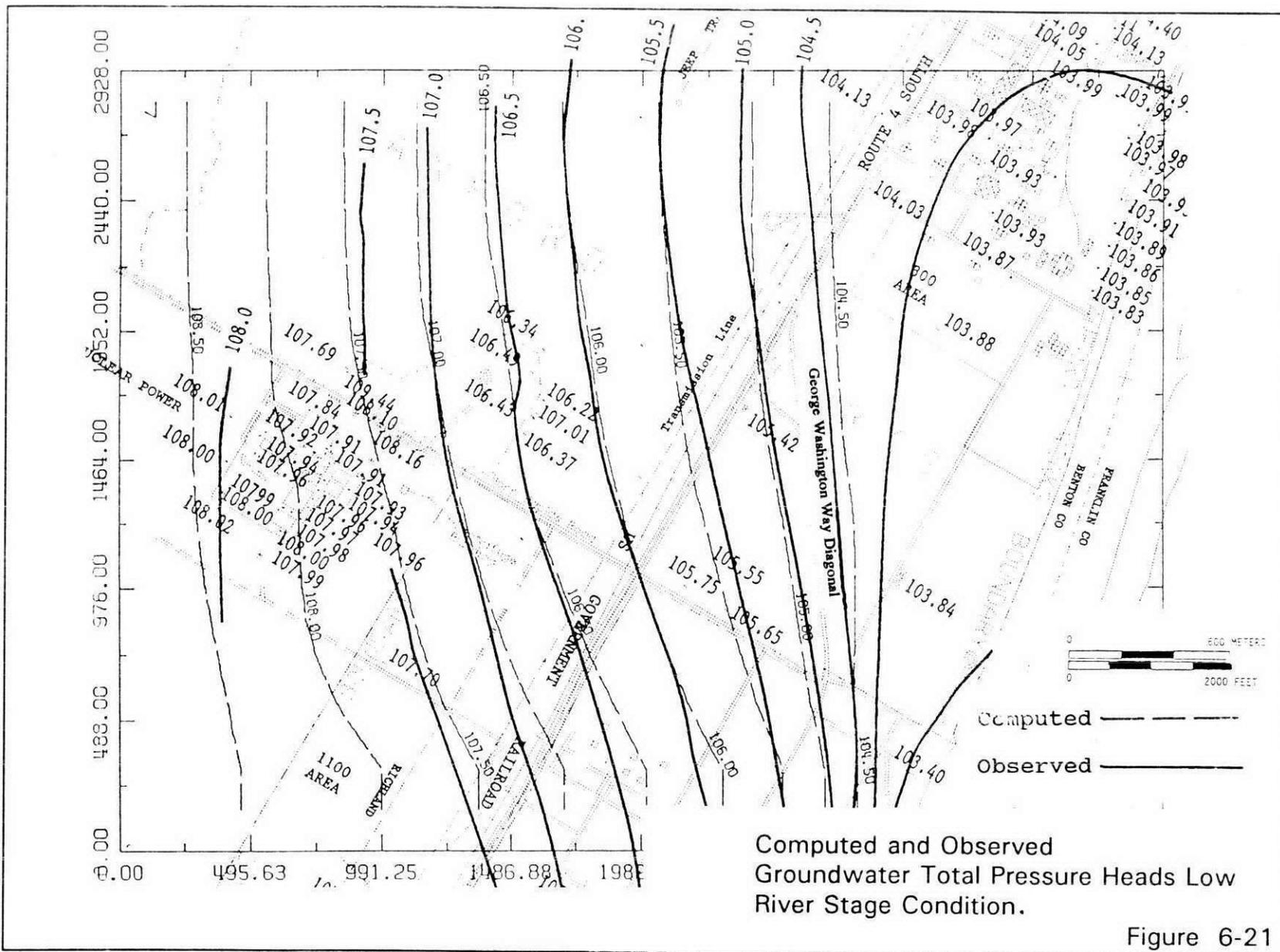
ZONE #	GEOLOGIC UNIT	HORIZON. HYDRAUL CONDUCT.	VERTICAL HYDRAUL CONDUCT.	EFFECTIVE POROSITY	DIFFUSIVE POROSITY	TOTAL POROSITY	STORE COEFF.
1	Lower Ringold (sand/gravel)	20. ¹	1.2	.20, .28 ²	.20, .28	.23, .32	0.2
4	Upper Ringold (sand/gravel)	60.	3.400	.20, .28	.20, .28	.23, .32	0.2
5	Upper Ringold (silt)	0.01	0.001	.20, .24	.20, .24	.23, .27	0.2
7	Hanford (near river)	1000.	64.	.20, .28	.20, .28	.23, .32	0.2
8	Hanford (HRL vicinity)	400.	13.7	.20, .28	.20, .28	.23, .32	0.2
9	Ringold (ASH)	0.05	0.005	.20, .24	.20, .24	.23, .27	0.2
10	Hanford (near river)	5000.	50.	.20, .28	.20, .28	.23, .32	0.2

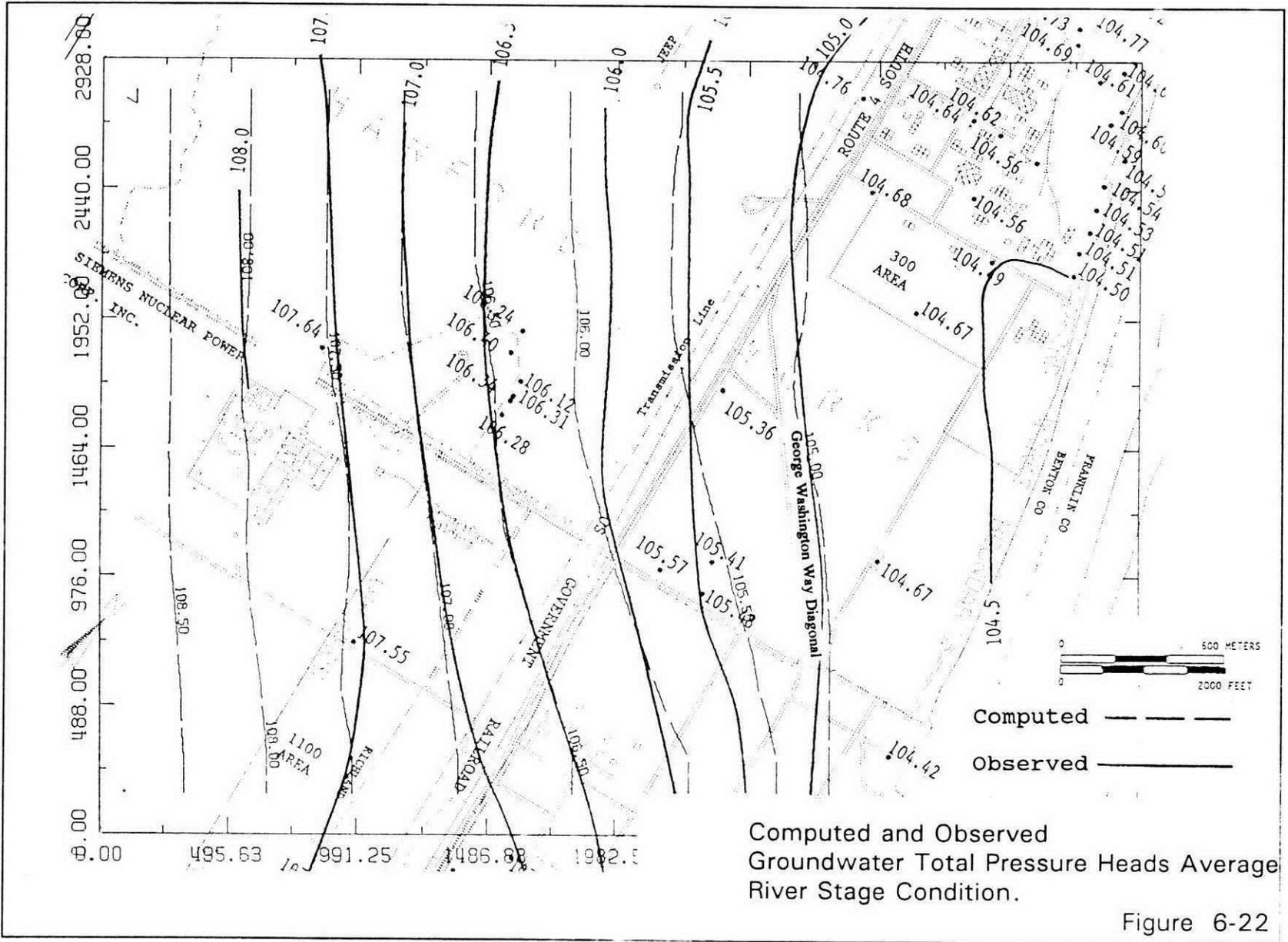
¹ Hydraulic conductivity values are in meters per day.

² The first value was used in the unconservative simulations, the

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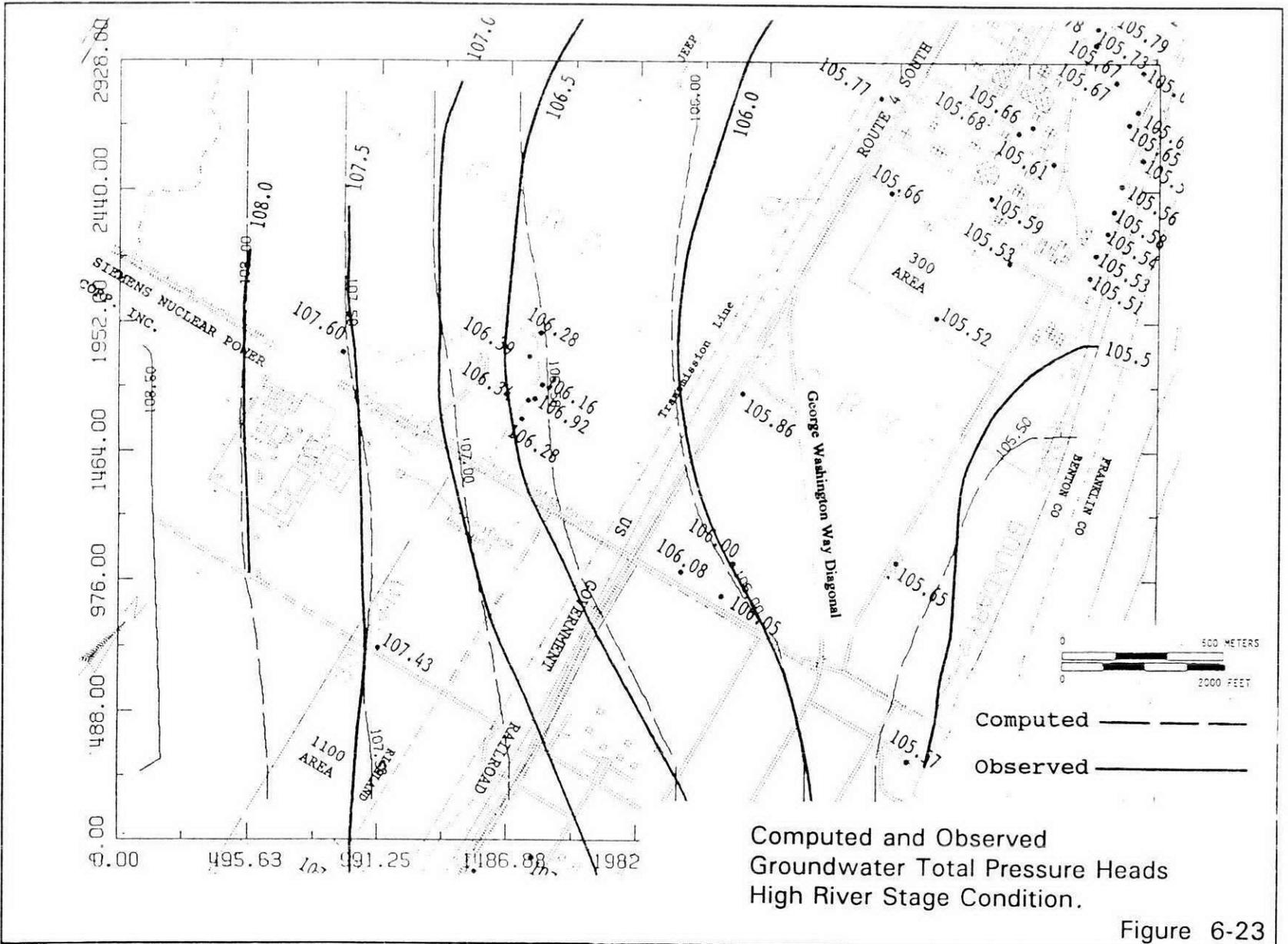




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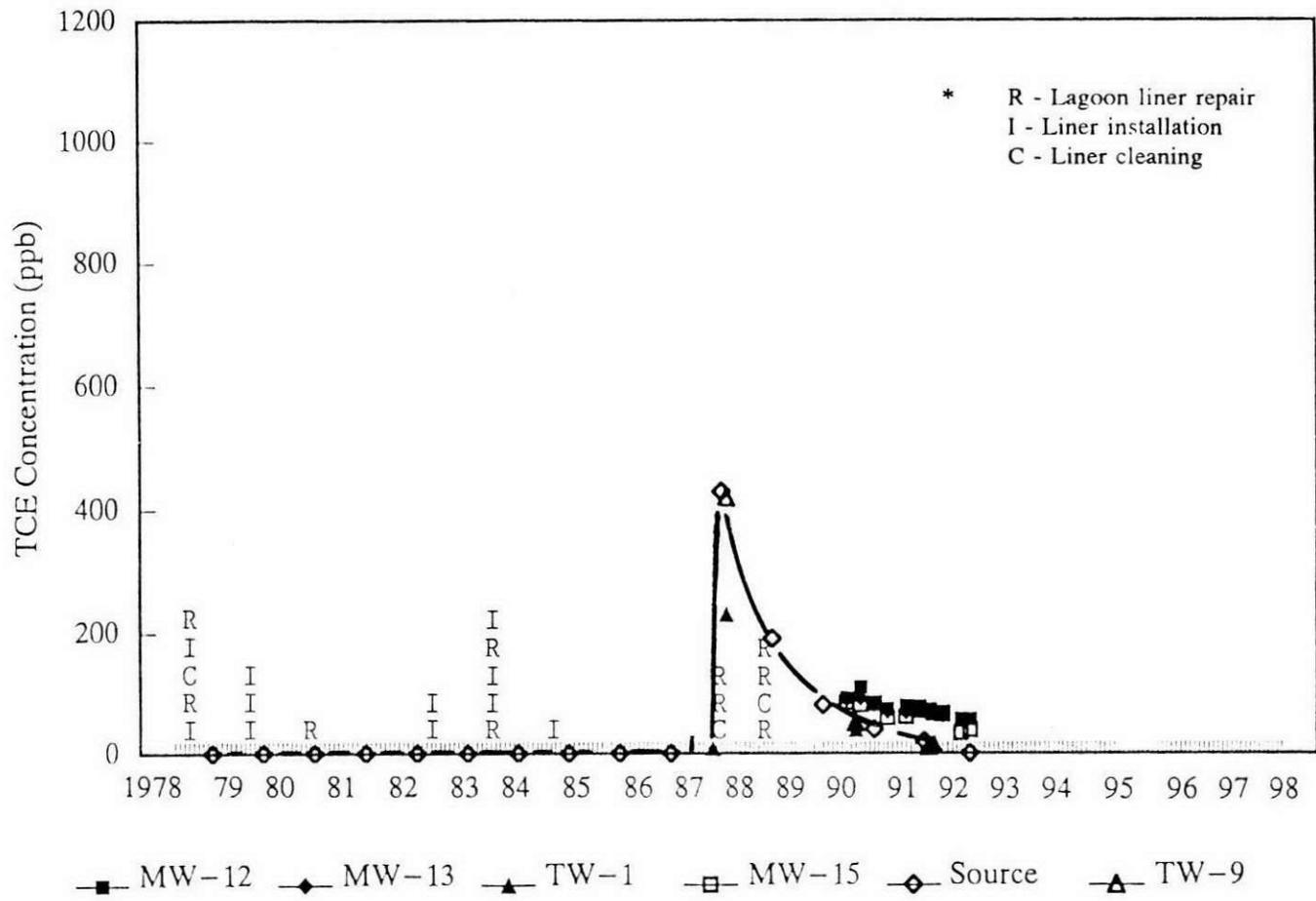
6-72

Figure 6-22
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Computed and Observed Groundwater Total Pressure Heads High River Stage Condition.

Figure 6-23



Observed TCE Concentrations and Model Source Spike of 450 ppb.

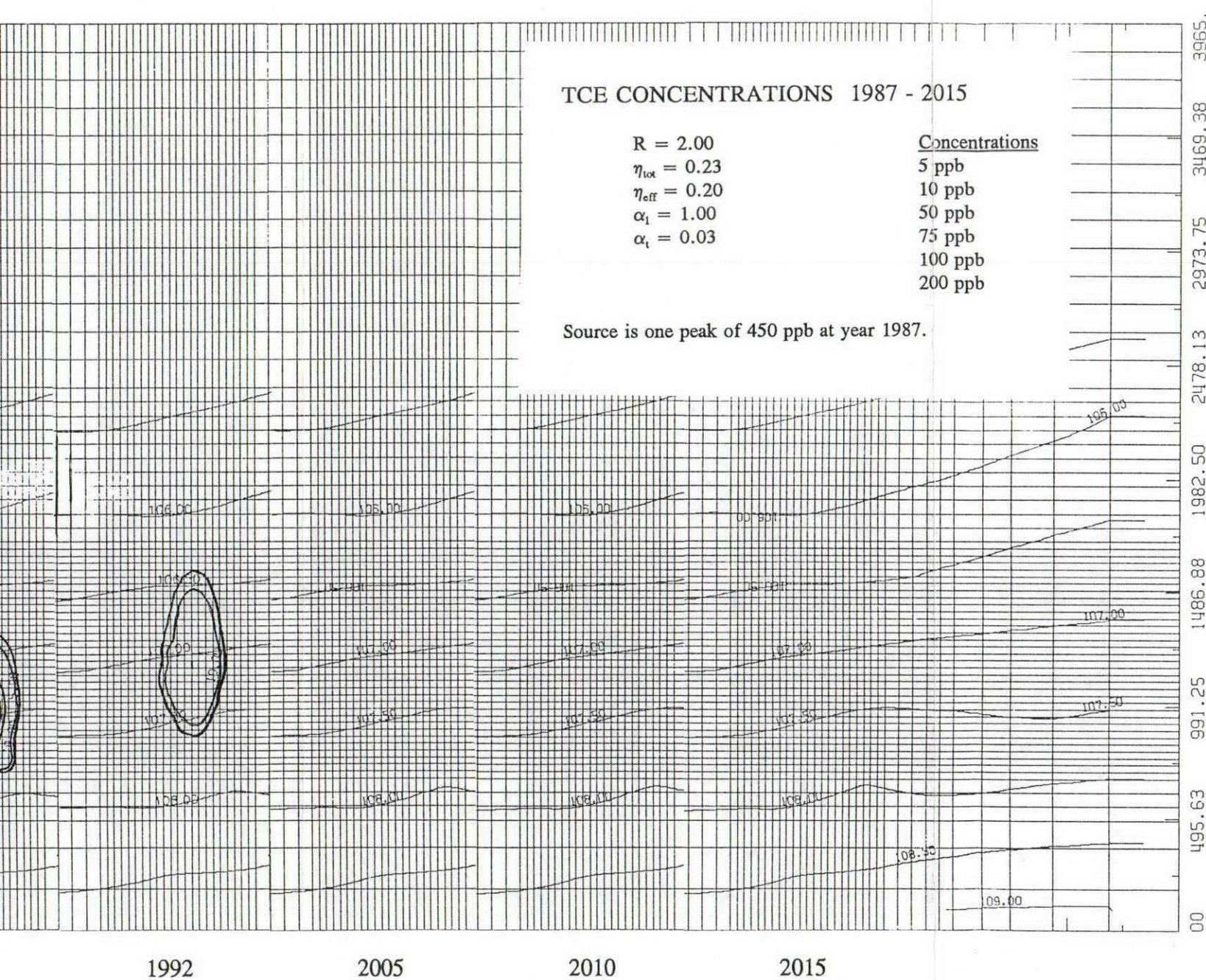
Figure 6-24

TCE CONCENTRATIONS 1987 - 2015

$R = 2.00$
 $\eta_{\text{tox}} = 0.23$
 $\eta_{\text{eff}} = 0.20$
 $\alpha_1 = 1.00$
 $\alpha_2 = 0.03$

Concentrations
 5 ppb
 10 ppb
 50 ppb
 75 ppb
 100 ppb
 200 ppb

Source is one peak of 450 ppb at year 1987.



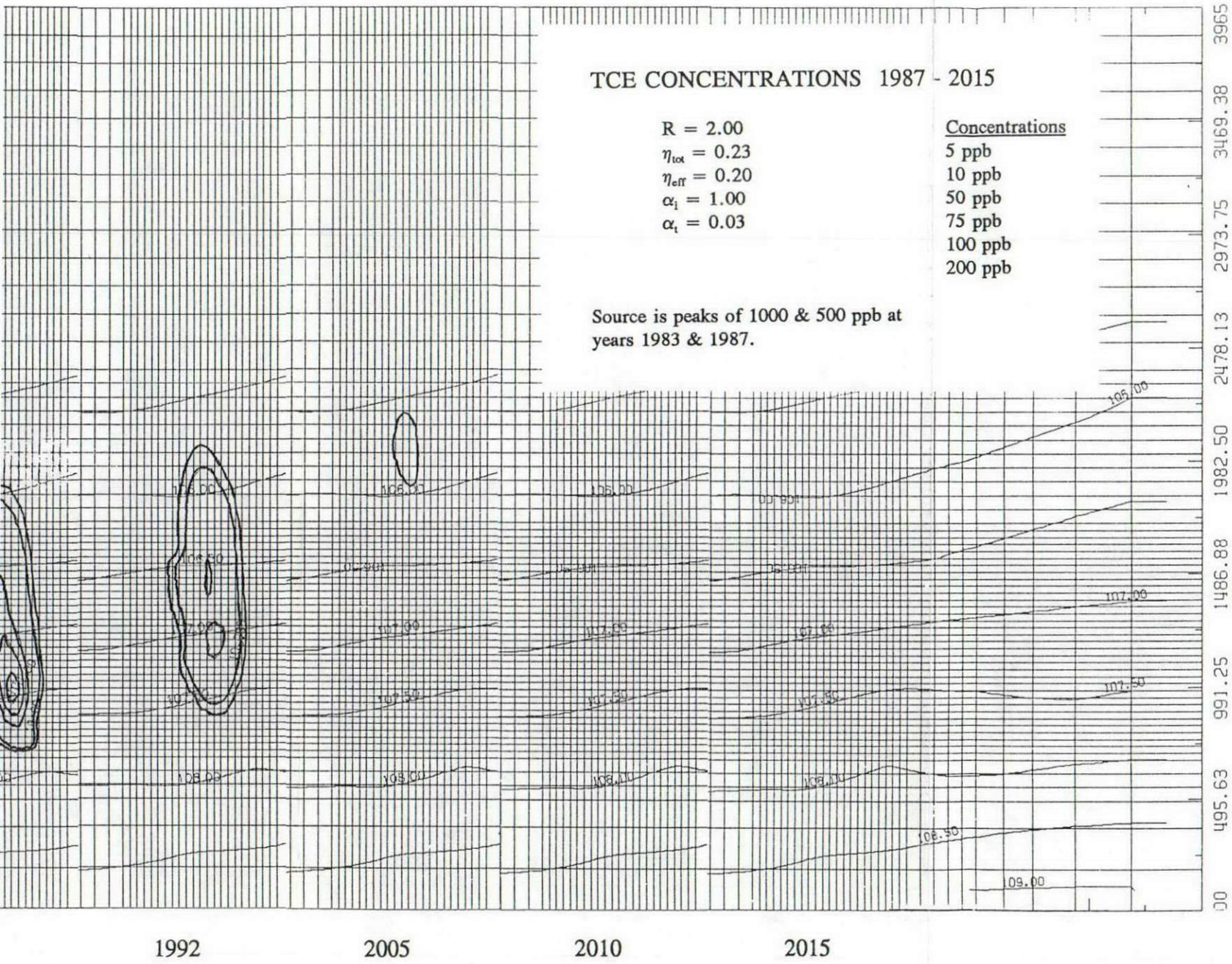
Computed TCE Plumes With One Source Peak in 1987.

TCE CONCENTRATIONS 1987 - 2015

$R = 2.00$
 $\eta_{tox} = 0.23$
 $\eta_{eff} = 0.20$
 $\alpha_i = 1.00$
 $\alpha_t = 0.03$

Concentrations
 5 ppb
 10 ppb
 50 ppb
 75 ppb
 100 ppb
 200 ppb

Source is peaks of 1000 & 500 ppb at years 1983 & 1987.



Computed TCE Plumes With Source Peaks in 1983 and 1987.

For the purposes of determining the sensitivity of the modeled results to the contaminant transport parameters, additional simulations were made with retardation, dispersion, and porosity values stretched to more conservative degrees with results being shown in figures H-16 through H-18 in appendix H. These simulations do not match the 1987 to 1992 observed data well enough to be considered calibrated, but do demonstrate that the model results are not extremely sensitive to transport parameters. In other words, even when out-of-range porosity, retardation, and dispersivity values were used, TCE concentrations approached 5 ppb at about the same time (2015 to 2020) as the calibrated conservative simulation discussed earlier.

Reported contaminant transport values, for another groundwater modeling study involving TCE migration at the Fort Lewis, Washington site (USACE, 1990), were: retardation factor (R) of 3.0, dispersivity factors of 0.75 (α_l , longitudinal) and 0.075 (α_t , transverse), and porosity values (η) of 0.25. These values compare fairly closely with the conservative simulation factors of $R = 2.55$, $\alpha_l = 0.30$, $\alpha_t = 0.01$, and $\eta = 0.28$ to 0.32. Reported retardation values were assigned to the Hanford and Ringold Formations' gravel and sand deposits; the retardation for the silt layer was set at 10 because of its low hydraulic conductivity.

6.4.6 Model Simulation Results

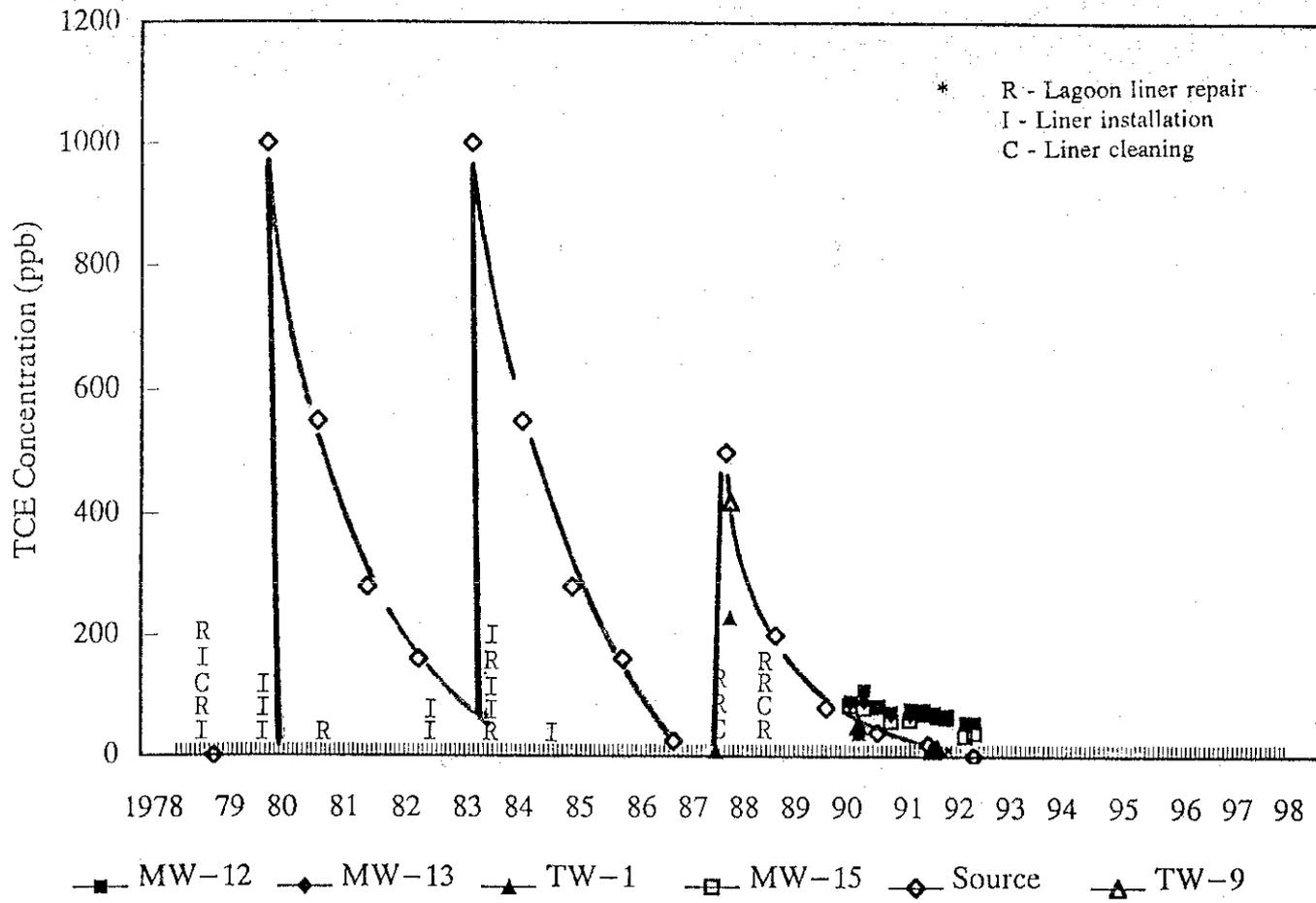
The calibrated contaminant transport model was used to determine TCE persistence and migration extent for the baseline (no active remediation) and for three remediation scenarios the selection of which was determined by an optimization analysis.

6.4.6.1 Baseline Scenario Results. The migration of TCE was simulated using both the unconservative and conservative contaminant transport parameters with results shown in figures 6-28 and 6-29, respectively. These simulation results predict that the TCE plume will attenuate to below 5 ppb between the years 2007 and 2017. They also predict that the TCE plume will attenuate to below 5 ppb before crossing the George Washington Way Diagonal (and line extending straight therefrom as shown in figure 6-25) and that the maximum predicted level of TCE reaching the Columbia River will be approximately 1 ppb. Other potential simulations providing results to the contrary and still matching the observed data were not found. The analysis assumed no additional TCE source introduction.

The above results were checked in a simulation that used the conservative parameters and ran the high, average, and low river stage boundary conditions in a cyclical series. This series followed a pattern so that the average condition was used 50 percent of the time and the high and low conditions were each used 25 percent of the time. Figure 6-31 shows the time series plots for this simulation and shows that the results are similar whether or not the river boundary was set at the average river stage or caused to fluctuate.

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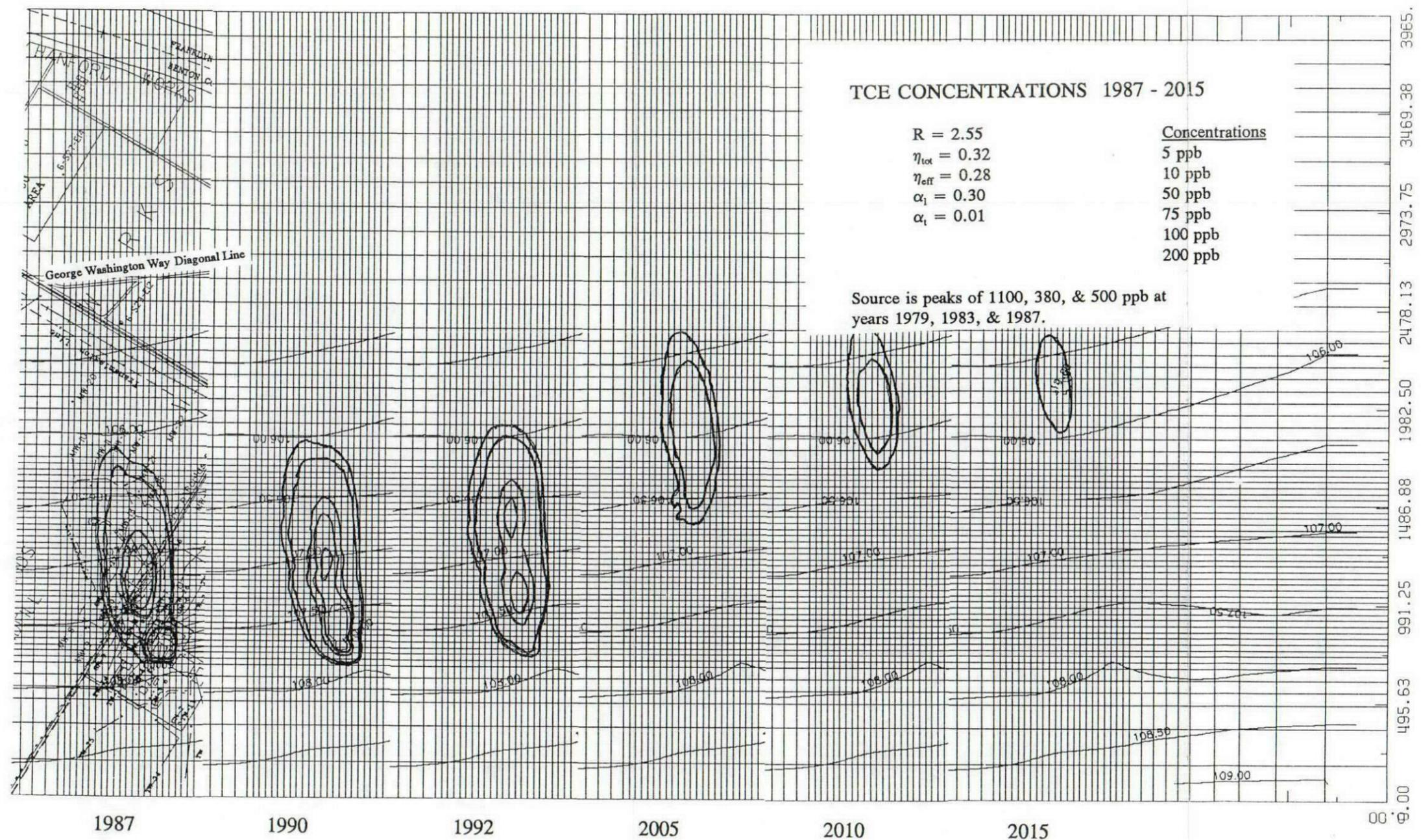
Observed TCE Concentrations and Model Source Spikes of 1000, 1000, and 500 ppb.

Figure 6-27

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9 3 1 2 8 6 2 0 4 8 7

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TCE CONCENTRATIONS 1987 - 2015

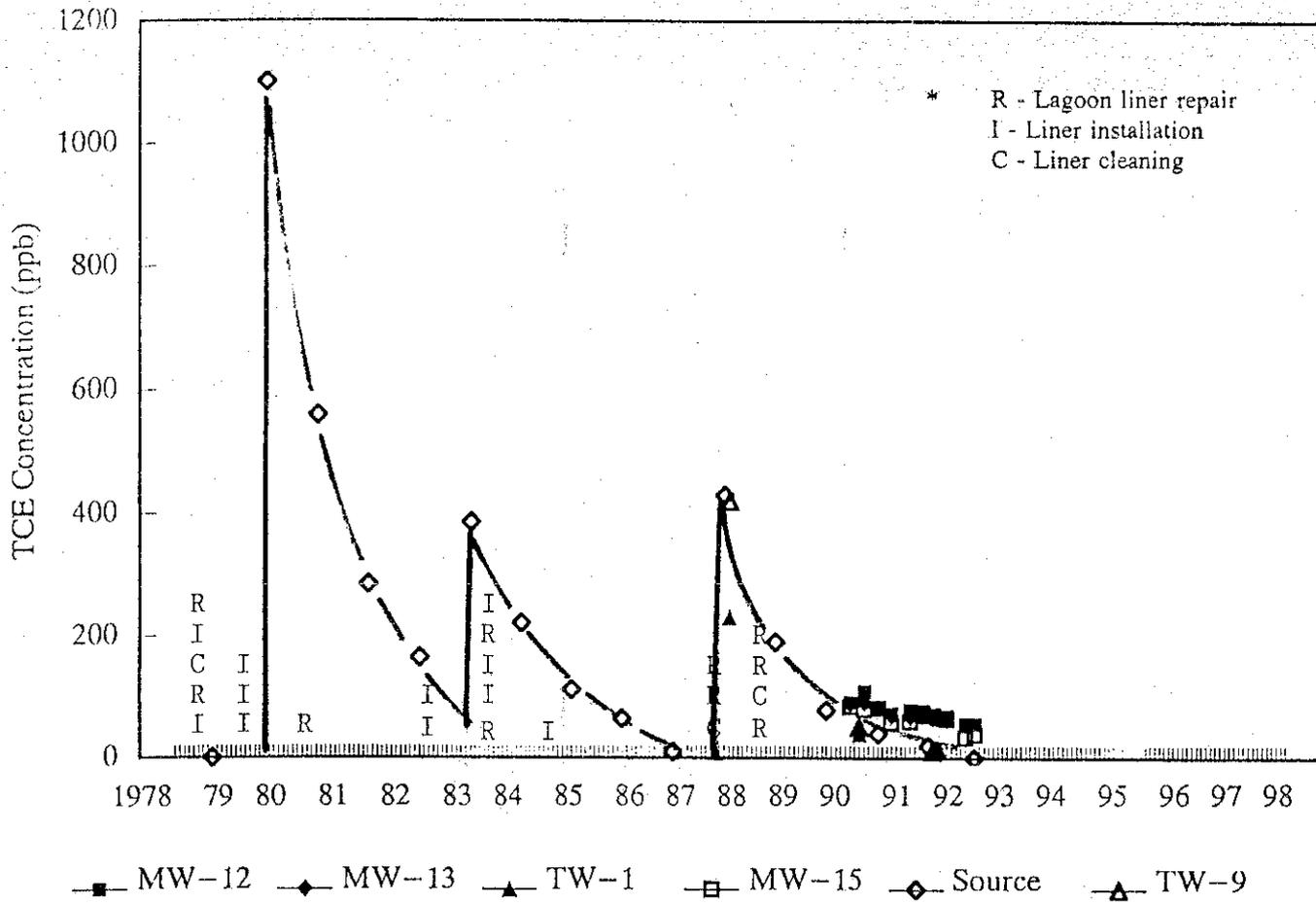
$R = 2.55$
 $\eta_{tot} = 0.32$
 $\eta_{eff} = 0.28$
 $\alpha_1 = 0.30$
 $\alpha_2 = 0.01$

Concentrations
 5 ppb
 10 ppb
 50 ppb
 75 ppb
 100 ppb
 200 ppb

Source is peaks of 1100, 380, & 500 ppb at years 1979, 1983, & 1987.

Computed TCE Plumes with Source Peaks in 1979, 1983, and 1987.
 Conservative Calibration.

Figure 6-29



Observed TCE Concentrations and Model Source Spikes of 1500, 380, and 400 ppb.

Figure 6-30

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Figure 6-30
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6.4.6.2 Remediation Scenario Results. Extraction-treatment-infiltration (pump and treat or extraction-infiltration) scenarios were the only action remediation scenarios analyzed with the model. A preliminary optimization of possible site extraction-infiltration scenarios was accomplished to select a limited number of scenarios for further analysis. The results of the optimization simulations are shown in figure 6-32. The graphed data points represent the dates when maximum plume concentration dropped below 5 ppb for the pumping rates and well configurations simulated. The results predict the greatest TCE reductions with the first few wells [between 379 and 1,136 l/min (100 and 300 gal/min) total extraction rate] and decreasing reductions thereafter. Only a small amount of contaminant is reduced for total extraction rates greater than 1,894 l/min (500 gal/min). This effect occurs because the first well can be located in the most optimum place, wells added thereafter are located in increasingly less effective places. This, and effects from low permeability areas and the adsorption and desorption process, preclude a linearly effective extraction of contaminants.

Based on the preliminary optimization, three extraction-infiltration scenarios were identified for further analysis: (1) a single well system extracting 379 l/min (100 gal/min), (2) a three well, T-configuration system extracting 300 gpm, and (3) a 10 well, longitudinally linear system extracting 3,788 l/min (1000 gal/min). Figure 6-33 shows these three configurations, each being the most effective configuration for their respective extraction rates. For each, the treated water is infiltrated, in a near-surface trench, just downgradient of the extraction wells. The model simulated extraction wells screened in the unconfined aquifer.

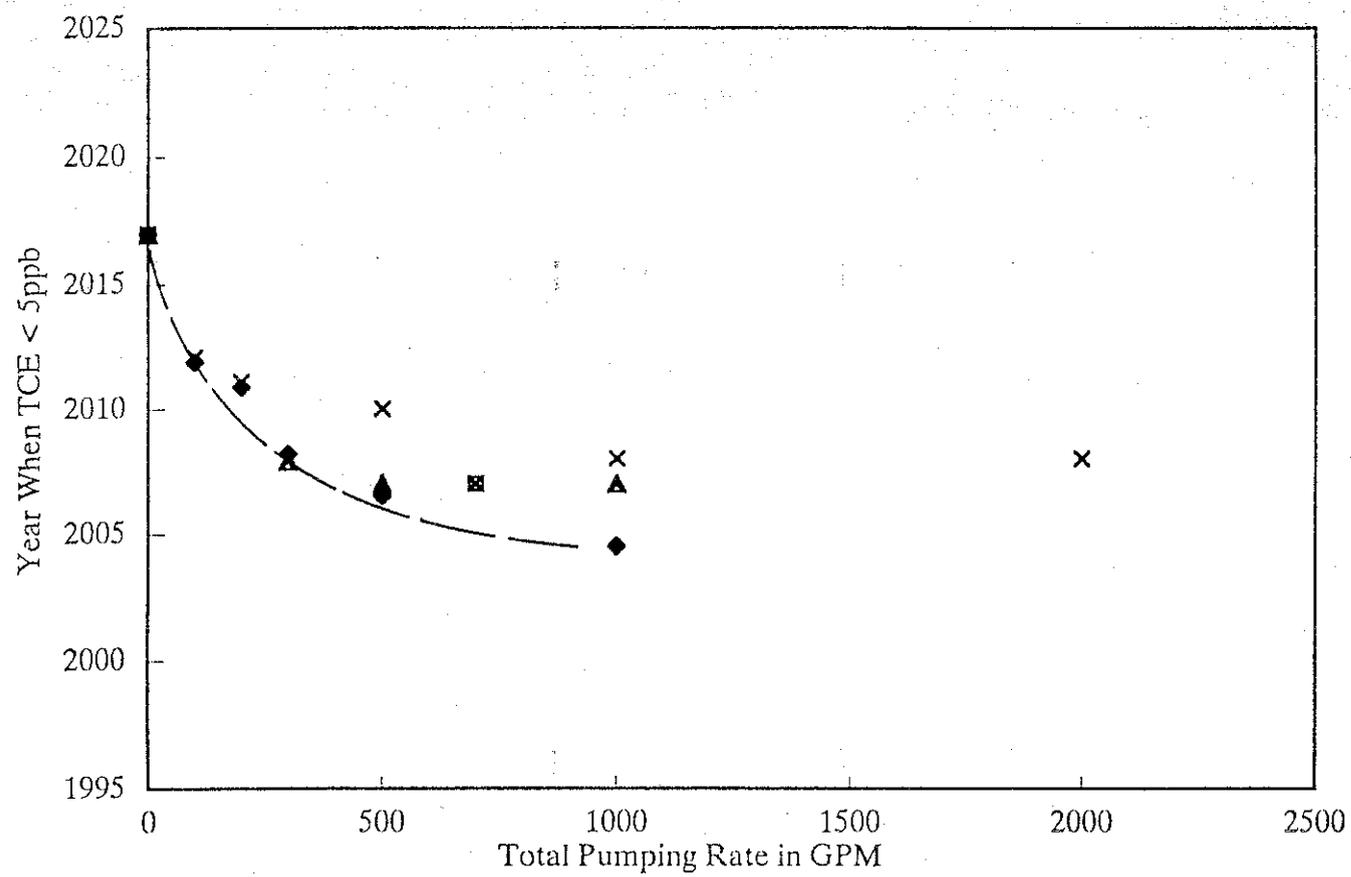
The effectiveness of these scenarios was evaluated in two ways: (1) using the calibrated hydraulic flow portion of the model only, the area of the aquifer captured by the extraction wells was identified and compared to the observed extent of the plume, and (2) using the calibrated flow and contaminant transport model functions, the migration of the plume, with the features of extraction of contaminated water and infiltration of clean water, was run in a time-series (transient) mode.

Figure 6-34 shows the predicted capture zones (shaded areas) for the three scenarios. Comparison of these zones with the 1992 TCE plume shown in figure 6-14, shows that scenario 1 would capture only the most highly concentrated portion of the plume (levels above approximately 35 ppb), scenario 2 would just capture the 5 ppb plume, and scenario 3 would capture the 5 ppb plume and about 100 percent additional water outside the 5 ppb plume. If scenario 3 were implemented and operated continually until clean-up standards were achieved, most of the water treated would be already below the TCE MCL. Likewise for scenario 2, although it captures the current 5 ppb plume almost exactly, after a few years of operation, its capture zone would also include water with below 5 ppb concentrations. From an efficiency standpoint, the optimum scenario treats the most highly concentrated portion of the plume with the untreated portion attenuating to MCL about the same time the treated portion achieves MCL. The capture zone analysis indicates that the optimum pump and treat scenario for this site would include wells extracting between 379 and 1,136 l/min (100 and 300 gal/min) (one to three wells).

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- transverse line
- ◆ longit. line
- ▲ T-config.
- × T w/wells at plume front

Results of a Preliminary Extraction-Infiltration Well Configuration Optimization

Figure 6-32.

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The three extraction-infiltration scenarios were also analyzed in the contaminant transport mode using the conservative parameters discussed earlier. Figures 6-35 through 6-37 show the time series results. Predicted dates when TCE concentrations are reduced to below 5 ppb are years 2012, 2008, and 2004 for scenarios 1, 2, and 3, respectively. These dates compare to the predicted baseline clean-up date of 2017 for the conservative condition. Simulations were not made using the unconservative transport parameters, but would result in earlier dates than those above. Table 6-16 lists these results for the baseline and the three pump and treat scenarios.

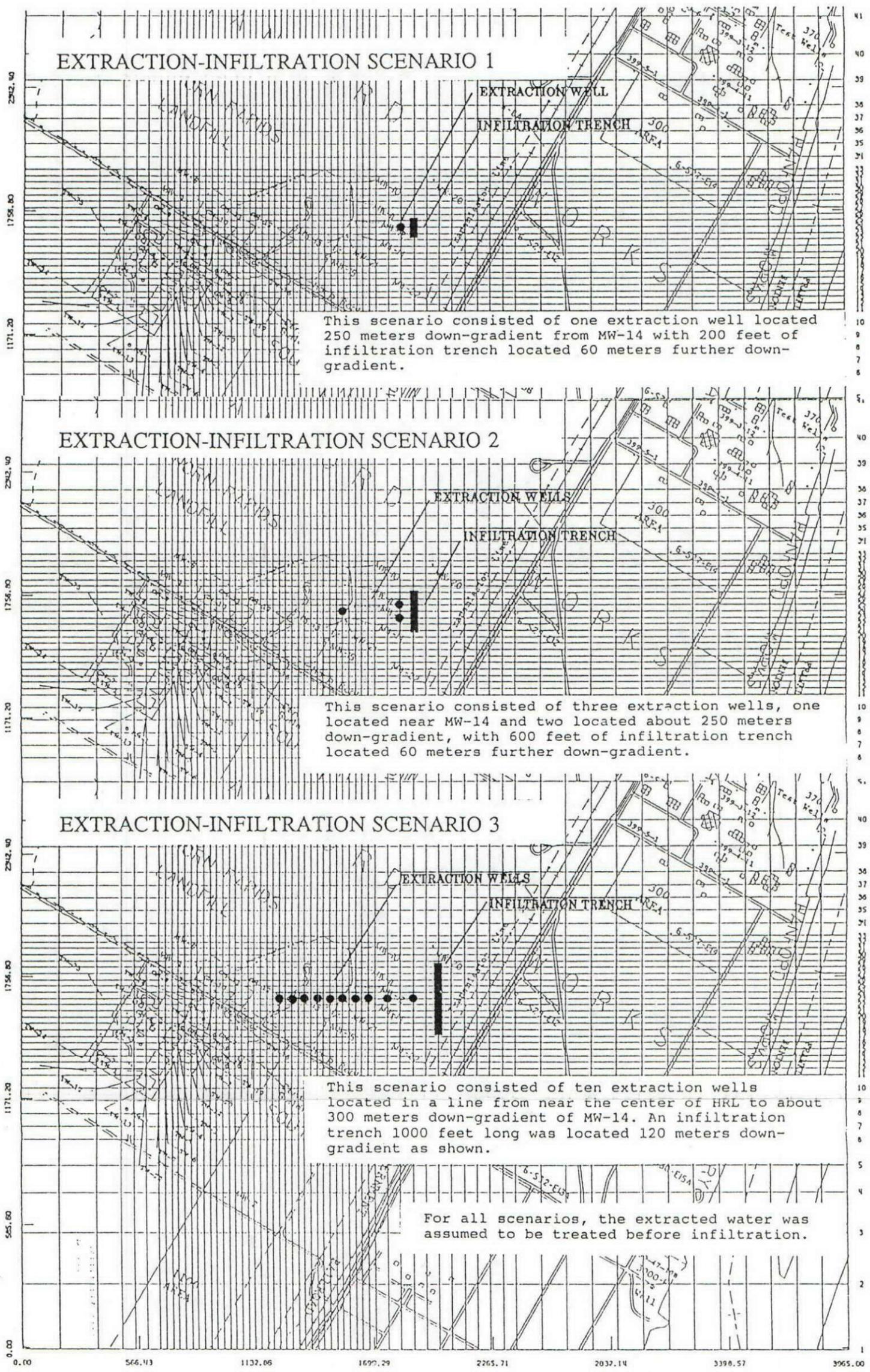
Nitrate migration was simulated and results predict nitrate attenuation to below 10 ppm before the year 2005. These results are given in appendix H and were derived using conservative transport parameters (with no retardation) and the assumption of no future nitrate source introduction. This simulation was calibrated to the observed nitrate data but had greater uncertainty than the TCE simulations because of less detailed plume delineation and less information about the source term. As discussed earlier, nitrate was considered a conservative solute and has greater dispersion and attenuation than TCE. Because of this, and because the nitrate concentrations are closer to MCL's than TCE, nitrate is predicted to attenuate to MCL's faster than TCE, both for the baseline and active remediation scenarios. However, if a remediation scenario included pump and treat for nitrate, the optimum well placement would be slightly different than those shown in the TCE pump and treat scenarios because the two plumes are not exactly aligned (figure 6-12).

The results for the baseline scenario are reported as a range, and the results for the remediation scenarios are reported as expected upper limits, because of the uncertainty associated with the source terms and the contaminant transport parameters. This uncertainty was dealt with by setting the conservative condition transport parameters to their maximum limits while still matching the observed 1987 to 1992 data (*i.e.*, the conservative simulated contaminant plume was slightly more persistent than the observed plume so that predictions beyond 1992 are considered expected upper limits). Also, the simulations did not include biodegradation and volatilization losses, making the results more conservative.

Some predictions of TCE attenuation at other sites, particularly at pump and treat project sites, have been shown to be overly optimistic due to uncertainty concerning the amount of TCE available for desorption back into the groundwater. At some sites, the concentrations resulting from desorption alone leveled off above clean-up levels and are anticipated to remain so for a long time, implying long operation times and limited effectiveness of pump and treat in reaching low target concentration levels ("The Effectiveness of the Pump and Treat Method for Aquifer Restoration," Environmental Restoration '91 Conference Proceedings, sponsored by DOE Office of Environmental Restoration, Pasco, Washington, 1991). This is not expected to be the case for this site because of the smaller source amount and relatively low concentration levels (50 ppb compared to 1,000 and 10,000 ppb at other sites), and a relatively rapid attenuation that is not leveling off.

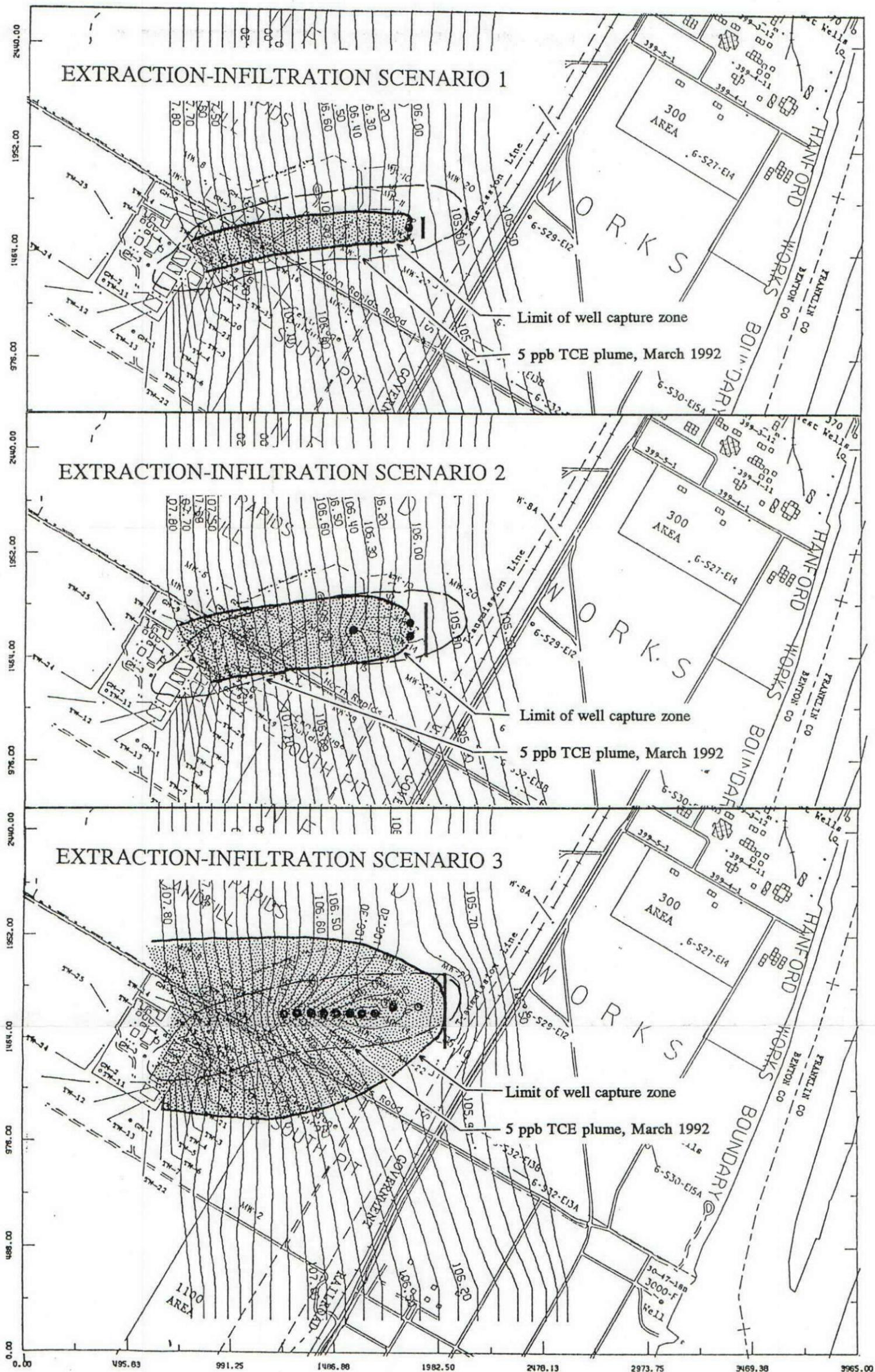
As discussed earlier, if current reduction rates in the MW-12 area wells were to continue, assuming a half-life of 2 years, the concentrations would attenuate to 5 ppb by about the year 2000. This simple extrapolation does not account for the plume movement or the adsorption-desorption relationship over time, but does add to the credibility of the 2007 to 2017 range predicted by the model that did include these factors. The modeling results reported are the best predictions possible, using all available data, state-of-the-art simulation software, and sound modeling and model calibration methods.

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Well Configurations for Extraction-Infiltration Scenarios 1-3.

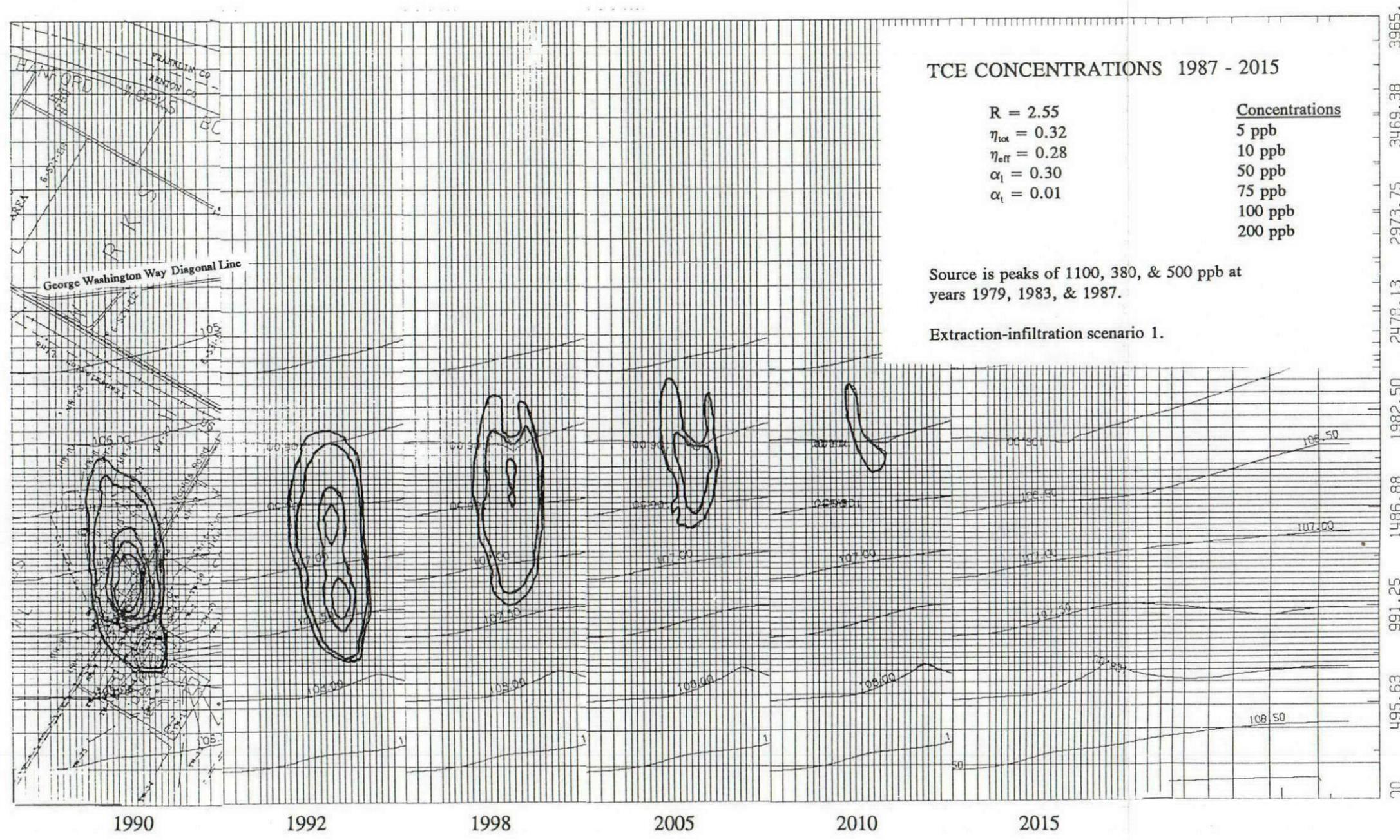
Figure 6-33



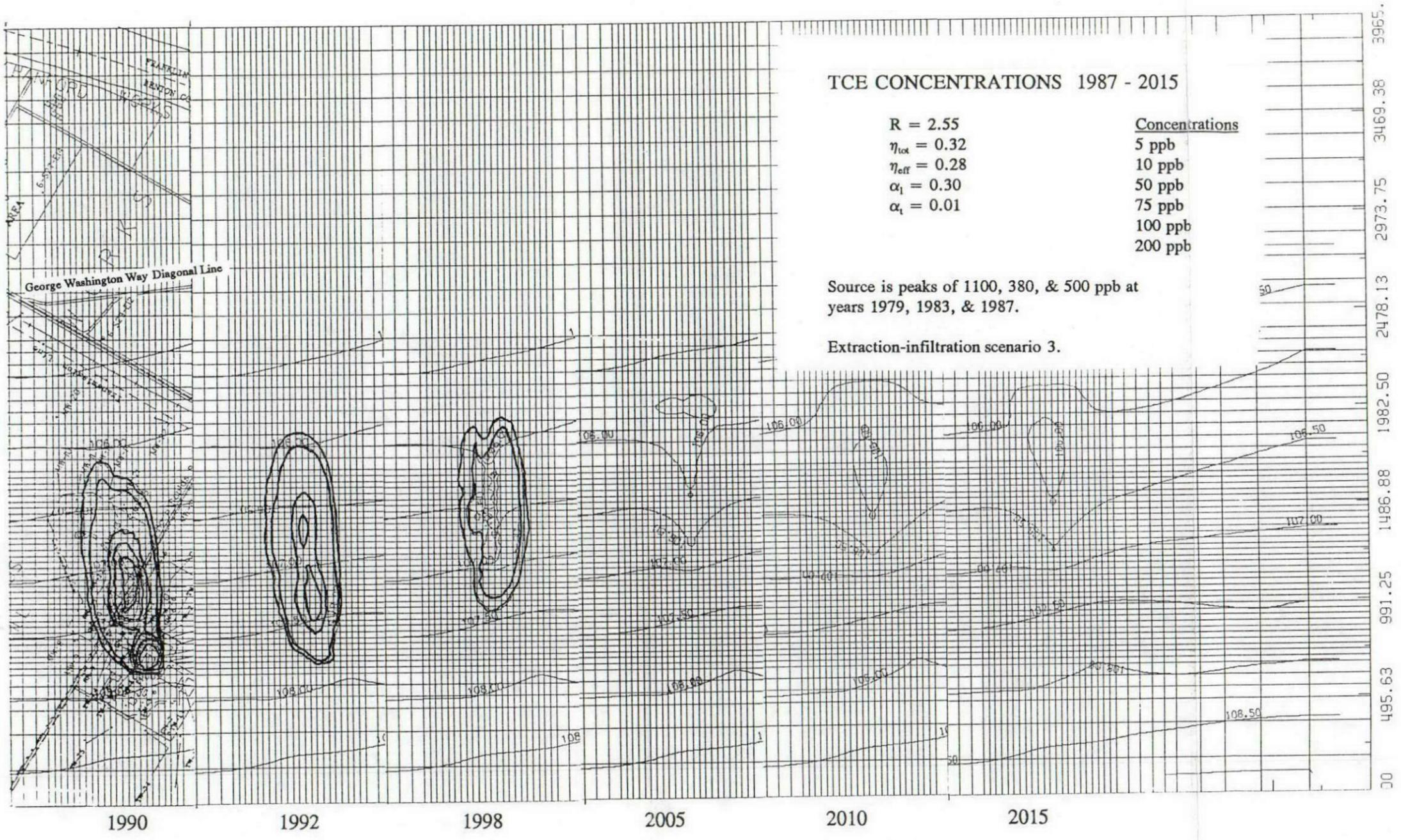
Well Capture Zones for Extraction-Infiltration Scenarios 1-3.

Figure 6-34

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Computed TCE Plumes for Extraction-Infiltration Scenario 3.

Figure 6-37

Table 6-16. Clean-up Times and Operation Duration for the Baseline and Selected Remediation Scenarios

	<u>Start of Operation</u>	<u>Treatment Rate, # Wells</u>	<u>Predicted End of Operation</u>	<u>Predicted Date when Conc. < 5 ppb</u>
1. Baseline Scenario (no active remediation)	NA	NA	NA	2007 - 2017
2. Scenario 1	Jan 1995	100 gpm, 1	< 2012	< 2012 ¹
3. Scenario 2	Jan 1995	300 gpm, 3	< 2008	< 2008
4. Scenario 3	Jan 1995	1000 gpm, 10	< 2004	< 2004

¹ < arrow indicates that the value indicated was a result of a simulation using the conservative parameters and is a upper limit of the predicted range.

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7.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

7.1 INTRODUCTION

The objectives of this RI/FS report are to identify and screen a range of waste management technologies. Appropriate technologies should ensure the protection of human health and the environment and should involve the complete elimination or destruction of hazardous substances at the site, the reduction of concentrations of hazardous substances to acceptable health-based levels, prevention of exposure to hazardous substances via engineering or institutional controls, or some combination of the above. The process for identifying and screening technologies consists of six steps, which are discussed below (EPA, 1988).

1) Develop remedial action objectives (RAO's) specifying contaminants and media of interest, exposure pathways, and preliminary remediation goals. Preliminary remediation goals are based on chemical-specific ARAR's, when available, other pertinent information (e.g., carcinogenic slope factors), and site-specific, risk-related factors.

2) Develop general response actions for each medium of interest defining containment, treatment, excavation, pumping, or other actions that may be taken, singularly or in combination, to satisfy the remedial action objectives for the site.

3) Identify volumes or areas to which general response actions might be applied, taking into account the requirements for protectiveness as identified in the remedial action objectives and the chemical and physical characterization of the site.

4) Identify and screen technologies applicable to each general response action and eliminate those that cannot be technically implemented at the site.

5) To the extent possible, identify and evaluate the retained technologies and select one representative process for each technology type retained for consideration. These processes are intended to represent the broader range of process options within a general technology type.

6) Assemble the representative processes into alternatives that represent a range of treatment and containment combinations, as appropriate.

7.2 REMEDIAL ACTION OBJECTIVES

RAO's are site specific goals that define the extent of cleanup necessary to achieve the specified level of remediation at the site. The RAO's include preliminary remediation goals derived from ARAR's, the points of compliance, and the restoration timeframe for the remedial action. These goals are formulated to meet the overall goal of CERCLA, which is to provide protection to overall human health and the environment.

This section describes the RAO's for the 1100-EM-1 Operable Unit. Contaminants of potential concern were identified based on a statistical and risk-based screening process in site-affected media and the potential for adverse effects to human health and the environment were initially identified in the Phase I RI report (DOE-RL-90-18), and are further evaluated in the BISRA and the BRSRA (appendixes K and L). Findings of these assessments are summarized below. There are no contaminants that pose risks to ecological receptors that are distinguishable from the baseline conditions (appendix L).

7.2.1 Chemicals and Media of Concern

Risks from soil and groundwater contaminants of concern identified in appendixes K and L are at levels that exceed the EPA risk threshold and may, therefore, pose a threat to human health. The NCP requires that the overall incremental cancer risk at a site not exceed the range of 10^{-6} to 10^{-4} . For systemic toxicants or noncarcinogenic contaminants, acceptable exposure levels shall represent levels to which the human population may be exposed without adverse effect during a lifetime or part of a lifetime. This is represented by a hazard quotient. Where the cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 10^{-4} , and the noncarcinogenic hazard quotient is less than 1, action generally is not warranted unless there are adverse environmental impacts. However, if MCL's or nonzero MCLG's are exceeded, action generally is warranted (EPA, 1991).

Contaminated soil at three 1100-EM-1 subunits account for the incremental cancer risks associated with the industrial use scenario. The maximum calculated incremental cancer risk from any one subunit is $5E-5$ based on the 95-percent UCL. These subunits are:

- UN-1100-6 Subunit (Discolored Soil Site);
- HRL;
- Ephemeral Pool.

Contaminants detected in soils and identified as posing incremental cancer risks to human health at these three subunits include: BEHP at the Discolored Soil Site; chromium and PCB's at HRL; and PCB's at the Ephemeral Pool. Based on the review of the RI results and associated risk assessments, EPA, Ecology, and DOE have concluded that there is no chronic threat to human health.

Chromium was identified as a contaminant of concern at HRL due to the fugitive dust exposure pathway. This determination was made using maximum and 95-percent UCL soil chromium concentrations taken at depths from 0 to 4.6 m (0-15 ft) in selected boreholes and exploratory trenches. Using these values in risk based screening within the risk assessment is appropriate. However, RAO's to protect the ambient air quality from contaminated fugitive dust migration should specifically apply to surface soils. Upon reevaluating sample analyses from chromium in only the top 0.6 m (2 ft) of HRL, a mean concentration for chromium in soils of 9.06 mg/kg with a 95-percent UCL of 9.76 mg/kg was calculated. The Phase I RI reported chromium in background soils with a mean concentration of 9.19 mg/kg and a 95-percent UCL of 12.9 mg/kg providing evidence that chromium

concentrations in the HRL surface soils are typical of the site. Using the 95-percent UCL of 9.76 mg/kg to recalculate the incremental cancer risk of fugitive dust from the HRL gives a risk of $2E-7$ under the industrial scenario. Therefore, chromium is determined not to be a contaminant of concern and will not be considered when developing RAO's.

Friable asbestos was also found to be dispersed throughout HRL. The risk assessment did not evaluate the risks associated with this contaminant because there are no published reference doses or carcinogenic potency factors for asbestos. However, releases of friable asbestos in fugitive dust does pose health risks to onsite workers and RAO's will be developed to address this health risk.

The Phase II RI has confirmed the presence of groundwater contaminants at the site. These contaminants do not present any risk to human health under the current and future industrial land use scenarios of the site because: (1) downgradient users are supplied by the city's water distribution system, and (2) the Phase I and II RI's determined that the city's well field is not impacted by the contaminant plume and is not at risk. The uncontrolled land use future uncertainty assessment using residential exposure (appendix L) indicates a higher, but acceptable, risk range.

A summary of the chemicals and media of concern, and the risks associated with each is provided in section 5.0 of this report.

7.2.2 Exposure Routes

The exposure routes and receptors that may be affected by the currently identified chemicals of concern are discussed by medium in the following paragraphs.

7.2.2.1 Soils. Contaminants of concern are identified in surface and near-surface soils of three subunits. Primary receptors include people with direct site access and job duties pertaining to the UN-1100-6 Discolored Soil Site, HRL, and the Ephemeral Pool. Receptors could be exposed through dermal contact, incidental ingestion, or inhalation of fugitive dust. Additional risk and pathway discussions can be found in appendix K.

The Phase II RI study has investigated the potential for future leaching of soil contaminants to the aquifer and has ruled out percolation and vertical migration of contaminants to the water table as an operative pathway under existing land- and water-use conditions. These conclusions are based on the low solubility and mobility of the soil contaminants and the minimal recharge rate at the site (paragraph 6.3). That soil contaminants are not leaching from contaminated sites soil is further demonstrated by the fact that, to date, no elevated concentrations of site soil contaminants of potential concern have been identified through groundwater sampling and analyses.

7.2.2.2 Groundwater. Primary exposure routes for groundwater are through the ingestion of drinking water and the inhalation of contaminants released through the household use of water. However, no known or expected groundwater users presently exist and are unlikely to be present within the next 20 years (appendix J).

7.2.3 Applicable or Relevant and Appropriate Requirements

In addition to the baseline risk assessment, section 121 of the Superfund Amendments and Reauthorization Act (SARA) provides a framework for selection of remedial actions and evaluation of cleanup standards for Superfund sites. This section of the statute sets forth the need for appropriate remedial actions, consistent with the National Oil and Hazardous Substances Pollution Contingency Plan, 40 CFR, part 300 (NCP), that provide a cost-effective response. Subsection (d) of section 121, generally, requires that remedial actions attain a level or standard of control at least equivalent to ARAR's promulgated under Federal or state laws.

Identification of ARAR's is done on a site-specific basis and involves a two-part analysis: first, determining whether a given requirement is applicable; and second, if a given requirement is not applicable, determining whether it is relevant and appropriate. When the analysis determines that a requirement is relevant and appropriate, substantive compliance is the same as if it were applicable.

Applicable standards are those cleanup or control standards and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action location, or other circumstance at a CERCLA site. Relevant and appropriate standards refer to those cleanup or control standards, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or state law that, while not applicable, address problems or situations sufficiently similar to those encountered at a CERCLA site that their use is well-suited to the particular site. Nonpromulgated advisories or guidance documents issued by Federal or state governments do not have the status of potential ARAR's. However, they are to be considered (TBC) in determining the necessary level of cleanup for protection of human health and the environment. The EPA has identified three categories of ARAR's:

- Chemical specific;
- Location specific (*e.g.*, wetland limitations or historical sites); and
- Action specific (*e.g.*, performance and design standards).

Chemical-specific requirements set health or risk-based concentration limits or ranges in various environmental media for specific hazardous substances, pollutants, or contaminants. These requirements may set protective cleanup levels for the chemicals of concern in the designated media, or may indicate an acceptable level of discharge (*e.g.*, air emission or wastewater discharge) where it occurs in a remedial activity.

There are a limited number of chemical-specific requirements; therefore, it is frequently necessary to use chemical-specific advisory levels, such as carcinogenic slope factors or reference doses (RfDs). While not ARAR's, these chemical-specific advisory levels may factor into the establishment of protective cleanup goals (EPA, 1988). The ARAR's and TBC's for the operable unit are comprehensively discussed in appendix M.

7.2.4 Land Use

A key component in the identification of ARAR's is the determination of current and potential future land use at the site. The current use and long range planning by the city, county, and Hanford Site planners show this site as industrial (appendix J). Area planners expect that the current land use patterns will remain unchanged as long as the Hanford Site exists. If control of the site is relinquished by the Government, land use in the vicinity of the Operable Unit would remain unchanged due to the presence of established commercial and industrial facilities that could be readily utilized by the public sector.

7.2.5 Preliminary Remediation Goals (PRG's)

PRG's are goals that when achieved will both comply with ARAR's and result in residual risks that fully satisfy the NCP requirements for the protection of human health and the environment. Chemical-specific PRG's establish concentration goals for contaminants in medias of concern based on the land use at the site. For the 1100-EM-1 Operable Unit, chemical-specific PRG concentrations are determined by ARAR's. ARAR's include concentration levels set by Federal or state environmental regulations. PRG's for this report are either based on MCL's set under the Safe Drinking Water Act (SDWA) or clean-up levels determined under the State of Washington's Model Toxics Control Act (MTCA).

7.2.5.1 Media Specific PRG's. PRG's for the ingestion and dermal contact exposure pathways for contaminated operable unit soils were derived using the MTCA (WAC) 173-340]. For these exposure pathways, the points of compliance for contaminated soil sites will be throughout the subunit from ground surface to a depth of 15 feet. The migration of contaminants to surface water or groundwater is not considered an operative pathway and PRG's, based on these contaminant migration pathways were not calculated.

Groundwater under HRL is not a current or potential future drinking water source and meets the MTCA criteria to disqualify it as such. However, EPA and MTCA guidance requires that the groundwater be remediated to its most beneficial use (source of drinking water), where practicable. PRG's for groundwater are based on the most stringent of applicable Federal or state requirements that have been determined to be SDWA MCL's. Groundwater remediation will be affected in the shortest timeframe determined to be technically feasible. The points or alternate points of compliance will be as determined by the EPA and Ecology. Proposed points of compliance are discussed in section 8.0 as part of the selection of alternative remedies.

Selection of the appropriate ARAR's for the determination of these PRG's is discussed in appendix M. Tables 7-1 and 7-2 summarize the PRG's associated with each media and exposure pathway for the contaminants of concern at each operable subunit.

7.2.5.2 Remediation Timeframe. Soil and groundwater remediation will generally be accomplished in the shortest timeframe that is technically feasible and that meets the fiscal constraints of the site. Promising innovative technologies may require a longer timeframe to implement than more proven technologies. However, because the immediate site risk is low, innovative technologies should not be screened out on this basis alone. The overall goal is to select a remediation alternative that will both be effective and that can be implemented in a reasonable timeframe.

7.2.6 Soil RAO's

RAO's have been identified for the contaminated near surface and subsurface soils at the Discolored Soil Site, the Ephemeral Pool, and HRL based on detected concentrations of chemicals of concern in exceedence of chemical-specific ARAR's. All RAO's shall be accomplished in the shortest timeframe that is technically feasible and shall minimize exposure to contaminated soils during remediation. These specific operable unit RAO's are:

- **UN-1100-6 Subunit (Discolored Soil Site)**

- a. Prevent the ingestion of and dermal contact with soils having BEHP concentrations greater than the MTCA B cleanup level of 71 mg/kg. Soils shall be remediated from the surface to a depth at which the contaminant level falls below the cleanup level throughout the identified area of subunit contamination, where practicable, to attain clean closure.

- b. For remedial actions that leave any contaminant in place above MTCA B levels, provide adequate institutional controls to monitor the site after remediation and to prevent potential future receptor exposure to contaminants.

- **Ephemeral Pool**

- a. Prevent the ingestion of and dermal contact with soils having PCB concentrations greater than the MTCA A cleanup level of 1 mg/kg. All contaminated soils shall be remediated from the surface to a depth at which the contaminant level falls below the cleanup level throughout the identified area of subunit contamination, if practicable, to attain clean closure. Remediation would extend to a maximum of 4.6 m (15 ft).

- b. For remedial actions that leave any contaminant in place above MTCA A levels, provide adequate institutional controls to monitor the site after remediation and to prevent potential future receptor exposure to contaminants.

TABLE 7-1. RISKS ASSOCIATED WITH SOIL PRG's

Operable Subunit	Contaminant	PRG Conc (mg/kg)	Soil Ingestion		Fugitive Dust		Dermal Exposure		Contaminant Totals		Subunit Totals	
			HQ	Risk	HQ	Risk	HQ	Risk	HQ	Risk	HQ	Risk
UN-1100-6 Discolored Soil Site	BEHP	71 ¹	0.001	8E-08	--	9E-11	0.0001	9E-09	0.0011	9E-08	0.0011	9E-08
Ephemeral Pool	PCB's	1 ²	--	6E-07	--	2E-09	--	7E-07	--	1E-06	--	1E-06
HRL	PCB's	17 ³	--	1E-05	--	8E-08	--	1E-05	--	2E-05	--	2E-05
Maximum Site Risks										0.0011	2E-05	

¹ PRG for subsurface soils based on MTCA Method B.
² PRG for subsurface soils based on MTCA Method A Table.
³ PRG for subsurface soils based MTCA Method C.

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TABLE 7-2. SITE RISKS ASSOCIATED WITH PRG's FOR CONTAMINATED GROUNDWATER¹

Operable Subunit	Contaminant	PRG Conc (mg/l)	Water Ingestion		Inhalation of Household Release		Dermal Exposure		Contaminant Totals		Subunit Totals	
			HQ	Risk	HQ	Risk	HQ	Risk	HQ	Risk	HQ	Risk
Site-wide Groundwater	TCE	0.005	--	6E-07	--	1E-06	--	--	--	2E-06		
	Nitrate	10	0.17	--	--	--	--	--	0.17	--	0.17	2E-06
Site Totals										.17	2E-06	

¹ PRG's for groundwater are based on SDWA MCL's.

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- HRL

a. Prevent soil ingestion of and dermal contact with soils having PCB's at concentrations greater than the MTCA C cleanup level of 17 mg/kg. All contaminated soils shall be remediated from the surface to a depth at which the contaminant level falls below the cleanup level throughout the identified area of subunit contamination, if practicable, to attain clean closure.

b. Prevent inhalation of fugitive dust from soils that may contain asbestos fibers. Soils shall be remediated from the surface to a depth of 0.6 m (2 ft) throughout the subunit.

c. For remedial actions that leave any contaminant in place above MTCA C levels, provide adequate institutional controls to monitor the site after remediation and to prevent future receptor exposure to contaminants.

7.2.7 Groundwater RAO's

For the contaminated groundwater, the following RAO's based on chemical-specific ARAR's are identified.

a. Minimize exposure to contaminated groundwater during remediation through existing institutional controls and the use of the domestic water supply system.

b. Restore contaminated aquifers to SDWA MCL's of 5 $\mu\text{g}/\text{l}$ for TCE and 10 mg/l for nitrate as nitrogen at the designated points of compliance. The points of compliance are to be defined by EPA and Ecology. Cleanup levels shall be met at these points within the shortest timeframe practicable. Monitoring for compliance with this cleanup level will be performed at the perimeter of the area defined by the points of compliance.

c. Protect environmental receptors in surface waters by reducing groundwater contaminant concentrations in the plume to levels that are safe for biological and human receptors that may be affected at the groundwater discharge point to the Columbia River.

7.2.8 Residual Risks Post-Achievement of PRG's

Residual risks after meeting PRG's were calculated and are presented in tables 7-1 and 7-2. Maximum site risks from contaminated soils are reduced from 5E-05 based on the 95-percent UCL to 2E-05 for a 60-percent reduction in the incremental cancer risk. Although the groundwater is not a current or potential future source of drinking water and there are no receptors, risks based on ingestion and inhalation were calculated for purposes

of comparison to the baseline condition. For nitrates, remediation to the PRG gives a hazard quotient of 0.17 compared to a 95-percent UCL based hazard quotient of 0.8. For TCE, the total incremental cancer risk due to inhalation and ingestion is reduced from 2E-05 based on the 93-percent UCL to 3E-06 for a 90-percent reduction in risk.

Not included in these are the potential risks to human health and the environment associated with remedial activities at the site. An example would be the remediation of any soils within the HRL. Because there is a significant presence of asbestos in landfill soils, fugitive dust poses a health threat to remedial workers. Any activities conducted must include the suppression of fugitive dust. Typically this is accomplished by thoroughly wetting the contaminated soils. While PCB's are relatively insoluble in water, this practice could potentially lead to the migration of other contaminants from the vadose zone to the groundwater.

7.3 GENERAL RESPONSE ACTIONS

These paragraphs describe general response actions that satisfy the remedial action objectives, with a range of response actions presented for soil and groundwater contamination. These response actions should ensure the protection of human health and the environment, maintain protection over time, and minimize untreated waste (40 CFR 300). Each general response action, with appropriate technology and process options, is more fully evaluated in paragraph 7.4 and section 8.0. The following paragraphs describe the general response actions, and include identification of areas and volumes of contaminated soils and groundwater.

7.3.1 Areal Extent and Volume of Contaminated Media

The areal extent and volumes of contaminated soil, and the areal extent of and the volume of contaminant in groundwater are estimated in the following sections. In the case of soils, estimates are based on the results of Phase I and II RI soil sampling. For groundwater, the estimates are based on modelling results that used Phase I and II RI groundwater sampling results as input.

7.3.1.1 Extent and Volume of Soil Contamination. Soil contamination is believed to be restricted to surface and near surface soils. As discussed in section 4.0, the origin of the BEHP at the Discolored Soil Site appears to be the result of one, and possibly several, incidents where containers of liquid organic material were dumped onto the ground. The contamination at the Ephemeral Pool is probably the result of parking lot runoff containing PCB's. The PCB's contaminated hot spot at the HRL is believed to have originated either as a release of hydraulic fluid from heavy machinery or from an incident where containers of liquids containing PCB's were dumped. The extent and volume of these contaminated areas are estimated as follows:

- UN-1100-6 Subunit (Discolored Soil Site)--A grid was established and 15 soil samples were taken at this site (samples A6141S through A6155S on figure 4-3). Of these, BEHP was only detected in samples A6150S through A6155S. These sample locations are within or in close proximity to the area of the soil discoloration. Because of the transport

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mechanisms of BEHP (section 6.0), the soil contamination is believed to be confined to this area. A conservative estimate of the areal extent of the contamination is made by considering the contaminated area to be bounded by the sample points, which did not detect any BEHP. This area is shown in figure 7-1 and measures 0.07 hectares (0.18 acres). The depth to which discolored soils can be distinguished is less than 0.25 m (10 in). Since BEHP is strongly sorbed to soils, the depth of contamination is not anticipated to extend much past this point. Contamination is conservatively assumed to extend from the surface to a depth of 0.46 m (1.5 ft). The volume of contaminated material is thus calculated to be 340 m³ (440 yd³).

- **Ephemeral Pool**--Six surface soil samples were taken during the Phase II RI along the bottom of the surface depression that constitutes the Ephemeral Pool (figure 4-7). PCB's contamination was detected at only two of these locations (E2 and E3). Runoff from the parking area (presumed source) is discharged by a storm drainage pipe whose outlet is approximately 12 m (40 ft) south of E3. Because no PCB's contamination was detected at E4, it is used as the southern most boundary of the contaminated area. The northern boundary of the contamination is chosen as the point in the depression that is equal in elevation to that of E4, which is 122.4 m (401.5 ft) above msl. This area is depicted in figure 7-2 and averages 7.1 m (20 ft) in width and is 93 m (305 ft) long. The depth of contamination is assumed to be shallow as the PCB's should be confined to the fine sediments deposited as a result of multiple runoff events. Contamination is assumed to extend from the surface to a depth of 0.46 m (1.5 ft). The volume of contaminated soils associated with this site is 250 m³ (340 yd³).

- **HRL**--HRL was investigated in both the Phase I and II RI's. These investigations are summarized in section 3.0. Sampling concentrated on areas of the landfill known to have been actively used. Because access to the landfill was uncontrolled, it is difficult to determine what other areas may have been used. As a result of this unknown, the active area of the landfill is assumed to be bounded by physically undisturbed topological features. The outline of this area is shown in figure 7-3 and the area calculated by planimetry is approximately 10.1 hectares (25 acres). The exception is the southwest portion of the site that appears to have been used as a source of borrow material. Soil sampling in this area gave no indication of contamination that is distinguishable from background.

Only one contaminant, PCB, is present at levels that may pose a risk to human health. The PCB's are concentrated around boring HRL-4 (figures 7-3 and 7-4) from which samples were analyzed during the Phase I RI. PCB's were detected in soils from the surface to a depth of 0.85 m (2.8 ft). PCB's were not detected in the next sample interval that was taken at depths greater than 1.52 m (5 ft). Additional surface and near surface samples were taken during two separate soil sampling events during the Phase II RI (figure 4-24) in an effort to delineate the areal extent of the contamination. All samples were taken within an area approximated by a 8.5 m by 8.5 m (28 ft) square centered around HRL-4. Samples taken during the last sampling event, at the vertices of this square, contained detectable concentrations of PCB's. In order to determine the approximate areal extent of the contamination, straight line extrapolations were made from the presumed center of the hot spot, along the diagonals of the sampled area, to a point where PCB's concentrations would be zero. Using the most conservative of these extrapolations, the contaminated area is

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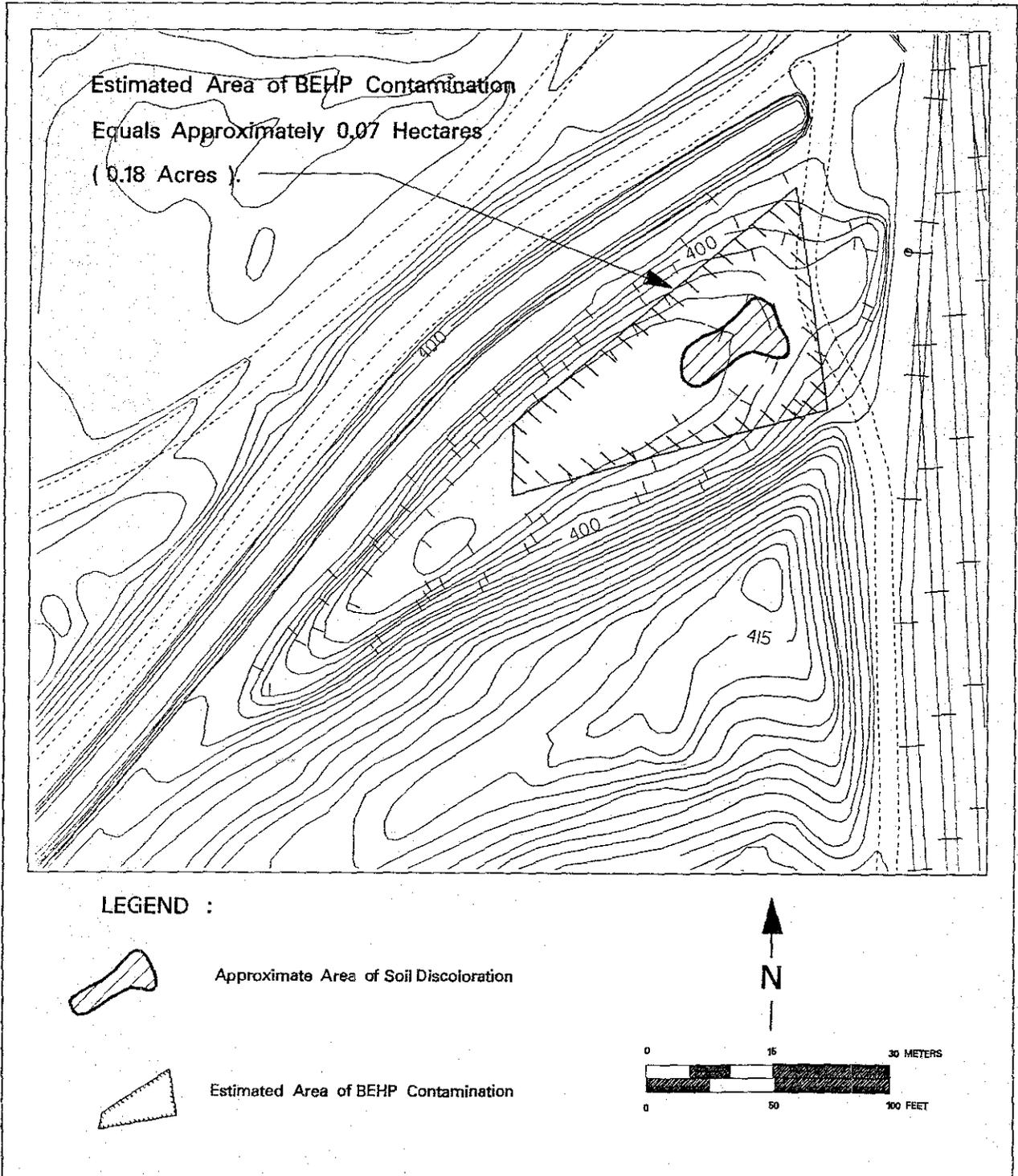


Figure 7-1. Estimated Area of BEHP Contamination at the UN-1100-6 Operable Subunit

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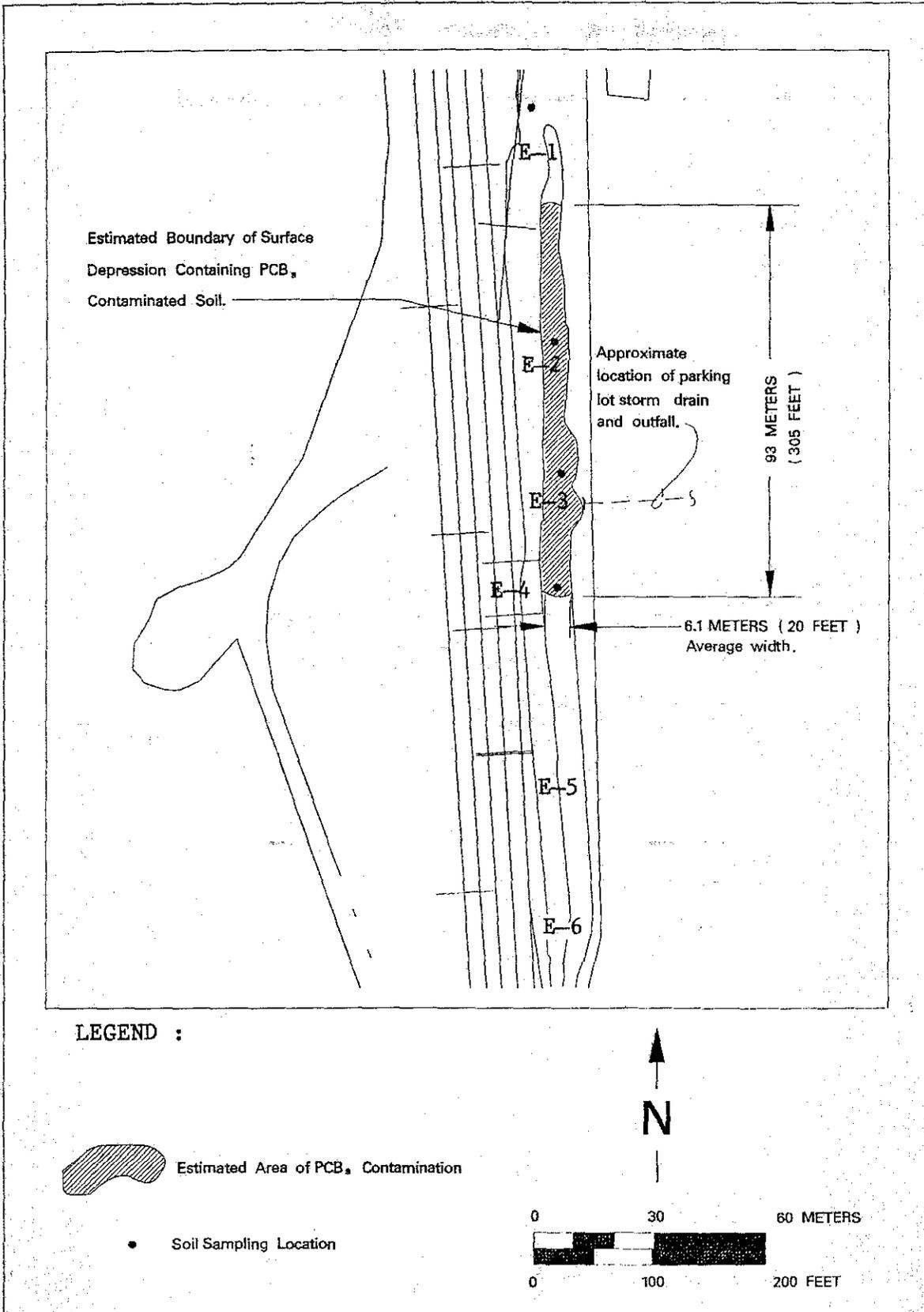
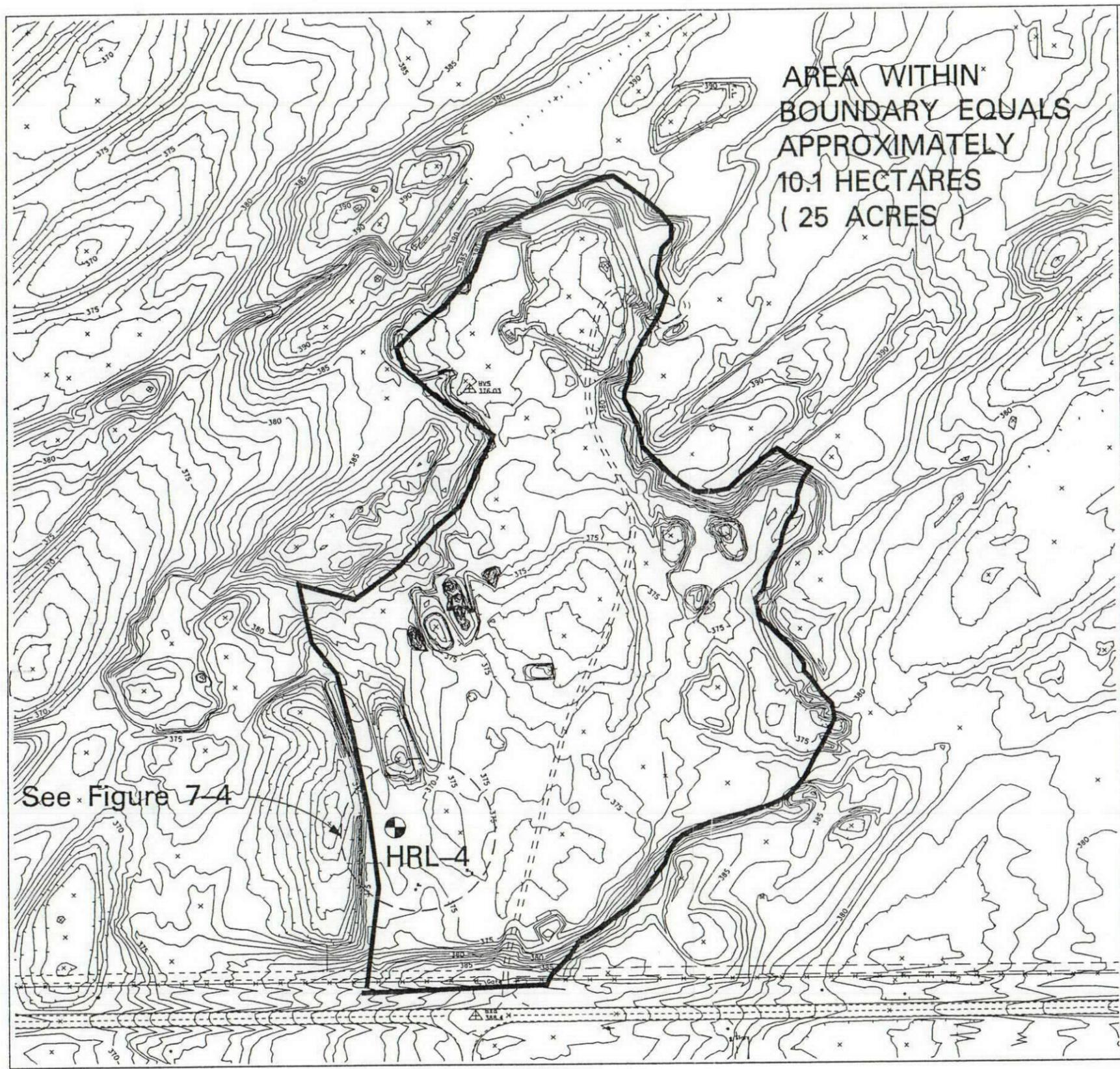


Figure 7-2. Estimated Area of PCB_s Concentration at the Ephemeral Pool Operable Subunit.

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LEGEND :

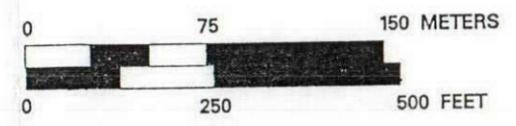
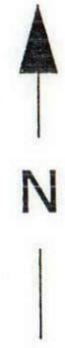


HRL-4

Location and Designation of Borehole



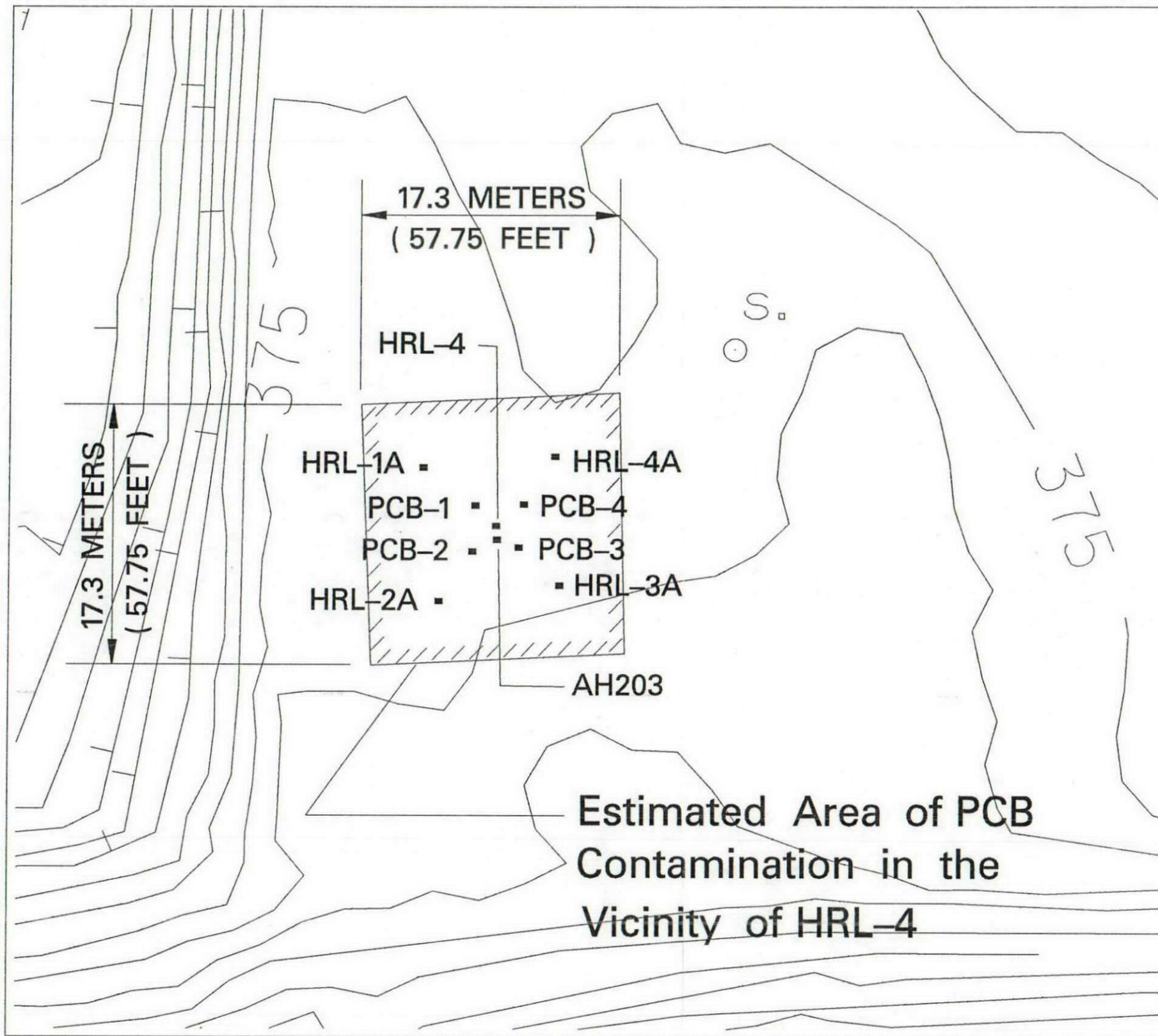
Horn Rapids Landfill Boundary of Actively Used Area (Estimated)



Estimated Boundary of the Actively Used Area of the Horn Rapids Landfill Operable Subunit.

Figure 7-3.

931280521



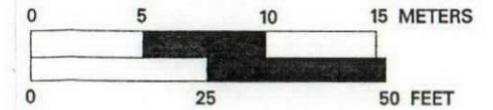
LEGEND :

PCB-4

- Soil Sampling Location and Designation



Area = 300 sq. meters
3,335 sq. feet



Estimated Area of PCB_s Contamination in the Vicinity of HRL-4

Figure 7-4.

estimated to be bounded by a 17.3 m by 17.3 m (57.75 ft) square centered around HRL-4. Using 1.52 m (5 ft) as the depth of the contamination gives a volume of 460 m³ (600 yd³).

7.3.2. Extent and Volume of Groundwater Contamination

The source of groundwater contamination at and downgradient of the HRL is presumed to have originated from activities conducted offsite. The present length and width of the TCE plume is 1.61 km (1 mi) and 0.32 km (0.2 mi), respectively. The estimated volume of TCE in groundwater is 75-115 L (20-30 gal). This volume does not account for the amount of TCE which may be adsorbed onto saturated zone soils. The length of the nitrate plume is 2 km (1.25 mi) and its width is also 2 km (1.25 mi). The TCE and nitrate plumes are shown in figure 6-12 of section 6.0.

7.3.3 General Response Actions for Soils and Groundwater

General response actions for soils and groundwater are classes of actions that will satisfy either one or more of the remedial action objectives described in paragraph 7.2. Appropriate response actions include no action, institutional controls, containment, excavation/treatment/disposal for soils, extraction/treatment/discharge for groundwater, and in situ treatment, all of which may be used alone or in combination. General response actions have been determined for the UN-1100-6 Subunit Discolored Soil Site, the Ephemeral Pool, HRL, and the groundwater beneath the HRL, and are discussed in paragraphs 7.3.3.1 through 7.3.3.6.

7.3.3.1 No Action. This alternative is required by the NCP and has been retained for comparison with other alternatives. Because no remedial activities would be implemented, long-term human health and environmental risk for the site would be those identified in the baseline risk assessments (appendixes K, L, and M).

7.3.3.2 Institutional Controls. Institutional controls include fencing, posting of signs, land-use restrictions, and other controls that restrict future access to, and use of, contaminated soils and groundwater. Continued monitoring of air and groundwater quality would also be implemented to assess the migration of contaminants offsite.

7.3.3.3 Containment. Containment actions usually involve capping contaminated soils with a protective barrier, such as clay, concrete, or plastic liners, or isolating contaminated soils by placing an in situ barrier, such as a bentonite slurry wall. These barriers limit infiltration, prevent plants and animals from being exposed to contaminated soils, prevent fugitive dust, and provide long-term stability with relatively low maintenance requirements.

Containment options for groundwater prevent the further migration of contaminants offsite. Typically, this is achieved through the use of vertical barriers such as a bentonite slurry wall or by controlling the hydraulic gradient using a series of extraction and injection wells. Impervious caps are also sometimes used to prevent infiltration and aquifer recharge.

7.3.3.4 **Excavation/Treatment/Disposal for Soils.** Excavation/treatment/disposal actions include excavation and disposal of untreated soils at an offsite landfill; excavation, offsite contaminant destruction, immobilization, or other treatment, and disposal at an offsite landfill; and excavation, onsite contaminant destruction, immobilization, or other treatment, and onsite disposal. Typical treatment options include biological landfarming, thermal processing, soils washing/dechlorination, and stabilization/fixation.

7.3.3.5 **Extraction/Treatment/Disposal for Groundwater.** Extraction wells are used to collect contaminated groundwater for treatment. Treatment options consist of physical, chemical, and biological processes. Physical treatment processes include carbon adsorption, air stripping, and reverse osmosis. Chemical oxidation, ultraviolet radiation, irradiation, and ion exchange are several of the chemical processes. The use of aerobic and/or anaerobic bacteria to degrade the contaminants are the basis of biological processes. Treated groundwater is discharged either back into the aquifer through injector wells or discharge trenches, to storm or sanitary sewers, or directly to surface waters.

7.3.3.6 **In Situ Treatment.** In situ technology types can include biological, chemical, physical, and thermal processes. In situ treatment for soil includes aerobic or anaerobic biological processes, surfactant soils washing, vapor extraction, chemical oxidation, radio-frequency heating, stabilization/fixation, and in situ vitrification. These treatments attempt to either destroy, immobilize, physically remove or chemically alter the contaminant(s) to minimize harmful impacts to the groundwater or surface environment.

For groundwater, in situ treatment includes aerobic or anaerobic biological processes, aeration, heating, and chemical oxidation or reduction. These treatments attempt to destroy, physically remove, or chemically alter the groundwater to minimize the potential risks to human health and the environment.

7.4 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS

In these paragraphs, the universe of potentially applicable technology types and process options are identified. The process options are screened with respect to technical implementability, and the candidate list is reduced to reflect only those options that can be implemented at the site. Site specific information obtained during the Phase I and II RI's is used as a basis for screening. This information includes contaminant types, concentrations, and volumes, and site soil and hydrogeological characteristics.

Technology types and process options are selected within each general response action to satisfy the remedial action objectives for the site. Appropriate treatment technologies were identified and screened using the following references: *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988), *Handbook for Stabilization/Solidification of Hazardous Waste* (EPA, 1986a), *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites* (EPA, 1989c), *Handbook on In Situ Treatment of Hazardous Waste-Contaminated Soils* (EPA, 1990b), *Innovative Treatment Technologies: Overview and Guide to Information Sources* (EPA, 1991b), *Treatment Technologies Second Edition* (GII, 1991), and *Water Treatment Principles and Design* (JMM, 1985).

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7.4.1 Identification and Screening of Soil Technologies and Process Options

The initial screening of soil technologies and process options is summarized in table 7-3. Capping is the only technology type retained for the containment general response action. Other containment alternatives are infeasible because of the extent and depth of the contamination (specifically at HRL). In situ thermal treatment is also rejected as a technology type because of the low volatility of the organic contaminants and the non-homogenous nature of HRL. A summary of the technology types and process options retained after initial screening is provided in table 7-4.

7.4.2 Identification and Screening of Groundwater Technologies and Process Options

Table 7-5 summarizes the groundwater technologies and process options initially screened. Hydraulic gradient control is the only process option retained for the containment general response action. All other containment options are not feasible due to the areal extent and depth of the contaminant plume. In situ chemical treatment is rejected as a technology type because chemical treatments are not applicable to the contaminants of concern or their concentrations, or because of the depth of the aquifer. Table 7-6 is a summary of the groundwater technology types and process options remaining after initial screening.

7.5 EVALUATION OF RETAINED PROCESS OPTIONS

In this section, process options that were retained after the initial screening are evaluated with respect to effectiveness, implementability, and cost. This evaluation focuses on the technologies and the general response actions they are intended to satisfy, and not of the site as a whole. A greater emphasis is placed on the effectiveness of the process option, with implementability and cost receiving less consideration. The goal of this step on the screening process is to select a representative process from each technology type to simplify the development and evaluation of alternatives to be accomplished in subsequent steps.

The effectiveness evaluation considers the following:

- The ability of the process option to effectively handle the estimated areas or volumes of contaminated media in meeting the RAO's;
- The risks to human health and the environment during the construction and implementation phase; and
- The demonstrated reliability of the process for the contaminants and conditions of the site.

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TABLE 7-3
INITIAL SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS

Page 1 of 6

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
No Action	None	Not Applicable	Contaminated soils are left in place with no further disturbance of site.	Consideration required by NCP.
Institutional Controls	Access Restrictions	Administrative Controls	Regulations would be established to restrict the use of land in the area of concern.	Potentially feasible.
		Deed Restrictions	Change of ownership deeds would require limitations on future land uses.	Potentially feasible.
		Excavation Restrictions	Existing and future landowners would be restricted in new subsurface construction or excavation.	Potentially feasible.
		Fences	Access to contaminated soil sites would be restricted by use of fence.	Potentially feasible.
	Monitoring	Air Monitoring	Air sampling stations would be installed to monitor dust-borne contaminated particulates on a regular basis.	Potentially feasible.
		Groundwater Monitoring	Sample and test groundwater on a regular basis.	Potentially feasible.

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TABLE 7-3 (Continued)
INITIAL SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS

Page 2 of 6

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Containment	Capping	RCRA Cap	Cap complying to RCRA standards for closure of landfills.	Potentially feasible.
		MSWLF Cap	Cap complying to the Washington Administrative Code (WAC) for closure of municipal solid waste landfills (MSWLF) in arid regions.	Potentially feasible.
		Asbestos Cap	Cap complying to the code of Federal regulation for closure of landfills containing asbestos.	Potentially feasible.
	Horizontal Barriers	Options Include: Grout Injection and Liners	A horizontal barrier is placed below the contaminated soil to prevent migration of contaminants to groundwater.	Not feasible due to extent and depth of contamination.
		Options Include: Slurry Walls, Grout Curtains, and Sheet Piling	A vertical barrier is placed to prevent contaminants from migrating.	Not feasible due to extent of contamination.

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TABLE 7-3 (Continued)
INITIAL SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS

Page 3 of 6

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Excavation/ Treatment/ Disposal	Excavation	Earth-Moving Equipment	Backhoes, loaders, bulldozers, dump trucks, etc. used to excavate and move contaminated soil to treatment area if required.	Potentially feasible.
	Thermal Treatment	Rotary Kiln Incinerator	Slightly inclined, refractory-lined cylinder used for the controlled combustion of organic waste.	Potentially feasible for organics.
		Infrared Incinerator	Silicon carbide elements are used to generate thermal radiation beyond the red end of the visible spectrum to combust organic waste.	Potentially feasible for organics.
		Circulating Fluidized Bed Incinerator	Refractory-lined vessel containing a fluidized bed of inert, granular, sand-like material at high temperatures is used to combust organic waste.	Potentially feasible for organics.
		Low Temperature Thermal Desorption	Low temperature treatment to remove volatile and semivolatile organic compounds from soil.	Not applicable to PCB's or BEHP.
		Vitrification	Contaminated soils are fed into a melter which destroys organics and melts inorganic constituents into a glass pool.	Potentially feasible.

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Table 7-3
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TABLE 7-3 (Continued)
INITIAL SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Excavation/ Treatment/ Disposal (cont.)	Chemical Treatment	Dechlorination	Soils mixed with chemical reactant to destroy chlorinated compound such as PCB's.	Potentially feasible for PCB's.
		Fixation/Stabilization	Excavated soil is mixed with pozzolanic material to form leach-resistant blocks.	Potentially feasible for inorganics. Effectiveness on organics would require testing.
		Chemical Oxidation	Soils treated with ozone or hydrogen peroxide to oxidize organics.	Not applicable to non-water-soluble PCB's and BEHP. Partial degradation byproducts are toxic.
	Physical Treatment	Solvent Extraction	An organic solvent is used to extract organic contaminant from soil.	Potentially feasible for PCB's and BEHP.
		Supercritical CO ₂ Extraction	Organics are extracted from contaminated soils by mass transfer to supercritical CO ₂ .	Potentially feasible for PCB's and BEHP.
		Soil Washing	Mechanical processes are used to separate particles that contain contaminants.	Potentially feasible.

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TABLE 7-3 (Continued)
INITIAL SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Excavation/ Treatment/ Disposal (cont.)	Biological Treatment	Aerobic	Oxygen-utilizing bacteria destroy contaminants by oxidation.	Potentially feasible for PCB's and BEHP.
		Anaerobic	Cosubstrate is introduced to stimulate anaerobic bacteria to degrade contaminants.	Potentially feasible for PCB's and BEHP.
	Disposal	Onsite	Treated soils exhibiting no hazardous characteristics redeposited onsite.	Potentially feasible.
		Offsite	Treated soils meeting RCRA BDAT criteria deposited in hazardous waste landfill.	Potentially feasible.
In Situ Treatment	Thermal Treatment	Radio Frequency Heating	Electrodes are placed in contaminated soils and radio frequency energy is used to heat soils and volatilize organics.	Not feasible due to low volatility of organic contaminants.
		In Situ Vitrification	Electrodes are placed in contaminated soils and resistive heating melts soil and forms stable glass.	Not feasible for nonhomogenous landfill soils or shallow contaminated soils.

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TABLE 7-3 (Continued)
INITIAL SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS

Page 6 of 6

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
In Situ Treatment (cont.)	Chemical Treatment	Fixation/Stabilization	Stabilizing agents are mixed into soils to immobilize contaminants.	Potentially feasible.
		Surfactant Enhanced Soil Washing	Surfactant solution is percolated through soil column to expedite removal of contaminants.	Not feasible due to areal extent of contamination.
	Physical Treatment	Vacuum Extraction	Vertical and/or horizontal vents are used to extract volatile organic contaminants.	Not feasible due to low volatility of PCB's and BEHP.
	Biological Treatment	Aerobic	Nutrients and acclimated oxygen-utilizing bacteria are introduced into soils to stimulate biological degradation of contaminants.	Potentially feasible for PCB's and BEHP.
Anaerobic		Cosubstrate and nutrients are introduced to subsurface and anaerobic bacteria are stimulated to degrade chlorinated organics.	Potentially feasible for PCB's and BEHP.	

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TABLE 7-4
SOIL PROCESS OPTIONS REMAINING
AFTER INITIAL SCREENING

General Response Action	Remedial Technology Types	Process Options
No Action	None	Not Applicable
Institutional Controls	Access Restrictions	Administrative Controls Deed Restrictions Excavation Restrictions Fences
	Monitoring	Air Monitoring Groundwater Monitoring
Containment	Capping	RCRA Cap MSWLF Cap Asbestos Cap
Excavation/Treatment/Disposal	Excavation	Earth-Moving Equipment
	Thermal Treatment	Rotary Kiln Incinerator Infrared Incinerator Circulating Fluid Bed Incinerator Vitrification
	Chemical Treatment	Dechlorination Fixation/Stabilization
	Physical Treatment	Solvent Extraction Supercritical CO ₂ Extraction Soil Washing
	Biological Treatment	Aerobic Anaerobic
	Disposal	Onsite Offsite
	In Situ Treatment	Chemical Treatment
	Biological Treatment	Aerobic Anaerobic

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TABLE 7-5
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

Page 1 of 10

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
No Action	None	Not Applicable	Contaminated groundwater will be attenuated naturally by dispersion, diffusion, and dilution.	Consideration required by NCP.
Institutional Controls	Alternate Water Supplies	Municipal Water	Extend existing water supply system to future users.	Potentially feasible.
		Commercially Supplied	Supply commercially bottled water to future users.	Potentially feasible.
		Surface Water	Use surface water to supply future users.	Not feasible because there is currently a moratorium on new surface water withdrawals from the Columbia River.
	Point of Entry/ Point of Use Treatment	Activated Carbon Adsorption	Adsorb contaminants onto activated carbon by passing water through carbon column.	Potentially feasible only for removal of TCE.
		Filtration	Remove suspended solids by straining and adsorption onto filter media.	Not effective for removal of TCE or nitrates.
		Ion Exchange	Hazardous anions and/or cations are removed by passing water through ion exchange resins.	Potentially feasible for removal of nitrates only.
	Reverse Osmosis	Water is forced through a membrane under high pressure to filter out contaminants.	Potentially feasible.	

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

Page 2 of 10

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Institutional Controls (cont.)	Point of Entry/ Point of Use Treatment (cont.)	Distillation	Miscible liquids are separated.	Not feasible due to low concentration of TCE.
		Ozonation	Ozone used as an oxidant to destroy contaminant.	Potentially feasible for TCE only.
		Ultraviolet Radiation	Ultraviolet radiation used to oxidize contaminant.	Potentially feasible for TCE only.
		Electrodialysis	Electric energy is used to transfer ions and anions in water through selective membranes leaving behind purified water.	Potentially feasible for nitrates only.
	Access Restrictions	Administrative Controls	Regulations would be established to restrict the use of groundwater in the area of concern.	Potentially feasible.
		Deed Restrictions	Property deeds would include restrictions on wells.	Potentially feasible.
		Fences	A fence around the groundwater plume would be installed to restrict access.	Not feasible due to extent of contamination and potential for further migration.

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Institutional Controls (cont.)	Monitoring	Monitoring Wells	Test groundwater samples on a regular basis.	Potentially feasible.
Containment	Capping	Various Options Include: Clay and Soil, Geomembrane, Asphalt, Concrete, and Multimedia Caps	Cap over areas of groundwater contamination to prevent infiltration from rainwater and further spread of contaminant plume. Capping options are only effective in combination with vertical barriers.	Not feasible due to extent of contaminant plume.
	Vertical Barriers	Various Options Include: Grout Curtains, Sheet Piling, and Slurry Walls	Vertical walls would be constructed around the contaminant plume to prevent further migration.	Not feasible due to extent of contaminant plume.
	Hydraulic Gradient Barrier	Hydraulic Gradient Control	Groundwater flow patterns are altered through use of extraction and recharge points to prevent migration of the contaminant plume.	Not feasible due to extent of contaminant plume.
	Horizontal Barriers	Various Options Include: Grout Injection and Liners	A horizontal barrier is placed below the contaminated plume to prevent downward migration.	Not feasible due to extent of contamination.

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Containment (cont.)	Surface Controls	Grading	Regrade area above contaminated plume to provide drainage for runoff and reduce infiltration of rainwater.	Not feasible due to extent of contaminant plume.
Extraction/ Treatment/ Discharge	Extraction	Deep Wells	Submersible pump used to pump water from a deep well.	Potentially feasible.
		Ejector Wells	Medium depth wells are pumped using a jet pump.	Potentially feasible.
		Well Points	Groups of wells are connected to a common header pipe or manifold and pumped by suction lift or vacuum pumps.	Not feasible due to depth of aquifer.
		Trench Drains	Excavated ditch backfilled with coarse gravel.	Not feasible due to depth of aquifer.
		Tile/Perforated Pipe Drains	Collection trench excavated, tile or perforated pipe placed, and trench backfilled with coarse gravel.	Not feasible due to depth of aquifer.
		Infiltration Galleries	Horizontally laid screens connected to a well to improve extraction capacity.	Not feasible due to depth of aquifer.

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Extraction/ Treatment/ Discharge (cont.)	Extraction (cont.)	Sumps	Excavated area to collect water at central location.	Not feasible due to depth of aquifer.
		Enhanced Extraction	Extraction/injection process to increase flow to extraction well.	Potentially feasible.
	Physical Treatment	Adsorption	Organics adsorbed onto the surface of a media (activated carbon).	Potentially feasible for TCE.
		Air Stripping	Mass transfer of VOC from liquid to air in a packed column by mixing high volumes of air with water.	Potentially feasible for TCE.
		Steam Stripping	Mass transfer of VOC from liquid to steam in a packed column by mixing high volumes of steam with water.	Potentially feasible for TCE.
		Reverse Osmosis	Water is forced through a membrane under high pressure to filter out contaminants.	Potentially feasible.
		Ultrafiltration	Liquid is forced through a membrane under pressure and large molecular weight contaminants are filtered out.	Not feasible due to low molecular weight of TCE and nitrates.

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Extraction/ Treatment/ Discharge (cont.)	Physical Treatment (cont.)	Electrodialysis	Electric energy is used to transfer ions and anions in water through selective membranes, leaving behind purified water.	Potentially feasible for the removal of nitrates.
		Solvent Extraction	Contaminated water is mixed with a solvent and mass transfer of the contaminant from the liquid to the solvent occurs.	Not feasible due to low concentration of TCE.
		Critical Fluid Extraction	Supercritical gas is used to dissolve organic wastes and extract them from contaminated water.	Not feasible due to low concentration of TCE.
		Distillation	Miscible liquids are separated.	Not feasible due to low concentration of TCE.
		Freeze Crystallization	Separates contaminated water into separate phases by freezing.	Not feasible due to low concentration of TCE.
		Coagulation/ Flocculation	Suspended solids are aggregated to facilitate settling.	Not applicable to TCE or nitrates.
		Dissolved Air Flotation	Air is forced into the contaminated liquid under pressure and suspended solids are floated to the water surface.	Not applicable to dissolved contaminants.

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Extraction/ Treatment/ Discharge (cont.)	Physical Treatment (cont.)	Centrifugation	Separation process by which contaminants are separated from water through rapid rotation of the water.	Not applicable to the separation of TCE or nitrates from water.
		Evaporation	The concentration of solutions of nonvolatile solutes through heat-induced vaporization of the water.	Not applicable to TCE or nitrates.
	Chemical Treatment	Chemical Oxidation	An oxidizing agent is mixed into the contaminated water and the contaminant is oxidized.	Potentially feasible for TCE.
		Reduction	Metal ions are reduced to solid form.	Not applicable for TCE or nitrates.
		Hydrolysis	Destruction of organic molecules by adjusting pH to acidic or basic conditions.	Not applicable due to low concentration of TCE.
		Chemical Dechlorination	High temperatures and pressures used to remove chlorine atoms from contaminant.	Not applicable to dilute aqueous waste streams.
		Ultraviolet Radiation/ Photolysis	Contaminants are oxidized using ultraviolet radiation or sunlight.	Potentially feasible for TCE.
		Irradiation	Chemical reactions are initiated by exposing the contaminated water to gamma irradiation.	Potentially feasible.

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Table 7-5
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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Extraction/ Treatment/ Discharge (cont.)	Chemical Treatment (cont.)	Neutralization	Acidic or basic waters are neutralized by adding acid or base.	Not applicable to groundwater contaminated with TCE or nitrates.
		Precipitation	Metals are converted to an insoluble form and precipitated.	Not applicable to TCE or nitrate removal.
		Ion Exchange	Hazardous anions and/or cations are removed by passing water through ion exchange resins.	Potentially feasible for removal of nitrates.
	Biological Treatment	Aerobic	Bacteria requiring oxygen for metabolism oxidize contaminant in groundwater.	Potentially feasible.
		Anaerobic	Bacteria which do not require oxygen for metabolism oxidize contaminants in groundwater.	Potentially feasible.
		Aerobic/Anaerobic	Oxidation of contaminants using a combination of aerobic and anaerobic bacteria.	Potentially feasible.
	Sewage Treatment Plant	Onsite Sewage Treatment Plant	Extracted groundwater pumped to an onsite sewage treatment plant.	Not feasible because there is no onsite plant.

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
Extraction/ Treatment/ Discharge (cont.)	Sewage Treatment Plant (cont.)	Offsite Sewage Treatment Plant	Extracted groundwater is treated at a publicly owned sewage treatment plant.	Not feasible due to low concentration of TCE. Diluted wastewater could potentially upset system.
		Discharge	Sanitary Sewer	Treated water discharged to sanitary sewer and conveyed to publicly owned treatment plant.
		Storm Sewer	Treated water discharged to storm sewer.	Not feasible because there is no storm sewer network in this proximity.
		Surface Water	Treated water discharged to surface water (Columbia River).	Potentially feasible.
		Reuse/Recycle	Treated water reused or recycled onsite.	Potentially feasible.
		Recharge	Treated water recharged into the ground.	Potentially feasible.
In Situ Treatment	Physical	Aeration	Air is pumped into the contaminated aquifer in order to volatilize contaminants.	Potentially feasible for TCE.
		Heating	Contaminants are volatilized through the addition of heat to the aquifer	Potentially feasible for TCE.

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TABLE 7-5 (Continued)
INITIAL SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Description	Screening Comments
In Situ Treatment (cont.)	Physical (cont.)	Treatment Trenches	Trenches are excavated downgradient of the contamination and backfilled with activated carbon to adsorb the contaminant.	Not feasible due to depth of aquifer.
		Chemical	Hydrolysis	Destruction of organic molecules by adjusting pH to acidic or basic conditions.
		Oxidation	Addition of oxidizing chemicals to aquifer to oxidize contaminant.	Not applicable due to depth of aquifer and inability to adequately mix reagent and groundwater.
		Reduction	Addition of chemicals to aquifer to reduce metal ions to solid form.	Not applicable to TCE or nitrates.
		Neutralization	An acid or base is added to the aquifer to neutralize the groundwater.	Not applicable to groundwater contaminated with TCE or nitrates.
	Biological	Aerobic	Aerobic bacteria oxidize contaminants.	Potentially feasible.
		Anaerobic	Anaerobic bacteria oxidize contaminants.	Potentially feasible.
		Aerobic/Anaerobic	Combination of aerobic/anaerobic bacteria oxidize contaminants.	Potentially feasible.

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TABLE 7-6
GROUNDWATER PROCESS OPTIONS REMAINING
AFTER INITIAL SCREENING

General Response Action	Remedial Technology Types	Process Options
No Action	None	Not Applicable
Institutional Controls	Alternate Water Supplies	Municipal Water Commercially Supplied
	Point of Entry/Point of Use Treatment	Activated Carbon Adsorption Ion Exchange Reverse Osmosis Ozonation Ultraviolet Radiation Electrodialysis
	Access Restrictions	Administrative Controls Deed Restrictions
	Monitoring	Monitoring Wells
Containment	None Remaining After Screening	Not Applicable
Extraction/Treatment/Discharge	Extraction	Deep Wells Ejector Wells Enhanced Extraction
	Physical Treatment	Adsorption Air Stripping Steam Stripping Reverse Osmosis Electrodialysis
	Chemical Treatment	Chemical Oxidation Ultraviolet Radiation/Photolysis Irradiation Ion Exchange
	Biological Treatment	Aerobic Anaerobic Aerobic/Anaerobic

TABLE 7-6 (Continued)
GROUNDWATER PROCESS OPTIONS REMAINING
AFTER INITIAL SCREENING

General Response Action	Remedial Technology Types	Process Options
Extraction/Treatment/ Discharge (cont.)	Discharge	Surface Water Reuse/Recycle Recharge
In Situ Treatment	Physical	Aeration Heating
	Biological	Aerobic Anaerobic Aerobic/Anaerobic

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The technical feasibility of implementing the process options was considered at initial screening. At this stage, the administrative feasibility of the process options are considered. The evaluation criteria used includes:

- The ability to obtain the necessary permits from the appropriate agencies for offsite actions;
- The ability to access and use treatment, storage, and disposal services;
- The availability of skilled workers and proper equipment to implement the technology; and
- The ability to meet ARAR's.

At this stage cost plays a limited role in screening of process options. Cost analysis is made on the basis of engineering judgement. Relative capital and operation and maintenance (O&M) costs are used in lieu of detailed estimates to compare costs within each technology type, and processes are evaluated as to whether costs are high, medium, or low.

Summaries of the evaluations of soil and groundwater process options are provided in tables 7-7 and 7-9. A detailed narrative evaluation of each of the process options is provided in appendix M. The process options remaining after this screening evaluation are presented in tables 7-8 and 7-10 for soils and groundwater, respectively. For soils, applicability of the process option to each specific subunit is also noted. The next step is to assemble the retained technologies into remedial action alternatives representing a range of treatment and containment combinations. This is presented in section 8.

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TABLE 7-7
SUMMARY EVALUATION OF SOIL PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
No Action	None	Not Applicable	Health risks for industrial land use would remain the same. Contaminants are persistent and would remain onsite.	Easily implemented, but ARAR's would not be met and this option may not be acceptable to the regulators or public.	---	Yes
Institutional Controls	Access Restrictions	Administrative Controls	Land use can be controlled in the near-term future (20 years). Risks to public remain the same unless site is remediated.	Existing zoning and land use plans are in place and currently are being implemented.	Low capital. Low O&M.	Yes
		Deed Restrictions	New owners could still be exposed to contaminated soils if they remain in place.	Not implementable because Government will not dispose of land which is contaminated.	Low capital. Low O&M.	No
		Excavation Restrictions	Owners could still excavate in contaminated soils which remain in place.	This restriction would be difficult to enforce if land use changes.	Low capital. Low O&M.	No
		Fences	Access to contaminated sites would be restricted. Contaminated soils would remain in place.	Easily implemented.	Moderate capital. Low O&M.	Yes

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TABLE 7-7 (Continued)
SUMMARY EVALUATION OF SOIL PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
	Monitoring	Air Monitoring	Valuable to document conditions and monitor releases. Does not reduce risks.	Easily implemented.	Moderate capital. Moderate O&M.	Yes
		Groundwater Monitoring	Valuable to document conditions and monitor releases. Does not reduce risks.	Easily implemented.	High capital. High O&M.	Yes
Containment	Capping	RCRA Cap	Effective barrier to prevent infiltration and prevent fugitive dust.	Possible clay source nearby. Easily implemented.	High capital. Low O&M.	No
		WAC Cap	Effective barrier to prevent infiltration and prevent fugitive dust.	Easily implemented.	High capital. Low O&M.	Yes
		Asbestos Cap	Does not prevent infiltration. Effective in prevention of fugitive dust.	Easily implemented.	Moderate capital. Low O&M.	Yes
Excavation/ Treatment/ Disposal	Excavation	Earth-Moving Equipment	Effectiveness methods for excavation and hauling of contaminated soils.	Easily implemented. Operators may require protective clothing and respirators.	Moderate capital. Moderate O&M.	Yes

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TABLE 7-7 (Continued)
SUMMARY EVALUATION OF SOIL PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Excavation/ Treatment/ Disposal (cont.)	Thermal Treatment	Rotary Kiln Incinerator	Effective in destroying organic contaminants.	Onsite and offsite technology readily available. May require some special material handling. Permits will be required for onsite processing.	Moderate capital. Moderate O&M.	Yes
		Infrared Incinerator	Effective in destroying organic contaminants.	Onsite and offsite technology readily available. Will require special material handling. Permits will be required for onsite processing.	Moderate capital. Moderate O&M.	No
		Circulating Fluid Bed Incinerator	Effective in destroying organic contaminants.	Onsite and offsite technology readily available. Will require special material handling. Permits will be required for onsite processing.	Moderate capital. Moderate O&M.	No
		Vitrification	Effective in destroying organic contaminants.	Technology not readily available.	Moderate capital. Moderate O&M.	No

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TABLE 7-7 (Continued)
SUMMARY EVALUATION OF SOIL PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Excavation/ Treatment/ Disposal (cont.)	Chemical Treatment	Dechlorination	Effective in dechlorinating PCB's.	Technology available. Large quantities (>10,000 tons) required for cost effectiveness.	Moderate capital. High O&M.	No
		Stabilization/ Solidification	Effectiveness in stabilizing organic soil contaminants is not well proven.	Readily implementable with a number of stabilizing reagents available. Treatability tests required.	Moderate capital. Moderate O&M.	No
	Physical Treatment	Solvent Extraction	Removal efficiencies for PCB's between 84 to 98 percent. Not proven for BEHP but likely to be effective.	Readily implementable. Special handling considerations. Extract must be recycled or treated. Requires multiple treatment passes.	High capital. High O&M.	No
		Supercritical CO ₂ Extraction	Has proven effective in bench scale studies for removal of organics.	Full scale technology not yet developed for HTW remediation. Extract must be recycled or treated.	No costs available.	Yes

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TABLE 7-7 (Continued)
SUMMARY EVALUATION OF SOIL PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Excavation/ Treatment/ Disposal (cont.)	Physical Treatment (cont.)	Soil Washing	Effective in reducing contaminated soil volumes.	Readily implementable. Large quantities (> 10,000 tons) required for cost effectiveness. Residual soils require additional treatment.	High capital. High O&M.	No
		Aerobic	No field demonstrated remediation of PCB's. Biodegradation of BEHP reported but not conclusive.	Readily implementable. Would require treatability study. May not be able to achieve BDAT standards.	Moderate capital. Moderate O&M.	Yes
	Anaerobic	Bench scale studies have demonstrated degradation of PCB's. No field results.	Would require treatability studies. Reactors for anaerobic conditions would be required.	High capital. High O&M.	No	
	Disposal	Onsite Disposal	Effective for disposal of treated soils which meet the BDAT requirements for land disposal.	Readily implementable.	Low capital. Low O&M.	Yes
		Offsite Disposal	Effective for disposal of PCB contaminated soils. No reduction in toxicity would be achieved.	Readily implementable with facility in close proximity.	Moderate capital. No O&M.	Yes

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TABLE 7-7 (Continued)
SUMMARY EVALUATION OF SOIL PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
In Situ Treatment	Chemical Treatment	Stabilization/Solidification	Effectiveness in stabilizing organic contaminants in not well proven.	Readily implementable technology. Debris and concrete at HRL will pose problems.	Moderate capital. Low O&M.	No
	Biological Treatment	Aerobic	No field demonstrated remediation on PCB's. Biodegradation of BEHP reported but not conclusive.	Readily implementable. Would require treatability studies. May not be able to achieve BDAT standards.	Low capital. Moderate O&M.	Yes
		Anaerobic	Bench scale studies have demonstrated degradation of PCB's. No field results.	Maintenance of anaerobic conditions in field would be difficult.	Moderate capital. Moderate O&M.	No

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TABLE 7-8
SOIL PROCESS OPTIONS REMAINING
AFTER EVALUATION OF PROCESS OPTIONS

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General Response Action	Remedial Technology Types	Process Options
No Action	None	Not Applicable
Institutional Controls	Access Restrictions	Administrative Controls Fences
	Monitoring	Air Monitoring Groundwater Monitoring
Containment	Capping	WAC Cap Asbestos Cap
Excavation/Treatment/Disposal	Excavation	Earth-Moving Equipment
	Thermal Treatment	Rotary Kiln Incinerator
	Chemical Treatment	None Remaining
	Physical Treatment	Supercritical CO ₂ Extraction
	Biological Treatment	Aerobic
In Situ Treatment	Disposal	Onsite Offsite
	Chemical Treatment	None Remaining
	Biological Treatment	Aerobic

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TABLE 7-9
SUMMARY EVALUATION OF GROUNDWATER PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
No Action	None	Not Applicable	There is no current risk to human health because domestic water is supplied through the city of Richland's distribution network. The quality of the groundwater is not improved.	Easily implemented. This alternative may not be acceptable to regulators or the public.	---	Yes
Institutional Controls	Alternate Water Supplies	Municipal Water	Health risks to receptors are eliminated because all industrial and domestic users are supplied through the municipality.	The city of Richland currently supplies domestic and industrial users downgradient of the plume. Distribution network already in place.	Low capital. Low O&M.	Yes
		Commercially Supplied	Health risks are eliminated because domestic users drink bottled water.	Easily implementable. May be an inconvenience to users.	Low capital. Low O&M.	No
	Point of Entry/ Point of Use Treatment	Various (see Table 7-5)	Effective in treating water at the point of use to below MCL's.	Easily implemented. Would require maintenance of treatment units. May be an inconvenience to users.	Moderate capital. High O&M.	No

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TABLE 7-9 (Continued)
SUMMARY EVALUATION OF GROUNDWATER PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Institutional Controls (cont.)	Access Restrictions	Administrative Controls	Effective in restricting future well drilling. No reduction in contaminant concentrations.	Easily implemented. Both DOE and Ecology can restrict well drilling.	Low capital. Low O&M.	Yes
		Deed Restrictions	Effective in preventing future well drilling. No reduction in contaminant concentrations.	Difficult to implement if land comes under private ownership.	Low capital. Low O&M.	No
	Monitoring	Monitoring Wells	Effective in identifying the extent, spread, and concentration of the contaminant plume. No reduction in contaminant concentrations.	Easily implemented.	High capital. High O&M.	Yes
Containment	None Remaining After Initial Screening	Not Applicable	---	---	---	---
Extraction/Treatment/Discharge	Extraction	Deep Wells	Effective in pumping large volumes of groundwater from aquifers with high hydraulic conductivities.	Easily implemented.	High capital. High O&M.	Yes

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TABLE 7-9 (Continued)
SUMMARY EVALUATION OF GROUNDWATER PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Extraction/ Treatment/ Discharge (cont.)	Extraction (cont.)	Ejector Wells	Effective for intermittent pumping of aquifers with low hydraulic conductivities.	Easily implemented.	High capital. High O&M.	No
		Enhanced Extraction	Effective in flushing contaminants at a known source area.	Easily implemented. Injected water must meet ARAR.	High capital. High O&M.	No
	Physical Treatment	Adsorption	Effective in removing organic contaminants from groundwater to below MCL's.	Equipment available from multiple vendors. Large flow systems require special containment vessels.	High capital. High O&M.	No
		Air Stripping	Effective in removing organic contaminants from groundwater to below MCL's.	Equipment available from multiple vendors. TCE emissions may be a concern.	Moderate capital. Moderate O&M.	Yes
		Steam Stripping	Effective in removing organic contaminants that are not readily strippable in normal air stripping processes.	Equipment available. Requires large energy input.	High capital. Moderate O&M.	No

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TABLE 7-9 (Continued)
SUMMARY EVALUATION OF GROUNDWATER PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Extraction/ Treatment/ Discharge (cont.)	Physical Treatment (cont.)	Reverse Osmosis	Not effective in removing TCE. Effective in reducing nitrate concentrations to below MCL's.	Equipment readily available. Must treat or dispose of brine.	High capital. High O&M.	Yes
		Electrodialysis	Not effective for removal of TCE. Removal efficiencies for nitrates are less than 50%.	Equipment readily available.	High capital. High O&M.	No
	Chemical Treatment	Chemical Oxidation	Effective in oxidizing organic contaminants to terminal end products usually CO ₂ and H ₂ O.	Equipment readily available.	High capital. High O&M.	Yes
		Ultraviolet Radiation/ Photolysis	Effective when used in conjunction with chemical oxidation to destroy organic contaminants.	Equipment readily available. Influent water must have low turbidity.	Moderate capital. High O&M.	Yes
		Irradiation	Not effective by itself in treating organic contaminants.	Requires long reaction times.	Moderate capital. High O&M.	No

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TABLE 7-9 (Continued)
SUMMARY EVALUATION OF GROUNDWATER PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Extraction/ Treatment/ Discharge (cont.)	Chemical Treatment (cont.)	Ion Exchange	Effective for treatment of nitrates to below MCL's. Not effective in treating TCE.	Equipment readily available. Regenerant requires treatment and disposal.	High capital. High O&M.	No
	Biological Treatment	Aerobic	Studies have shown that TCE and nitrates can be treated effectively.	Easily implemented. Would require the introduction of organic inducers to stimulate process which may not be acceptable to regulators.	High capital. High O&M.	No
		Anaerobic	Effective in reducing TCE concentrations.	Easily implemented. Intermediate byproducts (vinyl chloride) have greater risk to humans. Organic inducers are required to stimulate process.	High capital. High O&M.	No
	Discharge	Surface Water	Effective for discharge of treated groundwater.	Easily implemented. Would require NPDES permit. Pipeline would traverse two major arterials.	High capital. Low O&M.	No

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TABLE 7-9 (Continued)
SUMMARY EVALUATION OF GROUNDWATER PROCESS OPTIONS

General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
Extraction/ Treatment/ Discharge (cont.)	Discharge (cont.)	Reuse/Recycle	Effective for supplying treated water to end users.	Easily implemented. No end users exist.	Moderate capital. Moderate O&M.	No
		Recharge	Effective for discharge of treated groundwater.	Easily implemented. Must meet groundwater treatment standards.	Moderate capital. Moderate O&M.	Yes
In Situ Treatment	Physical Treatment	Aeration	Effective in volatilizing organics to the gas phase. Contaminant is not destroyed but transferred to separate phase for treatment.	Difficult to implement for large contaminant plumes.	High capital. High O&M.	No
		Heating	Effective in volatilizing organics which are not easily volatilized by the injection of air. Does not destroy, but transfers contaminants to separate phase for treatment.	Difficult to implement for large contaminant plumes. Requires significant energy input.	High capital. High O&M.	No

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TABLE 7-9 (Continued)
SUMMARY EVALUATION OF GROUNDWATER PROCESS OPTIONS

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General Response Action	Remedial Technology Type	Process Option	Effectiveness	Implementability	Relative Cost	Used to Develop Alternatives?
In Situ Treatment (cont.)	Biological Treatment	Aerobic	Studies have shown that TCE and nitrates can be treated effectively.	Would require supplements of oxygen, nutrients, and organic stimulant. Difficult to treat large plumes.	High capital. High O&M.	No
		Anaerobic	Effective in reducing TCE concentrations.	Would require supplements of nutrients and organic stimulant. Difficult to treat large plumes.	High capital. High O&M.	No

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TABLE 7-10
GROUNDWATER PROCESS OPTIONS REMAINING
AFTER EVALUATION OF PROCESS OPTIONS

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General Response Action	Remedial Technology Types	Process Options
No Action	None	Not Applicable
Institutional Controls	Alternate Water Supplies	Municipal Water
	Point of Entry/Point of Use Treatment	None
	Access Restrictions	Administrative Controls
	Monitoring	Monitoring Wells
Containment	None Remaining After Screening	Not Applicable
Extraction/Treatment/Discharge	Extraction	Deep Wells
	Physical Treatment	Air Stripping
	Chemical Treatment	Chemical Oxidation Ultraviolet Radiation/Photolysis Ion Exchange
	Biological Treatment	None
	Discharge	Recharge
	In Situ Treatment	Physical
	Biological	None

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8.0 DEVELOPMENT AND SCREENING OF ALTERNATIVES

8.1 INTRODUCTION

In this section, the retained process options are assembled into remedial action alternatives that offer varied degrees of treatment for the contaminated media at the site. The assembled alternatives are then evaluated and screened. The remaining alternatives are analyzed in detail in section 9.0.

8.2 PROCESS OVERVIEW

Alternatives are initially developed to meet a set of remedial action objectives for each medium of interest. The goal of this process is to assemble a wide range of response actions that achieve different degrees of cleanup, treat different volumes of the contaminated media, and achieve the cleanup in different timeframes. These alternatives should include appropriate containment and treatment options.

At this point in the process, alternatives are defined in sufficient detail to allow for the differentiation of each with respect to effectiveness, implementability, and cost. Also, volumes of media to be treated are well defined. The following information will be developed, as appropriate, for the various technology processes used in an alternative:

- Size and configuration of onsite extraction and treatment systems;
- Timeframe in which treatment, containment, or removal goals can be achieved;
- Rates or flows of treatment;
- Spatial requirements for constructing treatment or containment technologies or for staging construction materials or excavated soil or waste;
- Distances for disposal technologies; and
- Required permits for actions and imposed limitations.

The assembled alternatives are next screened using three broad criteria: effectiveness, implementability, and cost. These criteria are defined as follows (EPA, 1988):

- Effectiveness Evaluation--Each alternative is evaluated as to its effectiveness in providing protection and the reductions in toxicity, mobility, or volume that it will achieve. Both long- and short-term components of effectiveness should be evaluated; long-term referring to the period after the remedial action is complete, and short-term referring to the construction and

implementation period. Reduction of toxicity, mobility, or volume refers to changes in one or more characteristics of the hazardous substances or contaminated media by the use of treatment that decreases the inherent threats or risks associated with the hazardous material.

- **Implementability Evaluation**--Implementability, as a measure of both the technical and administrative feasibility of constructing, operating, and maintaining a remedial action alternative, is used during this screening to evaluate the process options with respect to the conditions at the 1100-EM-1 Operable subunits. Technical feasibility refers to the ability to construct, reliably operate, and meet technology-specific regulations for process options until a remedial action is complete. Administrative feasibility refers to the ability to obtain approvals from the appropriate entities, the availability of treatment, storage, or disposal services and capacity, and the requirements for, and availability of, specific equipment and technical specialists.
- **Cost Evaluation**--Both capital and operation and maintenance (O&M) costs are considered. This evaluation will include those O&M costs that will be incurred as long as necessary, even after the initial remedial action is complete. Potential future remediation costs are considered to the extent that they can be defined. Present worth analysis should be used during this screening to evaluate expenditures that occur over different time periods. In this way, costs for different actions are compared on the basis of a single figure for each alternative.

Appendix P contains detailed cost estimates for the initial capital construction costs of each of the alternatives. Capital costs presented in the following paragraphs are taken from these estimates. Life-cycle O&M costs are estimated based on utility usage and historical costs supplied by various equipment vendors. These costs are reflected by a present worth cost using a annual discount rate of 8.5 percent used over the lifetime of the alternative.

8.3 SOIL REMEDIAL ACTION ALTERNATIVES

Soil remedial action alternatives are assembled from the various process options to present a range of treatment alternatives. These are represented by alternatives S-0 through S-5D in table 8-1. Alternatives with the same first two descriptors are similar except that the amount of material to be treated or the containment method are changed. Common components of each alternative are first described and evaluated, then the features which make each alternative unique, are described and evaluated against the screening criteria.

PROCESS OPTION	TABLE 8.1 - SOIL REMEDIAL ACTION ALTERNATIVES																					
	S 0	S 1A	S 1B	S 1C	S 1D	S 2A	S 2B	S 2C	S 2D	S 3A	S 3B	S 3C	S 3D	S 4A	S 4B	S 4C	S 4D	S 5	S 5A	S 5B	S 5C	
No Action	•																					
Institutional Controls	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Bioremediation of BEHP		•	•	•	•																	
On Site Incineration /Disposal																						
• All Sites						•		•														
• UN-1100-6 and Ephemeral Pool							•		•													
Off Site Incineration /Disposal																						
• All Sites										•		•										
• UN-1100-6 and Ephemeral Pool											•		•									
• UN-1100-6																			•	•	•	•
Off Site Disposal																						
• HRL and Ephemeral Pool		•		•															•		•	
• Ephemeral Pool			•		•															•		•
Supercritical CO ₂ Extraction																						
• All Sites														•		•						
• UN-1100-6 and Ephemeral Pool															•		•					
Containment at HRL																						
• WAC Cap				•	•			•	•			•	•			•	•				•	•
• Asbestos Cap		•	•			•	•			•	•			•	•			•	•			

8.3.1 Common Components.

Common components of each of the alternatives are discussed in the following paragraphs.

8.3.1.1 Institutional Controls. Institutional controls will consist of maintaining the current industrial land use, and restricting access and continuing groundwater monitoring hydraulically downgradient of sites on which contaminants remain in place. These controls are both technically and administratively implementable. The cost of these controls will vary according to the cleanup level achieved and will be evaluated with respect to each alternative. For purposes of alternative comparison, it is assumed that the no action alternative will require continued monitoring of all presently monitored wells over the next 30 years. Using historical costs of \$52,150 per monitoring round, this has a life-cycle present worth of \$561,435. For all other alternatives, removal or treatment options are assumed to obtain cleanup levels that facilitate clean closure, therefore, wells specifically installed to monitor releases from these remediated sites would no longer require sampling and the only monitoring requirements will be for the HRL. Pro-rated costs for this reduced monitoring effort is \$40,500 per annual sampling event. This has a life-cycle present worth of \$436,015 over 30 years.

8.3.1.2 Removal of PCB's at HRL. Ten of the twenty-one proposed alternatives include the removal of PCB's contaminated soils at the identified "hot spot" at HRL. As documented in section 7.0, a number of process options exist that will efficiently destroy the PCB's in the soil to below required cleanup levels. However, while implementable technology exists, the risks associated with the remediation of this site may be substantial due to the presence of both PCB's and friable asbestos. Additionally, because the landfill is not fully characterized and its past use was uncontrolled, there is a possibility of encountering additional contaminants and being exposed to their associated risks during remediation. To the MTCA cleanup goal of 17 mg/kg reduces incremental cancer risk associated with this site from 5E-5 to 2E-5. The primary exposure pathways are through dermal contact and ingestion. Exposure can be significantly reduced through the use of institutional controls that restrict access to the site, or through containment measures. These actions are considered in other alternative scenarios and are not uncommon when considering the closure of landfills.

Costs associated with the cleanup of the estimated 460 m³ (600 yd³) of contaminated soil at HRL either, by onsite or offsite incineration, or through disposal in a TSCA facility are \$1,355,930, \$2,699,620 and \$562,460, respectively. Although these costs are not prohibitive, removal and treatment of these soils is not considered further. Other actions, as mentioned above, are deemed more practicable in meeting site remedial action objectives. Therefore, alternatives S-1A, S-1C, S-2A, S-2C, S-3A, S-3C, S-4A, S-4C, S-5A and S-5C are dropped from further consideration.

8.3.1.3 Containment at the HRL. Of the remaining 11 alternatives, 10 include some sort of capping option at HRL. The first is a cap option designed in accordance with WAC 173-304 for the closure of municipal and solid waste landfills (MSWLF cap) in arid regions.

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The second option is a cap designed for the closure of inactive asbestos disposal sites under 40 CFR 61. Each is described and evaluated below.

8.3.1.3.1 Description of the MSWLF Cap--The MSWLF cap consists of a minimum of 15 cm (6 in) of topsoil over a 50-mil polyvinyl chloride (PVC) geomembrane. The cap is placed over the 10.1 hectare (25 acre) area, which is estimated to be the extent of the actively used landfill. The cap is designed to have a minimum 2-percent positive drainage slope to facilitate surface runoff. Because of the width of the landfill, intermediate drainage swales will be used to intercept this runoff. At these swales, 10-cm (4-in) diameter perforated pipe is used for surface drainage collection and the intercepted runoff is carried past the extent of the cap into a drain field where it is allowed to percolate through the vadose zone.

The construction of the cap will require approximately 86,500 m³ (113,000 yd³) of random fill material to be used in preparing an adequately sloped subgrade. Of this, special construction practices will be used in placing the first 15 cm (6 in) of material to prevent the exposure of remedial workers to fugitive dust which may contain asbestos. A 15 cm (6 in) geomembrane bedding layer consisting of 2.54 cm (1 in) minus material will be placed on top of the random fill. Next, 87,900 m² (105,000 yd²) of geomembrane will be placed and covered with 15 cm (6 in) of topsoil. The capped area will be reseeded to establish a vegetative cover and 1.83 km (6000 ft) of perimeter fence will be constructed to restrict access to the site. Appropriate warning signs will be posted to inform the public that the area is a past landfill site that contains asbestos material. It is assumed that all earthwork materials can be obtained from offsite sources within a 16-km (10-mi) radius of HRL.

8.3.1.3.2 Evaluation of the MSWLF Cap--The MSWLF cap is effective in preventing surface water intrusion into the landfill area which may contain a number of unknown contaminants, and in preventing the migration of fugitive dust. Fencing around the landfill area restricts access and limits the potential of exposure to receptors. Contaminant volume and toxicity are not reduced under this option; mobility of contaminated fugitive dust is eliminated and the low potential for contaminant migration from the vadose zone to the groundwater is reduced further. It should be noted that this action goes substantially beyond the RAO's for HRL that are to prevent the ingestion of and dermal contact with PCB's contaminated soils, and to prevent the migration of fugitive dust containing asbestos. Short-term risks associated with the construction of the cap are minimal and the long-term risks are substantially reduced. The long-term effectiveness of the cap is dependent on the chemical and weather resistant properties of the geomembrane and will need to be periodically evaluated. The impact to the environment is minimal as potential animal habitat is disturbed during construction but is enhanced by the placement of topsoil and a vegetative cover at the completion of cap placement.

This option is considered easily implementable. Construction of the cap involves common methods used in industry. Earth materials are readily available near the site. There are a multitude of suppliers of geomembranes and numerous contractors who are qualified in the special methods required for their installation. Occupational Safety and Health Administration (OSHA) guidelines will have to be followed to protect workers from asbestos hazards until the initial cover layer is placed over the site.

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The estimated initial capital cost for this option is \$5,208,420. O&M costs would involve periodic walkovers and visual evaluation of the cap system during its life, fence maintenance, and the maintenance of the surface drainage system. These costs are assumed to be negligible when considered over the lifetime of the cap. Additional annual costs would result from groundwater monitoring as described in paragraph 8.3.1.1.

8.3.1.3.3 Description of the Asbestos Cap--The asbestos cap will be constructed by placing 37,100 m³ (48,500 yd³) of clean random fill material over the 10.1 hectare (25 acre) site which is estimated to be the area actively used as the landfill. Placement of the first 15 cm (6 in) layer of this material will require the use of special construction practices to limit the exposure of remedial workers to fugitive dust. The random fill material will be placed uniformly over the site following existing contours; no effort will be made to direct surface runoff off of the cap area. A 15 cm (6 in) topsoil layer will then be placed and seeded to dryland grasses. Access to the landfill area will be restricted by constructing 1.83 km (6,000 ft) of perimeter fence. Appropriate warning signs will be placed to notify the public that the area was used as a landfill and that it contains asbestos.

8.3.1.3.4 Evaluation of the Asbestos Cap--Placement of the cap will meet the RAO of preventing the migration of fugitive dust from the landfill. Construction of a perimeter fence restricts site access and, therefore, the potential exposure to receptors is reduced. Contaminant volume and toxicity remains unchanged. Site risks are reduced because there is a significant reduction in the mobility of the asbestos. Because PCB's sorbed to soils have limited mobility within the vadose zone, a permeable cap system does not increase site risks. Because special construction practices are employed during initial placement of the fill, short-term risks to remedial workers are minimal.

Placement of the cap will involve standard earthwork practices and materials that are readily available within a 16-km (10-mi) radius of the site. OSHA standards will have to be followed until the initial cover layer is placed over the site to protect onsite workers from asbestos hazards. This option is considered to be easily implementable.

An initial construction capital cost of \$2,016,730 is estimated for this option. O&M costs specific to the cap would include periodic walkovers and evaluation of the cap, and fence maintenance. These costs are assumed to be negligible over the life of the cap. Yearly groundwater sampling and analysis would be required because contaminants would be left in place. These costs are provided in paragraph 8.3.1.1 above.

8.3.1.4 Offsite Disposal of Ephemeral Pool PCB's. Four of the remaining options consider excavating the PCB's contaminated soil at the Ephemeral Pool and disposing of them in the Toxic Substance Control Act (TSCA) permitted facility run by Chemical Waste Management Incorporated in Arlington, Oregon, approximately 145 km (90 mi) away. Under this option, approximately 250 m³ (340 yd³) of contaminated soil will be removed and disposed. Front end loaders used for excavation and hauling will be operated by Department of Transportation (DOT) approved hazardous waste haulers. The contaminated material will be hauled in bulk in approximately 28-ton truckloads. Removal of material will be in phases with confirmatory testing conducted between each phase. The RAO for this site is to remove all material to below the MTCA cleanup level of 1 mg/kg and to background levels if

practicable. If this RAO is not achieved, or if any PCB's remain onsite (<1 mg/kg) after the removal of 250 m^3 of material, institutional controls will be implemented (access restrictions and annual downgradient groundwater sampling). If cleanup to background levels is achieved, the site will be closed without restrictions. At the completion of the removal action the site will be regraded and covered with 15 cm (6 in) of clean random fill material.

This option reduces the mobility of PCB contaminated material at the site through removal actions; the volume and toxicity are not reduced. Placement in a permitted offsite facility ensures that controls are in place to prevent releases to the environment. The remedial action is easily implemented as it requires basic earth moving equipment, DOT licensed haulers, and offsite landfill capacity, all of which are readily available. The short-term risks to remedial workers is minimal as precautions will be taken to preclude worker exposure to contaminated material. If any PCB's remain onsite, access restrictions will prevent long-term exposure to onsite workers thus reducing risks.

The costs for this option are based on the assumption that the site will be remediated to background levels by removing a maximum of 250 m^3 of material. The estimated initial capital cost of this action is \$438,980. There would be no O&M costs associated with clean closure.

8.3.2 Alternative S-0 (No Action)

8.3.2.1 Description of Alternative. This alternative is required by the NCP to establish a baseline condition to which other alternatives can be compared. Under this alternative, no action would be taken to remediate any of the contaminated soil sites. The current monitoring program would be revised to require annual sampling only over the next 30 years. During this period, if sample analysis indicates that conditions at the site are deteriorating, the program would be reevaluated. If at the end of 30 years, conditions at the site are unchanged or are improved, the monitoring program would be discontinued.

8.3.2.2 Evaluation of Alternative. This alternative does not reduce the toxicity, mobility, or volume of the contaminated media. If the current land use patterns of the site remain the same, the maximum incremental cancer risk of $5\text{E-}5$ and hazard index of 0.3 for an onsite worker, as determined in appendix L based on the 95-percent UCL, would still exist. These levels are within the acceptable range set forth in the NCP. As stated in appendix M, there are no risks to ecological receptors from the contaminants present that are distinguishable from the baseline conditions.

There are no technical requirements for the implementation of this alternative. Administratively, there may be some opposition to leaving contaminants in place by regulatory agencies and the public. The costs of this alternative would be those associated with continued site-wide monitoring as identified in paragraph 8.3.1.1.

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8.3.3 Alternative S-1B and S-1D

8.3.3.1 Description of Alternatives. These alternatives consider the use of bioremediation for the BEHP contaminated soil at the UN-1100-6, removal and offsite disposal of the PCB's contaminated soil at the Ephemeral Pool, and either an asbestos cap (S-1A) or a MSWLF cap (S-1D) at HRL. Bioremediation will be through the method of landfarming. A diked treatment area approximately 30.5 m by 36.6 m (100 ft by 120 ft) will be constructed onsite and lined with an impervious geomembrane. The contaminated soil, estimated to be a maximum of 340 m³ (440 yd³), will be excavated and placed into the treatment area. A sprinkler system will deliver a mixture of water, nutrients, and microorganisms, specifically cultured for their ability to degrade BEHP, to the soils approximately twice a week. The soils will be tilled after each application of this mixture to provide additional mixing and aeration. Excess water is collected and recycled. A bioreactor is required onsite to culture the microorganisms. It is assumed that bioremediation will be conducted for 36 weeks a year with a suspension of operations during the colder winter months, which inhibit bacterial growth and respiration. The entire remediation process is assumed to take 2 years, however, this is a crude estimate and the actual time will be better estimated after treatability testing. After remediation, the soils will be placed back at the UN-1100-6 site and the area will be regraded and covered with 15 cm (6 in) of topsoil assuming that it meets the Land Disposal Restriction (LDR) Best Demonstrated Available Technology (BDAT) requirement of no more than 28 mg/kg of BEHP. If this requirement is not met, a land disposal treatability variance will be petitioned for.

8.3.3.2 Effectiveness of Alternatives. The effectiveness of bioremediation on BEHP soils is not well documented. At one site, BEHP in soils was reduced from 700 mg/kg to a few parts per million (WST, 1992). However, even with a treatment efficiency of 99 percent, for soils with a 95-percent UCL of 18,000 mg/kg, this treatment would not reduce contaminant levels to below the MTCA cleanup goal of 71 mg/kg. Treatability studies will better define the actual treatment levels that may be achieved. Therefore, it is difficult to predict the levels to which toxicity will be reduced. Unless the soils are remediated to background levels, which is unlikely, there will be no reduction in volume or mobility.

Landfarming is an easily implemented treatment method. Initial construction of the facility is simple. O&M is somewhat difficult due to the sensitivity of the bacterial colonies, however, this is overcome by initial operator training. The facility will have to meet RCRA guidelines for land treatment units.

The initial capital cost for each alternative, including offsite disposal of the Ephemeral Pool PCB's soil and capping of HRL is \$3,397,020 for alternative S-1B and \$6,558,640 for alternative S-1D. These costs include the anticipated 2 year O&M costs of the landfarming operation. The life cycle present worth costs of annual monitoring were identified in paragraph 8.3.1.1.

8.3.4 Alternatives S-2B and S-2D

8.3.4.1 Description of Alternative. These alternatives use onsite incineration and disposal for the destruction of PCB's and BEHP at the Ephemeral Pool and the UN-1100-6 subunits, respectively. Alternative S-2B uses a cap designed for asbestos containment while, alternative S-2D uses a MSWLF cap at the HRL.

Onsite incineration will be accomplished by using a small mobile incinerator capable of processing approximately 4.5 metric tons (5-tons) of contaminated soil per day. Between the two operable subunits there is approximately 1,100 metric tons (1,210 tons) of contaminated soils to be processed. Rotary kiln technology is used to process materials as big as 5 cm (2 in) in diameter. Electricity will be used to power the combustion source. Combustion off gases will be treated to meet air quality standards for emissions through use of a secondary combustion chamber and wet scrubbers. Ashes will be quenched with water and the quench water will be recirculated. After incineration, the ash will be placed back at the operable subunit and the area will be regraded and covered with 15 cm (6 in) of topsoil.

Materials will be excavated using standard equipment for earthwork. Confirmatory testing will be conducted to ensure that all contaminated soils above cleanup levels are removed. A 30.5-m (100-ft) graded square pad is required to house the incinerator. The pad will be located in an area that is central to both operable subunits. Precautions shall be taken to ensure that material is not spilled when transporting it from the site to the incinerator.

8.3.4.2 Evaluation of Alternatives. Incineration has been proven to be effective with 99.9999 percent destruction efficiencies for PCB's and BEHP. This option will reduce contaminant levels to below the MTCA requirements of 1 mg/kg for PCB's and 71 mg/kg for BEHP. Additionally, the LDR BDAT of 28 mg/kg for BEHP can be met. This method will significantly reduce the toxicity of the soils. The volume of soils will be slightly reduced, while the mobility of the contaminants that remain after incineration will stay the same. Soils redeposited after processing are likely to have some residual contaminants, however, these will be minimal and should not prohibit the delisting of the sites.

Mobile incinerator technology is readily available making these alternatives easy to implement technically. Administratively, acquiring the approvals to operate the incinerator may be difficult due to public opposition. A test burn may be required to ensure that air emissions criteria are met and to evaluate the ash characteristics.

Specific evaluation of the capping options are as described above. Costs for these alternatives including the O&M costs for the incinerator and the capping costs for HRL, are estimated to be \$4,982,050 and \$8,173,670 for alternatives S-2B and S-2D respectively. There would be no costs associated with O&M after incineration is complete.

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8.3.5 Alternatives S-3B and S-3D

8.3.5.1 Description of Alternatives. In these alternatives, offsite incineration to destroy contaminants in subunit soils is chosen as the remedial action. Approximately 1,100 metric tons (1,210 tons) of contaminated soils from the UN-1100-6 and Ephemeral Pool subunits will be excavated and shipped to an offsite incinerator. DOT licensed hazardous waste haulers will carry the contaminated soils in bulk truck loads of 18.2 metric tons (20 tons) to the Chemical Waste Management Incorporated RCRA licensed facility in Port Arthur, Texas, approximately 2,100 km (1,300 mi) away. After incineration, the ash is disposed of in this facility's ash disposal landfill. Post action sampling and analyses of remaining subunit soils is required to confirm the level of cleanup. These alternatives also require either an asbestos cap (alternative S-3B) or a MSWLF cap (alternative S-3D) as the containment option at HRL.

8.3.5.2 Evaluation of Alternatives. The capping component of these alternatives were described previously. The efficiency of this option is the same as that achieved for onsite incineration. In addition to reducing toxicity, this option reduces contaminant mobility because soils are removed from the site, treated, and placed in a controlled landfill. The volume of material is only slightly reduced in the incineration process.

There is both adequate incineration and transportation capacity to easily implement this alternative. Also, the public is less likely to oppose treating and disposing of the soils offsite in an already permitted facility.

The estimated cost of alternative S-3B including the asbestos cap for HRL is \$5,110,040. A cost of \$8,301,730, which includes the MSWLF cap at HRL, is estimated for alternative S-3D. Life-cycle present worth and annual monitoring costs were identified in paragraph 8.3.1.1. There would be no O&M costs associated with these alternatives.

8.3.6 Alternatives S-4B and S-4D

8.3.6.1 Description of Alternatives. Treatment for the UN-1100-6 and Ephemeral Pool soils are accomplished through the use of supercritical CO₂ extraction under these alternatives. Again, alternative S-4B includes the asbestos cap at the HRL, and alternative S-4D includes the MSWLF cap, both of which have been previously described. This treatment technology has been retained to this point because it is innovative in nature and bench scale studies have shown promising results. Although this application is commonly used commercially for the decaffeination of coffee, equipment has not yet been developed for the decontamination of soil. The process is described in detail in appendix N. Conceptually, contaminated soils would be fed into a reactor in which it would be subjected to a constant flow of supercritical CO₂ for a certain period of time determined through treatability testing. The treated soil would have the majority of contaminants removed and could possibly be redeposited at the sites. The extract would be brought back to ambient pressure and temperature and the CO₂ would return to its gaseous state. The remaining liquid would be free product of either PCB's or BEHP that could either be recycled or detoxified through some other treatment process.

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8.3.6.2 Evaluation of Alternatives. Bench scale studies recently performed (WHC, 1992) on contaminated soils from both the UN-1100-6 site and the HRL site have shown 97-percent and 99-percent removal efficiencies through this process for BEHP and PCB's, respectively. Improved efficiencies may be possible by altering the temperature or pressure used in the process. Further bench scale studies will concentrate on these parameters to determine the most optimal extraction conditions.

Because this technology is only emerging, there is no equipment available to implement this treatment method. Additionally, because of the small volume of material at the 1100-EM-1 Operable Unit site, developing the technology for use at only this site would not be cost effective. For these reasons, use of this technology at this time is not feasible and these alternatives are dropped from future consideration. However, there may be other potential sites at Hanford where this technology would be applicable and that would make development of a treatment process economically viable. This process option should be reconsidered if its development progresses significantly within the near future.

8.3.7 Alternatives S-5B and S-5D

8.3.7.1 Description of Alternatives. These alternatives treat 619 m tons (682 tons) of contaminated UN-1100-6 soils using offsite incineration, dispose of 250 m³ (340 yd³) of Ephemeral Pool soils in an offsite landfill, and use the asbestos cap (alternative S-5B) or the MSWLF cap (alternative S-5D) at HRL.

8.3.7.2 Evaluation of Alternatives. As previously discussed, offsite incineration for the treatment of BEHP soils will be effective in reducing contaminant toxicity and mobility. Disposal of PCB contaminated soils in a TSCA landfill does not reduce volume or toxicity, however, mobility is controlled through containment measures instituted by the facility. These options reduce long-term exposure to onsite workers by removing contaminated materials. As indicated, these options are all easily implementable. The estimated initial capital cost of alternative S-5B is \$4,472,510. Alternative S-5D is estimated to have an initial capital cost of \$7,664,200. There are no O&M costs associated with this alternative. The yearly groundwater sampling and analysis cost and the life-cycle present worth cost, assuming clean closure of the UN-1100-6 and Ephemeral Pool sites, would be as described in paragraph 8.3.1.1 for the 30-year period.

8.3.8 Summary of Remedial Alternative Costs

A summary of the retained remedial action alternative costs is provided in table 8.3. The detailed evaluation of these alternatives will be performed in section 9.0.

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TABLE 8.2. SOIL REMEDIAL ALTERNATIVE COSTS

Alternative	S-0	S-1B	S-1D	S-2B	S-2D	S-3B	S-3D	S-5B	S-5D
Capital Cost	\$0	\$3,397,020	\$6,558,640	\$4,982,050	\$8,173,670	\$5,110,040	\$8,301,730	\$4,472,510	\$7,664,200
Annual Monitoring Cost	\$52,150	\$40,500	\$40,500	\$40,500	\$40,500	\$40,500	\$40,500	\$40,500	\$40,500
Lifecycle Present Worth of Annual Costs ¹	\$561,434	\$436,015	\$436,015	\$436,015	\$436,015	\$436,015	\$436,015	\$436,015	\$436,015
Total Present Worth Costs	\$561,434	\$3,833,035	\$6,994,655	\$5,418,065	\$8,609,685	\$5,546,055	\$8,737,745	\$4,908,525	\$8,100,215

¹ 30 year life.

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8.4 GROUNDWATER REMEDIAL ACTION ALTERNATIVES

The remaining groundwater process options are assembled to present a range of treatment alternatives. These are represented by alternatives GW-0 through GW-4B in table 8-3. Alternatives with the same first three descriptions are similar except that the treatment method for TCE differs. Common features of alternatives are first described and evaluated. Finally, complete alternatives are described and evaluated against the screening criteria.

8.4.1 Common Components.

The components that are common to a number of alternatives are described in the following paragraphs.

8.4.1.1 Institutional Controls. Institutional controls will consist of maintaining the existing land use, preventing the drilling of consumptive wells, and supplying future users through Richland's existing municipal distribution system. These controls are both technically and administratively implementable. The costs of these controls are minimal. Additionally, yearly groundwater sampling and analysis will be required until such time as contaminant levels equal background. For this evaluation, groundwater monitoring is assumed to be continued for 30 years for each alternative. The annual cost of sampling and analysis associated with the monitoring of HRL plume is \$40,500, which corresponds to a life-cycle present worth of \$436,015. It should be noted that these are the same monitoring wells used for the evaluation of releases from the contaminated soil sites. Therefore, to preclude accounting for these costs twice, they have not been considered as part of the groundwater alternative costs as they have already been considered in the soil alternatives.

8.4.1.2 Extraction-Infiltration Scenario 1. Under this scenario groundwater is pumped at a rate of 0.38 m³/min (100 gpm) through one extraction well. The extracted water is treated and then is distributed to an infiltration system consisting of 61 m (200 ft) of 31-cm-(12-in) diameter perforated pipe from which the treated water is recharged into the ground. The extraction well is approximately 18.3 m (60 ft) deep. The bottom 6.1 m (20 ft) will be screened. A 5-horsepower(hp)-pump is used to push the water through 92 m (300 ft) of 8-cm-(3-in) diameter pipe to the head of the treatment train. After treatment, the water is pumped from a sump to the recharge system using a 1/2 hp pump. A general location of the well and recharge trench is shown in figure 6-33.

It is estimated that the plume can be remediated to below MCL by the year 2012 under this pumping scenario. Capital costs are associated with the well, pumping, and piping networks. O&M costs are required mainly for power and occasional pump servicing. These costs are included in the evaluations to follow.

8.4.1.3 Extraction-Infiltration Scenario 2. Three wells each being pumped at a rate of 0.38 m³/min (100 gpm) each, for a combined total of 1.14 m³/min (300 gpm), are the basis of this extraction scheme. Each well is 18.3 m (60 ft) deep and is screened over the bottom 6.1 m (20 ft). The water is pumped by 5 hp pumps through 8 to 10 cm (3 to 4 in) diameter transmission line to the head of the treatment train. A total of 495 m (1,625 ft) of pipeline is

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PROCESS OPTION	TABLE 8.3. GROUNDWATER REMEDIAL ACTION ALTERNATIVES							
	GW-0	GW-1	GW-2A	GW-2B	GW-3A	GW-3B	GW-4A	GW-4B
No Action	●	●						
Institutional Controls								
● Monitoring	●	●	●	●	●	●	●	●
● Points of Compliance with Remediation Trigger		●						
Extraction/Infiltration								
● Scheme 1			●	●				
● Scheme 2					●	●		
● Scheme 3							●	●
TCE Treatment								
● Air Stripping			●		●		●	
● Chemical/UV Oxidation				●		●		●
Nitrate Treatment								
● Reverse Osmosis			●	●	●	●	●	●

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required. After treatment, the effluent is collected in a sump and a 3 hp pump is used to discharge the effluent to a 183-m (600-ft) long infiltration trench containing 31-cm- (12-in) diameter perforated pipe. The approximate locations of the wells and the recharge trench for this scheme are shown in figure 6-33.

Under this scenario, the contaminated plume is estimated to be remediated to below MCL's by the year 2008. Capital costs are based on the installation of new wells and the transmission piping system. O&M costs reflect the cost of annual monitoring and occasional pump maintenance. Evaluations that follow include these costs.

8.4.1.4 Extraction-Infiltration Scenario 3. This scenario represents the most aggressive pumping scenario considered. Ten wells, each extracting at a rate of 0.38 m³/min (100 gpm), for a total of 3.79 m³/min (1,000 gpm), are installed. Each well is equipped with a 7.5 hp pump. The water is conveyed through a 8 to 20 cm (3 to 8 in) diameter transmission line to the head of the treatment train. Approximately 725 meters (2,375 ft) of transmission pipeline is required. After treatment, the effluent is collected in a sump and then pumped using a 20 hp pump to the infiltration system. The infiltration system consists of 610 m (2,000 ft) of 31-cm- (12-in)-diameter perforated pipe in a trench that is 305 m long by 6.1 m wide (1,000 ft by 20 ft).

Remediation of the contaminant plume to below MCL's is estimated to be complete by the year 2004 using this scenario. As in the other extraction-infiltration scenarios, initial capital costs are associated with well installation, pumps, and the transmission piping, while O&M costs are associated with yearly monitoring and the occasional maintenance of the pumps. Again, these costs are included in the evaluations that follow.

8.4.1.5 Additional Monitoring Wells. In all alternatives (except GW-0, the no-action alternative), six additional wells will be installed in order that the contaminant plume can be more effectively monitored. Three wells will be installed just west of and parallel to George Washington Way. Three other wells will be installed at locations to be determined downgradient of HRL. The depth of these wells will be approximately 18.3 m (60 ft). Wells shall be cased using 10.2 cm- (4 in-) diameter stainless steel. The bottom 6.1 m (20 ft) of the well shall be screened with a 10-slot stainless steel well screen. The initial capital costs of the additional wells is \$343,405. Annual sampling and analyses costs for these additional wells is \$24,300. Life-cycle present worth costs will vary according to the estimated life of the project.

8.4.2 Alternative GW-0.

8.4.2.1 Description of Alternative. This is the "no action" alternative required by the NCP for the purpose of establishing a baseline remediation scenario to which all other alternatives can be compared. Under this alternative, no active measures would be undertaken to remediate the TCE and nitrates in the groundwater. A long-term monitoring program would be implemented to characterize the migration of contaminants over time. Existing administrative controls would remain in place.

8.4.2.2 Evaluation of Alternative. It is estimated that the groundwater contaminants in the plume will be naturally attenuated to below MCL's by the year 2017 and that no contaminants above MCL's will cross the George Washington Way diagonal (section 6.0). Because there are no downgradient users, the risks to humans during this remediation timeframe would be minimal. This option does not reduce contaminant volume or mobility. Toxicity is reduced through dispersion and dilution. Technically, this alternative is easily implemented. Administratively, there may be some concern with leaving contaminants in place. The costs associated with this alternative are those required for yearly groundwater monitoring. There are no costs associated with this alternative.

8.4.3 Alternative GW-1

8.4.3.1 Description of Alternative. This alternative is similar to Alternative GW-0 in that no active remedial action is taken initially. Instead, points of compliance are established along a line just west and parallel to George Washington Way. The three new monitoring wells installed along this line will provide information on contaminant migration. Detection of contaminants at levels above MCL's, at these wells, would trigger a remedial design and action.

8.4.3.2 Evaluation of Alternative. Under the most conservative groundwater modelling scenario, contaminants at levels above MCL's do not migrate past George Washington Way and are naturally attenuated by the year 2017. Establishing George Washington Way as a point of compliance within the DOE site boundary, provides some insurance if the actual conditions differ from those modelled. If contaminants above MCL's are detected at these compliance points, remedial actions can be initiated to prevent further migration. As in the no action scenario, there are no risks to human health during the anticipated remediation timeframe because there are no downgradient groundwater users. This alternative is easy to implement technically and, administratively, may be better accepted because institutional controls would be in place to trigger an active remediation should conditions warrant. The costs of this alternative include the construction of six additional monitoring wells, and the yearly sampling and analysis required for monitoring. The initial capital cost and the present worth life-cycle costs of this alternative is \$605,515. This assumes that no remedial action will be necessary in the future based on modeling results.

8.4.4 Alternatives GW-3A Through GW-5B

8.4.4.1 Description of Alternatives. These alternatives treat various flow rates of extracted groundwater using two separate treatment trains. Alternatives GW-3A, GW-4A, and GW-5A treat 0.38, 1.14 and 3.79 m³/min (100, 300, and 1,000 gpm) flows, respectively, using air stripping for treatment of TCE and reverse osmosis for the treatment of nitrates. Alternatives GW-3B, GW-4B, and GW-5B use an ultraviolet (UV)/oxidation system to treat TCE and reverse osmosis for the treatment of nitrates at these same respective flows.

8.4.4.1.1 Pretreatment Units--At the head end of each process train, high flow multi-media filters will remove sediments from the groundwater. This will prevent fouling of the air

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stripping media and of the osmotic membrane. Filters or a combination of filters are available to meet the proposed design flows (Collagen, 1992). Filters have been sized for flow rates of $0.28 \text{ m}^3/\text{min}\text{-m}^2$ (7 gpm/ft²). Sedimentation ponds will be constructed onsite to facilitate settling of sediments from backwash water. Overflow from settling ponds will be discharged to a drain field.

8.4.4.1.2 Air Strippers--Air strippers are commonly used for the removal of TCE from groundwater. As described in appendix N, stripping makes use of TCE's favorable Henry's Law Constant. Air is passed countercurrent to water flow and the volatile organic contaminant is transferred from the liquid phase to the gas phase. Air stripping units for the various flow rates will have the following design parameters (Hydro Group, 1992). Strippers are used in Alternatives GW-3A, GW-4A, and GW-5A.

<u>Parameter</u>	<u>0.38 m³/min</u>	<u>1.14 m³/min</u>	<u>3.79 m³/min</u>
Height	7.63 m (25 ft)	7.63 m (25 ft)	7.63 m (25 ft)
Diameter	0.61 m (2 ft)	1.22 m (4 ft)	2.13 m (7 ft)
Packing Height	4.57 m (15 ft)	4.57 m (15 ft)	4.57 m (15 ft)
Blower Size	1 hp	3 hp	10 hp

All units will be constructed of structural aluminum and shall be free standing.

8.4.4.1.3 UV/Oxidation Units--The UV/oxidation process is described in appendix N and applies to the treatment of TCE (alternatives GW-3B, GW-4B, and GW-5B). Typical processes mix the contaminated water with ozone and hydrogen peroxide in a reaction chamber. This mixture is then irradiated with UV light. Off gases are treated in a catalytic ozone decomposer and then released to the air. Units, or a combination of units, are available to treat the range of design flows (ALTROSE, 1992). System components consist of an oxidation reactor, ozone generator, compressor, air dryer, air filter, hydrogen peroxide feed system, a vapor treatment unit, and associated programmable logic controls. For the respective flow rates, 12.7, 45.4, and 136.2 kilograms (kg) [28, 100, and 300 pounds (lbs)] of ozone must be generated per day.

8.4.4.1.4 Reverse Osmosis--Reverse osmosis is chosen as the process option to remove nitrates to below MCL's. As described in appendix N, hydrostatic pressure is used to drive feedwater through a semipermeable membrane while a major portion of the contaminant content remains behind and is discharged as waste. This waste discharge is then flash evaporated, leaving behind residue, which can easily be disposed. Units, or a combination of units, are available to treat the range of flows proposed (Culligan, 1992). Standard system features are a thin-film composite spiral-wound-reverse osmosis membrane, fiberglass membrane housings, panel mounted and in-line instruments for monitoring of system performance, and a water quality monitor. These systems are assumed to operate with a 75-percent recovery rate.

8.4.4.2 Evaluation of Alternatives. Each of these alternatives is effective in reducing the contaminant levels in the groundwater to below MCL's. Air stripping transfers the contaminant to the gas phase and does not reduce the overall volume or toxicity of the contaminant. Mobility is transferred from the liquid phase to the gas phase. Emissions of TCE to the atmosphere are not considered to be a substantial health risk at this industrial site. TCE emissions for the proposed treatment rates are estimated to be 52.6, 157.7, and 526.6 grams/day (0.12, 0.35, and 1.16 lbs/day) based on the average TCE concentrations from eight rounds of sampling. Because TCE concentrations have been falling with each successive sampling round, this estimate is conservative. TCE will also degrade in the atmosphere after several days. The process is easily implemented with a number of vendors available who can supply units. Administratively, obtaining approval for direct release of emissions to the atmosphere should not be difficult due to the low inherent risks.

Alternatives employing extraction-infiltration scenario 3 (GW-4A and GW-4B) are predicted to remediate the aquifer in the least amount of time (9 years). However, as stated in section 6.0, 100 percent additional water outside the 5 ppb TCE plume will be captured and treated. Treatment of this clean water more than doubles the costs of alternatives utilizing extraction-infiltration scenario 2 (GW-3A and GW-3B) and only reduces the remediation timeframe by 4 years. The capture zone analysis performed in section 6.0 indicates that the optimum pump and treat scenario would include wells extracting between 0.38 and 1.14 m³/min (100 and 300 gpm). For these reasons, alternatives GW-4A and GW-4B are dropped from further consideration.

The UV/oxidation system destroys the TCE and converts it to CO₂ and water. The system can effectively reduce TCE concentrations to below MCL's. Volume, mobility, and toxicity of the contaminant are all reduced. There is only one known vendor of this system, however, obtaining equipment should not pose a problem. Administratively, obtaining approval for the use of this system is not a concern.

Reverse osmosis has proven effective in removing nitrates to below MCL's. Residuals from this process are easily disposed. Volume is not reduced, but toxicity and mobility are reduced as nitrate will remain as a constituent of a solid residue. This technology is readily available and is easily implemented with a number of available equipment suppliers. There should be no administrative obstacle in using this technology.

Initial capital costs have been estimated and are summarized in table 8.4. Vendors quotes for all equipment were obtained. O&M costs are based on pumping, chemical, and energy requirements. Where possible, these were obtained from the vendor, otherwise these are approximate values.

Costs of all other retained alternatives are also summarized in table 8.4. Detailed evaluation of these alternatives will be conducted in section 9.0.

TABLE 8.4. GROUNDWATER REMEDIAL ALTERNATIVE COSTS¹

Alternative	GW-0 ²	GW-1 ²	GW-2A ³	GW-2B ³	GW-3A ⁴	GW-3B ⁴	GW-4A ⁵	GW-4B ⁵
Capital Cost	\$343,405	\$343,405	\$859,745	\$1,182,885	\$1,648,755	\$2,104,385	\$4,086,385	4,528,895
Annual O&M Cost	\$0	\$0	\$16,164	\$26,676	\$52,142	\$83,678	\$208,225	\$313,345
Annual Monitoring for Additional Wells	\$24,300	\$24,300	\$24,300	\$24,300	\$24,300	\$24,300	\$24,300	\$24,300
Lifecycle Present Worth Cost of Annual Costs	\$261,610	\$261,610	\$357,402	\$450,026	\$588,252	\$830,934	\$1,190,458	\$1,728,641
Total Present Worth Costs	\$605,015	\$605,015	\$1,217,147	\$1,633,136	\$2,237,007	\$2,935,319	\$5,276,843	\$6,257,536

¹ Annual sampling and analysis cost of \$40,500 for existing wells are not included in these costs; they were previously considered for soil alternatives.

² 30 year life.

³ 17 year life.

⁴ 14 year life.

⁵ 9 year life.

9.0 DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

9.1 INTRODUCTION

The candidate remedial alternatives are evaluated in detail in this section. The evaluation criteria used in this analysis are discussed in paragraph 9.2. Detailed descriptions of the alternatives were provided in section 8.0. After each alternative is individually assessed against these criteria, a comparative analysis is made to evaluate the relative performance of each alternative in relation to the specific evaluation criteria.

9.2 EVALUATION CRITERIA

Each alternative is evaluated against nine criteria. They are: the overall protection of human health and the environment; compliance with ARAR's; long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; cost; state acceptance; and community acceptance. Five of the criteria consider a number of subcriteria to allow a more thorough analysis and evaluation. State and community acceptance are appropriately reviewed during the development of the proposed plan. Evaluation of these two criteria are beyond the scope of this report. The criteria and subcriteria are those described in FS guidance (EPA, 1989) and are briefly summarized below.

9.2.1 Criterion 1--Overall Protection of Human Health and the Environment

This evaluation criterion provides a final check to assess whether each alternative meets the requirements that it is protective of human health and the environment. The overall assessment of protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARAR's.

This evaluation will focus on how an alternative achieves protection over time and how site risks are reduced. The analysis considers how each source of contamination is to be eliminated, reduced, or controlled for each alternative.

9.2.2 Criterion 2--Compliance with ARAR's

This evaluation criterion is used to determine whether each alternative will meet the Federal and state ARAR's that have been identified. The analysis will summarize the requirements that are applicable or relevant and appropriate to the alternative and will describe how each is met. The following is addressed for the detailed analysis of ARAR's:

- Compliance with chemical specific ARAR's;
- Compliance with action-specific ARAR's; and
- Compliance with location-specific ARAR's.

9.2.3 Criterion 3--Long-Term Effectiveness and Permanence

The evaluation of alternatives under this criterion addresses the results of a remedial action in terms of the risks remaining at the site after response objectives have been met. The primary focus of this evaluation is the extent and effectiveness of the controls that may be required to manage the risk posed by treatment residuals and/or untreated wastes. The following sub-criteria are addressed:

- Magnitude of residual risk;
- Adequacy of controls; and
- Reliability of controls.

9.2.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment

This evaluation criterion addresses both the Federal and state statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substance as their principal element. This preference is satisfied when treatment is used to reduce the principal threats at a site through the destruction of toxic contaminants, reduction of the total mass of toxic contaminants, irreversible reduction in contaminant mobility, or reduction in total volume of contaminated media.

The evaluation focuses on the following specific factors for a particular remedial alternative:

- The treatment processes the remedy will employ, and the materials they will treat;
- The amount of hazardous materials that will be destroyed or treated, including how the principal threat(s) will be addressed;
- The degree to which the treatment will be irreversible;
- The type and quantity of treatment residuals that will remain; and

- Whether the alternative would satisfy the statutory preference for treatment as a principal element.

9.2.5 Criterion 5--Short-Term Effectiveness

This evaluation criterion addresses the effects of the alternative during the construction and implementation phase until remedial response objectives are met (*e.g.*, a cleanup target has been met). Alternatives are evaluated with respect to their effects on human health and the environment during implementation of the remedial action. The following factors will be addressed:

- Protection of the community during remedial actions;
- Protection of workers during remedial actions;
- Environmental impacts; and
- Time until remedial action objectives are met.

9.2.6 Criterion 6--Implementability

The implementability criterion addresses the technical and administrative feasibility of implementing an alternative and the availability of various services and materials required during its implementation. The following factors are analyzed:

- Technical feasibility including construction and operation, reliability of technology, and the ease of undertaking additional remedial action;
- Administrative feasibility; and
- Availability of services and materials including offsite storage and treatment capacity, and the availability of equipment, services, and personnel.

9.2.7 Criterion 7--Cost

The cost of each alternative is presented including estimated capital, annual costs, and present worth costs. The accuracy of all costs are within the plus 50-percent to minus 30-percent range specified in the guidance. Capital costs include the direct costs of equipment, labor, and materials necessary to install remedial alternatives. Annual costs are post-construction costs necessary to ensure effectiveness of the remedial action. Present worth costs are calculated to evaluate expenditures that occur over different time periods by discounting all future costs and annual costs to a common base year. For this report a

discount rate of 8.5 percent was used to determine present worth costs. Detailed costs are presented in section 8.0 with backup provided in appendix P.

9.2.8 Criterion 8--State Acceptance

State acceptance is assessed based on the evaluation of the technical and administrative issues and concerns that state regulatory agencies have regarding each of the alternatives. This criterion will be addressed in the Record of Decision (ROD) once comments on the RI/FS report and the proposed plan are received.

9.2.9 Criterion 9--Community Acceptance

This assessment evaluates the issues and concerns the public may have regarding each of the alternatives. As with state acceptance, this criterion will be addressed in the Record of Decision once comments on the RI/FS report and proposed plan are received.

9.3 EVALUATION OF SOIL REMEDIAL ALTERNATIVES

The remaining soil remedial alternatives are evaluated against the seven criteria that are possible to address at this time in the following paragraphs. At the conclusion of these individual evaluations a comparative analysis is made.

9.3.1 Alternative S-0 (No Action)

Under this alternative, no action is taken to remediate the site actively and annual monitoring of existing downgradient wells will be implemented.

9.3.1.1 Criterion 1. The remedial action objectives for all the sites would not be satisfied. Continued exposure to contaminated soil by industrial onsite workers would be possible. MTCA cleanup levels would not be achieved, however, the residual maximum site incremental cancer risks from the no action alternative of $5E-5$ and the maximum hazard index of 0.3 are both within the acceptable range set forth in the NCP.

9.3.1.2 Criterion 2. MTCA cleanup levels would not be achieved by this alternative.

9.3.1.3 Criterion 3. Residual risks would be as stated above. Groundwater monitoring would be a reliable and adequate control to determine if contaminants are migrating offsite. Continued industrial land use would ensure that potential exposure would be limited to onsite workers.

9.3.1.4 Criterion 4. There would be no reduction in the toxicity, mobility, or volume of the contaminants under this alternative.

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9.3.1.5 Criterion 5. Because no remedial actions are involved there are no short-term risks to remedial workers or the public. There will be no impacts to the environment due to construction or operation.

9.3.1.6 Criterion 6. This alternative would be easily implemented. Monitoring would be conducted using established procedures. No permits, special equipment, or specialists would be required.

9.3.1.7 Criterion 7. The present worth cost of this alternative is \$561,434.

9.3.2 Alternative S-1B

Under this alternative soils at the UN-1100-6 are bioremediated, PCB contaminated soil from the Ephemeral Pool is removed and disposed of offsite, and HRL is capped for the containment of asbestos. Additionally, annual groundwater monitoring is conducted, access is restricted to sites on which contaminants remain, and the current land-use is continued.

9.3.2.1 Criterion 1. All of the remedial action objectives would be satisfied by this alternative. Potential receptor exposure to contaminated materials would be significantly reduced by either reducing the toxicity of the contaminants through bioremediation, removal of the contaminants offsite, or through the combined effects of containment and access restrictions.

9.3.2.2 Criterion 2. Achievement of MTCA cleanup levels may not be possible for the bioremediation of BEHP at the UN-1100-6 subunit. Also, the operation of this facility would need to comply with RCRA requirements. A land disposal variance would have to be petitioned for if these soils did not meet RCRA Land Disposal Restriction Best Demonstrated Achievable Technology requirements prior to land disposal.

Achievement of MTCA cleanup levels would be attained at the Ephemeral Pool. Materials would be disposed of in a TSCA approved facility and transported according to DOT regulations.

MTCA cleanup levels for PCB's would not be achieved at HRL, however, exposure to the contaminant is significantly reduced. Attainment of MTCA cleanup standards at HRL would result in greater risk to human health than this containment option. This risk is due to the known presence of asbestos and the potential for exposure to unknown contaminants that may be present but have not been identified. The asbestos cap would comply with the requirement for capping inactive landfills containing asbestos. Warning signs will alert the public to the potential hazards of the landfill as required.

9.3.2.3 Criterion 3. Cleanup to the MTCA levels at the UN-1100-6 and Ephemeral Pool subunits would reduce residual risks at those sites to the E-6 range and below. Because the PCB's at HRL are not removed or treated, the baseline risks associated with the ingestion and dermal contact with the soil would remain the same. However, capping and restricting access at this site are adequate and reliable controls will significantly reduce the potential for

exposure. Continued yearly downgradient monitoring will determine if contaminants are migrating offsite and if additional remedial measures are necessary.

9.3.2.4 Criterion 4. The toxicity of the bioremediated UN-1100-6 subunit soil is reduced under this alternative. Because residuals of the contaminant would still exist, volume and mobility would remain the same.

Offsite disposal of the PCB-contaminated soil at the Ephemeral Pool would reduce the mobility of the contaminant onsite. Disposal in a controlled TSCA facility would limit the mobility of the contaminant offsite. The volume and toxicity of the contaminated soil would be unchanged.

The asbestos cap will not reduce either the toxicity, mobility, or volume of PCB-contaminated soil at HRL. The mobility of fugitive dust containing asbestos would be reduced.

9.3.2.5 Criterion 5. There would not be any short-term risks to the community during the implementation phase of this alternative. Control measures would be taken to control fugitive dust as part of any remedial action. Remedial workers will be required to wear protective coveralls to protect against dermal exposure. At HRL, special construction practices will be utilized to prevent worker exposure to asbestos.

During remediation, there will be some disruption of the environment due to earthmoving activities. However, after the sites are remediated, the areas will be regraded to restore the land to near original conditions. At HRL, topsoil will be provided and the area will be seeded to dryland grass to provide future habitat for birds and small mammals.

Bioremediation of the UN-1100-6 subunit is estimated to require about 2 years from the start of onsite activities. This remediation timeframe is not well constructed and can be better established after treatability studies are conducted. The removal action at the Ephemeral Pool can be completed within 3 months of beginning site work. Six months will be required to complete the capping and installation of the fence at HRL.

9.3.2.6 Implementability. Bioremediation is a commonly used technology that requires no special equipment. Initial operator training will be required to establish procedures for culturing the microorganisms and for supplementing and aerating the soil. Confirmatory testing will be required to determine when cleanup levels are achieved. If this treatment cannot achieve cleanup objectives, other methods described in this report can be easily instituted.

Removal of PCB's to an offsite facility is also easily implemented. Excavation of material will be by using conventional earthmoving equipment. Confirmatory testing will be conducted to ensure that all material above the cleanup level is removed. An approved TSCA facility with more than sufficient capacity is located at Arlington, Oregon, approximately 145 km (90 miles) away. A number of licensed DOT hazardous waste haulers are available who could transport this material.

Construction of a cap to contain asbestos requires only conventional earthwork practices. Earth materials for fill are available within a 16.1-km (10-mile) radius of the site. No special permits are required.

9.3.2.7 Cost. The total present worth cost of this alternative is \$3,833,035.

9.3.3 Alternative S-1D

This alternative is similar to alternative S-1B except that a cap designed in accordance with WAC 173-304 is used instead of the asbestos cap. Consequently, the evaluation that follows only considers this difference.

9.3.3.1 Criterion 1. The use of a WAC cap in this alternative would satisfy the remedial action objectives. Potential receptor exposure to contaminants is significantly reduced through the capping of the site and the imposition of access restrictions.

9.3.3.2 Criterion 2. Again, MTCA cleanup levels for PCB's would not be achieved at HRL, however, exposure to the contaminant is significantly reduced. Attainment of MTCA cleanup standards at HRL would result in greater risk to human health than this containment option. This risk is due to the known presence of asbestos and the potential for exposure to unknown contaminants that may be present but have not been identified. The WAC cap conforms to state requirements for capping of landfills in arid climates. Warning signs will alert the public to the potential hazards of the landfill as required.

9.3.3.3 Criterion 3. Because the PCB's are not removed or treated, the long-term risks associated with the site remain. However, capping and access restrictions significantly reduce the likelihood of exposure and are adequate and reliable controls. Continued annual monitoring of downgradient wells will be used to evaluate the cap and to determine if additional measures are necessary.

9.3.3.4 Criterion 4. The cap will not reduce the volume or toxicity of the PCB's. The cap is impermeable thus infiltration is reduced. This should further reduce the already limited mobility of the PCB's. The mobility of fugitive dust containing asbestos would be reduced.

9.3.3.5 Criterion 5. Construction of the cap will not pose a risk to the community. Special precautions will be taken to control fugitive dust that may contain asbestos to protect remedial workers. Construction will disturb 10.1 hectares (25 acres), that may currently be inhabited by wildlife. A topsoil cover seeded to dryland grass will be provided to provide habitat after construction is complete. Construction of the WAC cap will be completed within 6 months of starting work at the site.

9.3.3.6 Criterion 6. The cap is constructed using conventional practices and should be easily implemented. Geomembranes are available from multiple vendors and there are a number of contractors that are qualified in their installation. Earth fill materials are readily available within a 16.1-km (10-mile) radius. No special permits are required for construction.

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9.3.3.7 Criterion 7. The total present worth cost of this alternative is \$6,994,655.

9.3.4 Alternative S-2B

This alternative considers the use of onsite incineration for the destruction of contaminants at the UN-1100-6 and Ephemeral Pool subunits. Remedial action at HRL consists of capping for the containment of asbestos and the use of access restrictions. The capping option was evaluated as part of a previous alternative and is not reviewed here. Annual downgradient groundwater monitoring is employed to evaluate remedial actions.

9.3.4.1 Criterion 1. Remedial action objectives are met through this alternative. Residual risks are reduced to less than E-6 if cleanup levels are obtained; no residual risks from these contaminants would remain if clean closure is obtained.

9.3.4.2 Criterion 2. The ARAR for MTCA cleanup levels would be met under this alternative. The onsite incineration facility would meet RCRA standards for incineration facilities and also meet regional air quality standards. Ash from the process would have little residual contaminant and should meet requirements to allow replacement at the subunits.

9.3.4.3 Criterion 3. There should be little or no residual risks associated with remediation of this site as indicated above. If contaminants above background remain, annual monitoring should provide reliable controls to establish if subsequent releases occur.

9.3.4.4 Criterion 4. Toxicity of the contaminants would be significantly reduced as these processes typically have 99.9999 percent destruction removal efficiencies. Incineration of soils will not reduce volume substantially. Mobility of the remaining residuals will remain the same.

9.3.4.5 Criterion 5. There should be no risk to the community during remediation if the incinerator is operating properly. Air quality will be monitored and the operation will not proceed if emissions do not meet standards. Remedial workers will require protective clothing to prevent dermal contact. Impacts to the environment will consist of the excavation of contaminated materials and the construction of a pad to house incineration facilities. After remediation these areas will be regraded to return the site to near original conditions.

9.3.4.6 Criterion 6. Vendors are available to supply onsite incineration facilities that have proven effectiveness in remediating soils with similar contaminants. Operation of the incinerator is typically done by vendor supplied operators. Ashes can be tested to determine if cleanup goals are being met. The incinerator must meet the requirements of RCRA and be approved by state agencies in accordance with the TPA.

9.3.4.7 Criterion 7. The present worth total cost of this alternative is \$5,418,065.

9 3 1 2 8 6 2 0 5 9 0

9.3.5 Alternative S-2D

This alternative is similar to alternative S-2B except that a WAC cap is employed for the containment at HRL. Evaluation of the first six criteria has previously been presented in the above discussions. The only criterion that differs is the present worth total cost which is \$8,609,685.

9.3.6 Alternative S-3B

This remedial alternative utilizes incineration at an offsite facility for the remediation of the UN-1100-6 and Ephemeral Pool contaminated soils in conjunction with a cap for asbestos containment and access restrictions at HRL. Actions at HRL were previously considered and are not evaluated further here. Groundwater sampling is conducted annually to monitor the effectiveness of the remedial actions.

9.3.6.1 Criterion 1. This alternative will meet the site-wide remedial action objectives. Risks to human health from these specific contaminants are reduced to below E-6 if MTCA cleanup levels are obtained and eliminated if the site attains clean closure.

9.3.6.2 Criterion 2. All ARAR's will be met. The contaminated material will be hauled by a licensed DOT hazardous waste hauler. The receiving facility will have a permit to operate a RCRA facility. Ash disposal will be in an RCRA-approved facility.

9.3.6.3 Criterion 3. Long-term risks, as indicated above, are significantly reduced through this action. If contaminant residuals do remain, monitoring of groundwater will provide adequate controls to measure the effectiveness of the action.

9.3.6.4 Criterion 4. Contaminant toxicity is reduced due to the high destruction removal efficiencies associated with this process option. If residuals remain, their mobility is unaffected. Volume is only slightly reduced through the incineration of soils.

9.3.6.5 Criterion 5. There are no risks to the community from the offsite incineration alternative. Risks to remedial workers are minimized by requiring the use of protective clothing to prevent dermal exposure. Excavation of the contaminated material will disturb the relatively small sites. Post remediation activities will include regrading to return the area to near original conditions. The two subunits can be remediated within 3 months of commencing site activities.

9.3.6.6 Criterion 6. This alternative is easily implemented. A commercial incinerator is available in Port Arthur, Texas, approximately 2,100 km (1,300 miles) away. This incinerator accepts contaminated soils and has adequate capacity. Excavation of material is by conventional equipment and transportation is readily available through a number of licensed haulers. There would be no administrative requirements for onsite activities. Confirmatory testing will be used to determine when cleanup levels are achieved.

9.3.6.7 Criterion 7. The total present worth cost of this alternative is \$5,546,055.

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9.3.7 Alternative S-3D

This alternative uses a WAC cap as the containment option at the HRL in lieu of the cap for asbestos containment thus distinguishing it from alternative S-3B. Evaluations of all the components that comprise this option have been discussed in previous sections. Cost is the only criterion that differs and the total present worth costs of this alternative is \$8,737,745.

9.3.8 Alternative S-5B

This alternative is a hybrid alternative that utilizes offsite incineration for the UN-1100-6 soils contaminated with BEHP and, offsite disposal for the PCB's contaminated soils of the Ephemeral Pool. A cap for asbestos containment is used at the HRL along with access restrictions and continued annual groundwater monitoring. Each of these components were previously discussed and are not evaluated further. The present worth total cost of this alternative is \$4,908,525.

9.3.9 Alternative S-5D

Like Alternative S-5B, offsite incineration for UN-1100-6 soils and offsite disposal for Ephemeral Pool soils is utilized. This option, however, employs a WAC cap at HRL, along with access restrictions and continued annual groundwater monitoring. The present worth total costs of this alternative is \$8,100,215.

9.3.10 Comparative Analysis

In the following analysis, the alternatives are evaluated in relation to one another for each of the evaluation criteria. The purpose of this analysis is to identify the relative advantages and disadvantages of each alternative.

9.3.10.1 Criterion 1. All the alternatives will meet the remedial action objectives established at the site with the exception of alternative S-0. Protection of human health is provided by reducing the risks associated with the dermal contact and ingestion pathways. Alternatives S-1B, S-1D, S-5B, and S-5D achieve protection by a combination of treatment, removal, and disposal, and containment options. Alternatives S-2B, S-2D, S-3B, and S-3D achieve protection by the same technology, incineration, except that the method (onsite or offsite) differs. Containment at HRL is through one of two capping options.

9.3.10.2 Criterion 2. All actions except alternative S-0 have the potential of meeting ARAR's. For alternative S-0, MTCA cleanup levels are not attained, however, the risks associated with the site are within the acceptable range established by the NCP. Bioremediation may be less effective in reducing BEHP levels in alternatives S-1B and S-1D. The efficiency of cleanup will need to be determined in order to evaluate if MTCA cleanup levels can be met.

9.3.10.3 Criterion 3. Alternatives S-2B, S-2D, S-3B, and S-3D offer the highest degrees of long-term permanence because these alternatives use treatment methods that permanently reduce toxicity at the UN-1100-6 and Ephemeral Pool subunits. For Alternatives S-3B and S-3D, soils containing residuals will be disposed of onsite. Alternatives S-5B and S-5D also have high degrees of long-term permanence because contaminants are either destroyed or removed offsite to a controlled facility. Alternatives S-1B and S-1D have the potential for long-term permanence if contaminants are degraded to below cleanup levels. No long-term maintenance will be required at these subunits.

The capping options would require periodic evaluation and maintenance to preserve their integrity. The asbestos cap would maintain its functionality provided that the asbestos material remains covered. Functionality of the WAC cap is maintained as long as the geomembrane remains covered and is not ruptured. This cap option has the added benefit of reducing infiltration into the landfill area. Long-term monitoring will ensure that releases from HRL are not occurring and is critical for evaluating effectiveness. The reduction in exposure to receptors relies on maintaining access restrictions and current land uses.

Alternative S-0 would not reduce any residual site risks.

9.3.10.4 Criterion 4. Toxicity is reduced through alternatives S-2B, S-2D, S-3B, and S-3D. Alternatives S-1B, S-1D, S-5B, and S-5D reduce toxicity for BEHP contaminated soils at the UN-1100-6 subunit only.

Onsite mobility is reduced through alternatives S-1B, S-1D, S-3B, S-3D, S-5B, and S-5D by removing materials offsite. However, mobilities of the contaminants at offsite facilities remain the same even though they may be controlled.

Alternatives utilizing incineration reduce soil volumes very little. All other alternatives do not reduce volume.

Capping options reduce the mobility of fugitive dust that may contain contaminants. Mobility of contaminants in the vadose zone remain the same (practically immobile) although, the WAC cap reduces infiltration that potentially could further reduce mobility.

Alternative S-0 will not reduce the toxicity, mobility, or volume of contaminated soils.

9.3.10.5 Criterion 5. All alternatives present relatively low risks to the community during implementation. Some fugitive dust emissions from cap construction activities are anticipated although precautions will be taken to reduce these to protect both remedial workers and the community. Risks to remedial workers for all other alternatives will be reduced by using protective clothing.

The onsite biological treatment option for alternatives S-1B and S-1D is estimated to require approximately 2 years to complete. The onsite incineration option of alternatives S-2B and S-2D is estimated to take less than 1 year to complete. All offsite treatment

options should be accomplished within 3 months. The capping options in each of the alternatives would be constructed within 6 months.

9.3.10.6 Criterion 6. All alternatives are technically easy to implement. Alternatives S-1B and S-1D require some operator training and knowledge of the process. Alternatives S-2B and S-2D require the mobilization, set up, and trial testing of the incinerator to ensure that applicable standards are met. Operating personnel would be supplied by the vendor. The capping options would only require typical construction practices using readily available materials. Offsite disposal or treatment facilities considered in alternatives S-1B, S-1D, S-3B, S-3D, S-5B, and S-5D all have adequate capacity to receive these materials. Also, there are numerous licensed haulers who are able to transport these materials.

9.3.10.7 Criterion 7. The no action alternative has the least total present worth costs. These costs are associated with annual groundwater monitoring for the next 30 years. O&M costs for all remaining alternatives are the same because total cleanup of the UN-1100-6 and Ephemeral Pool subunits is assumed and the only costs are associated with the yearly monitoring of wells downgradient of HRL. Options that use the asbestos cap at HRL are less costly than those that use the WAC cap. Alternatives that use a combination of treatment for soils at the UN-1100-6 subunit and offsite disposal of the soils from the Ephemeral Pool subunit are less costly than alternatives that utilize either onsite or offsite incineration. A summary of costs is presented in table 8-2.

9.4 EVALUATION OF GROUNDWATER REMEDIAL ALTERNATIVES

The remaining groundwater remedial alternatives are evaluated against the seven criteria that are possible to address at this time in the following sections. A comparative analysis is made at the conclusion of these individual evaluations.

9.4.1 Alternative GW-0

No active remedial measures are undertaken under this alternative. Annual groundwater monitoring will be implemented to evaluate the migration of contaminants over time. Existing administrative controls that specify land use and restrict well drilling for consumptive purposes would remain in place. New facilities would receive water supplied through the City of Richland's distribution network.

9.4.1.1 Criterion 1. This alternative will meet the remedial action objectives of the site. Overall risks to humans are minimal because there are no current receptors. Continued use of the institutional controls will prevent future exposure. This alternative leaves contamination in place, that allows for further migration of the plume. However, groundwater modeling results have estimated that at no point in time will contaminants above MCL's the George Washington Way diagonal.

9.4.1.2 Criterion 2. This alternative will attain SDWA MCL's by the year 2017 through natural attenuation as estimated by groundwater modeling. No other ARAR's apply to this alternative.

9.4.1.3 Criterion 3. After natural attenuation to below MCL's is complete, the long term residual incremental cancer risk is reduced to $1E-6$ and the hazard quotient is 0.17. Groundwater monitoring would be a reliable control to determine the rate and concentration of plume migration.

9.4.1.4 Criterion 4. The toxicity of contaminants is reduced through the effects of diffusion, dispersion, and dilution. Mobility and volume remain the same.

9.4.1.5 Criterion 5. There are no risks to the community during remediation because there are no users of this groundwater. Assuming a common start date for all alternatives in the year 1995, the most conservative modeling estimate is that natural attenuation to below MCL's will be complete in 22 years.

9.4.1.6 Criterion 6. This alternative is easily implemented. The annual groundwater monitoring would be conducted under procedures already established for this site.

9.4.1.7 Criterion 7. There are no costs associated with this alternative.

9.4.2 Alternative GW-1

This alternative is similar to the no action alternative except that points of compliance are established on a line just west and parallel to George Washington Way. Three monitoring wells will be installed along this line to monitor the plume migration. If contaminants above MCL's are detected at any of these wells, a remedial design and action would be triggered.

9.4.2.1 Criterion 1. Site remedial action objectives will be accomplished under this alternative. Maintenance of institutional controls will ensure that there are no receptors of the groundwater, thus making the risks to human health minimal. Again, contamination is left in place and are allowed to migrate. However, natural attenuation of the entire plume to below MCL's is expected by the year 2017.

9.4.2.2 Criterion 2. This alternative will comply with SDWA MCL's when attenuation is complete.

9.4.2.3 Criterion 3. The residual incremental cancer risk associated with attenuation to MCL's is $1E-6$ and the hazard quotient is 0.17. Groundwater monitoring is a reliable control to determine if attenuation is complete.

9.4.2.4 Criterion 4. There is no reduction in contaminant volume or mobility under this alternative. Contaminant toxicity is reduced through dispersion, diffusion, and dilution.

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9.4.2.5 Criterion 5. Because there are no downgradient users of this aquifer, the risks to the community during remediation are minimal. Risks associated with monitoring well installation are also low. Natural attenuation to MCL's is expected to be complete in 22 years under the most conservative modeling estimate.

9.4.2.6 Criterion 6. This alternative is technically easily implemented with the only new construction consisting of well development. Obtaining regulatory approval for setting the points of compliance and leaving contaminants in place is required. Annual groundwater monitoring will reliably evaluate the effects of natural attenuation throughout the remediation timeframe. If contaminants above MCL's are detected at the points of compliance, additional remedial action could easily be initiated in a relatively short timeframe.

9.4.2.7 Criterion 7. The total present worth costs of this alternative is \$605,015, which assumes that natural attenuation will occur as modelled and that no additional remedial action is necessary. These costs include the capital costs of well construction and annual monitoring over a 30-year period.

9.4.3 Alternative GW-2A

Groundwater is actively remediated under this scenario. An extraction rate of 0.38 m³/min (100 gpm) is used. Groundwater is treated by air stripping (to remove TCE) and by reverse osmosis (to remove nitrates) to reduce contaminant levels to below MCL's. Effluent from the treatment train is recharged through an infiltration trench. Current institutional controls remain in place and six additional monitoring wells are installed.

9.4.3.1 Criterion 1. This alternative meets the remedial action objectives for the site. Risks to human health are minimal because there are no current or potential consumptive users of the groundwater. Remediation to below MCL's is expected by the year 2012.

9.4.3.2 Criterion 2. The groundwater will be remediated to SDWA MCL's. TCE emissions from the air stripper are not expected to be above levels that require treatment.

9.4.3.3 Criterion 3. Remediation to MCL's reduces the site incremental cancer risk to below 1E-6 and the hazard quotient to 0.17. Groundwater monitoring will provide reliable controls to assess the effectiveness of the remedial action. Maintenance would be required for pumps and treatment units to ensure their proper operation.

9.4.3.4 Criterion 4. This extraction scenario only captures the portion of the TCE contaminant plume above 35 ppb. The rest of the plume would be allowed to migrate and naturally attenuate. Upon transfer of the TCE to the gas phase by stripping, its mobility will be increased. However, TCE will degrade naturally in the atmosphere after a number of days.

Likewise, only a portion of the nitrate plume is captured and the remainder is allowed to attenuate naturally. There is no reduction of nitrate volume. However, toxicity and

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mobility are reduced because nitrate is contained in the solid residue remaining after treatment.

9.4.3.5 Criterion 5. There are no downgradient users of the aquifer so the risks to the community from ingestion are minimal. The risks associated with TCE emissions are also minimal because of the low emission rate and the fact that there are no residential areas in close proximity. Risks to workers installing wells and the extraction system will be low.

Remediation under this scenario is expected to take 17 years. The environment will be minimally impacted by construction activities.

9.4.3.6 Criterion 6. This alternative can be implemented easily. The required equipment, materials, and construction techniques are common to industry. The treatment units should reliably meet remediation goals.

9.4.3.7 Criterion 7. The total present worth costs for this alternative, including additional monitoring wells and yearly sampling, is \$1,217,147.

9.4.4 Alternative GW-2B

This alternative is similar to alternative GW-2A except that a UV/Oxidation treatment unit is used in lieu of an air stripper for TCE treatment.

9.4.4.1 Criterion 1. This alternative meets the remedial action objectives for the site. Risks to human health are minimal because there are no current or potential consumptive users of the groundwater. Remediation to below MCL's is expected by the year 2012.

9.4.4.2 Criterion 2. SDWA MCL's are met under this alternative. No other ARAR's are identified.

9.4.4.3 Criterion 3. Remediation to MCL's reduces the site incremental cancer risk to below $1E-6$ and the hazard quotient to 0.17. Groundwater monitoring will provide reliable controls to assess the effectiveness of the remedial action. Maintenance would be required for pumps and treatment units to ensure their proper operation.

9.4.4.4 Criterion 4. This treatment scheme destroys TCE and thus reduces its volume. Again, only the portion of the plume above 35 ppb is captured using this extraction scenario. The remainder of the plume is allowed to naturally attenuate.

There is no reduction in nitrate volume; toxicity and mobility are reduced because nitrate exists in a solid state after treatment. Like TCE, only a portion of the nitrate plume is captured and the remainder is left to naturally attenuate.

9.4.4.5 Criterion 5. There are minimal risks to the community and remedial workers during the implementation of this alternative. The environment will be slightly impacted by

construction activities. It is estimated that the plume will be remediated to below MCL's in 17 years.

9.4.4.6 Criterion 6. The treatment units required for this alternative are available from vendors, and construction of the facilities requires only common practices. The treatment process will require review from the regulators and no difficulties are anticipated. Therefore, this alternative should be easily implemented.

9.4.4.7 Criterion 7. The total present worth cost of this alternative is \$1,633,136. The costs of institutional controls are included in these.

9.4.5 Alternative GW-3A

Under this alternative, groundwater is extracted at a rate of 1.14 m³/min (300 gpm) through three extraction wells. The water is treated through a treatment train similar to that of alternative GW-2A, except that it is sized for the larger flow. Six additional monitoring wells are installed and existing institutional controls remain in place.

9.4.5.1 Criterion 1. This alternative meets the remedial action objectives for the site. Risks to human health are minimal because there are no current or potential consumptive users of the groundwater. Remediation to below MCL's is expected by the year 2008.

9.4.5.2 Criterion 2. The groundwater will be remediated to SDWA MCL's. TCE emissions from the air stripper are not expected to be above levels that require treatment.

9.4.5.3 Criterion 3. Remediation to MCL's reduces the site incremental cancer risk to below 1E-6 and the hazard quotient to 0.17. Groundwater monitoring will provide reliable controls to assess the effectiveness of the remedial action. Maintenance would be required for pumps and treatment units to ensure their proper operation.

9.4.5.4 Criterion 4. This extraction scheme captures the portion of the TCE plume that is above the 5 ppb MCL. The remaining contaminants are allowed to migrate and attenuate naturally. TCE mobility is increased when it is stripped and transferred to the gas phase. However, TCE degrades in the atmosphere after only a few days.

This alternative also captures a larger portion of the nitrate plume. That portion that is not captured is allowed to migrate and naturally attenuate. There is no reduction of nitrate volume. However, toxicity and mobility are reduced because nitrate is contained in the solid residue remaining after treatment.

9.4.5.5 Criterion 5. There are no downgradient users of the aquifer so the risks to the community from ingestion are minimal. The risks associated with TCE emissions are also minimal because of the low emission rate and the fact that there are no residential areas in close proximity. Risks to workers installing wells and the extraction system will be low.

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Remediation under this scenario is expected to take 13 years. The environment will be minimally impacted by construction activities.

9.4.5.6 Criterion 6. This alternative is easily implemented. The treatment system will attain the MCL goals. Equipment, material, and skilled labor are all readily available. Review of the treatment process will be done by the regulators and approval should not be difficult.

9.4.5.7 Criterion 7. The total present worth costs of this alternative is \$2,237,007. These costs include the costs of institutional controls.

9.4.6 Alternative GW-3B

Use of a UV/Oxidation treatment unit for TCE replaces the air stripping unit in alternative GW-3A to distinguish this alternative.

9.4.6.1 Criterion 1. Risks to human health are minimal because there are no current or potential consumptive users of the groundwater. Remediation to below MCL's is expected by the year 2008. Therefore, this alternative meets site remedial action objectives.

9.4.6.2 Criterion 2. SDWA MCL's will be met under this treatment alternative. No other ARAR's are identified.

9.4.6.3 Criterion 3. Site incremental cancer risks will be reduced to $1E-6$ and the hazard quotient will be reduced to 0.17 when MCL's are attained. Maintenance would be required for pumps and treatment units to ensure their proper operation. Groundwater monitoring will provide reliable controls to assess the effectiveness of the remedial action.

9.4.6.4 Criterion 4. This treatment scheme destroys TCE and thus reduces its volume. Again, only the portion of the plume above 5 ppb is captured using this extraction scenario. The remainder of the plume is allowed to attenuate naturally.

There is no reduction in nitrate volume; toxicity and mobility are reduced because nitrate exists in a solid state after treatment. Like TCE, only a portion of the nitrate plume is captured and the remainder is left to attenuate naturally.

9.4.6.5 Criterion 5. There are minimal risk to the community and remedial workers during the implementation of this alternative. The environment will be slightly impacted by construction activities. It is estimated that the plume will be remediated to below MCL's in 13 years.

9.4.6.6 Criterion 6. This alternative is easily implemented. The treatment system will attain the MCL goals. Equipment, material, and skilled labor are all readily available.

9.4.6.7 Criterion 7. The total present worth cost of this alternative, including institutional controls, is \$2,935,319.

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9.4.7 Comparative Analysis

The purpose of this analysis is to identify the relative advantages and disadvantages of each alternative. The alternatives are evaluated in relation to one another for each of the evaluation criteria in the paragraphs that follow.

9.4.7.1 Criterion 1. All alternatives protect human health and the environment by attaining the site RAO's for groundwater. There are no current users of the groundwater and the continued use of institutional controls will ensure that consumptive use of the aquifer will not occur until remediation to below MCL's is complete.

9.4.7.2 Criterion 2. All alternatives attain the SDWA MCL's of 5 $\mu\text{g/L}$ for TCE and 10 mg/L for nitrate as nitrogen although the time required to reach these goals differs slightly. Alternatives GW-2A and GW-3A will produce TCE air emissions, however, these quantities of TCE released are small and do not require regulation.

9.4.7.3 Criterion 3. Alternatives GW-2B and GW-3B physically destroy a portion of the TCE and use natural attenuation to remediate the rest of the plume thus achieving the highest degree of permanence. All alternatives reduce the site incremental cancer risks to below $1\text{E-}6$ and the hazard quotient to 0.17. Alternatives GW-0 and GW-1 use natural attenuation to meet the MCL's. Alternatives GW-2A and GW-2B transfer a portion of the TCE to the gas phase and use natural attenuation to remediate the rest of the plume. TCE is naturally degraded in the atmosphere under these alternatives.

Alternatives GW-2A, GW-2B, GA-3A, and GW-3B require maintenance of the pumps and treatment trains throughout the remediation timeframe. All alternatives rely on annual groundwater monitoring to evaluate their effectiveness. Continued land use restrictions ensure that there will be no users of the groundwater.

9.4.7.4 Criterion 4. Alternatives GW-0 and GW-1 reduce toxicity through natural attenuation. Alternatives GW-2A, GW-2B, GW-3A, and GW-3B reduce toxicity through treatment and natural attenuation.

Alternatives GW-2B and GW-3B are the only alternatives that actively destroy TCE and reduce contaminant volumes. Alternatives GW-2A and GW-3A additionally rely on the natural degradation of TCE in the atmosphere to reduce volume of the contaminant.

TCE mobility is not reduced under any alternative. In fact, TCE mobility is increased by transfer to the gas phase under alternatives GW-2A and GW-3A. Nitrate mobility is reduced under all options that utilize treatment trains because it is incorporated in a solid residue after treatment.

9.4.7.5 Criterion 5. All alternatives present low remedial risks to the community and to onsite remedial workers. Emissions from the air strippers of alternatives GW-2A and GW-3A are relatively low. The site is distant from the community, therefore, posing minimal risk of exposure to emissions.

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Alternatives GW-0 and GW-1 will remediate the site in 22 years. Alternatives GW-2A and GW-2B remediate the site in 17 years. It is estimated that 13 years will be required to remediate the site under alternatives GW-3A and GW-3B.

9.4.7.6 Criterion 6. All alternatives are easy to implement technically. Alternatives GW-2A, GW-2B, GW-3A, and GW-3B require treatment units that are available from multiple vendors. These alternatives also require that the processes be reviewed and approved by regulators. All alternatives employ standard construction practices.

9.4.7.7 Criterion 7. Alternatives GW-0 and GW-1 share the same cost and are the least costly of all alternatives. It is assumed that alternative GW-1 will not require additional remedial action in the future. Alternatives that treat 0.38 m³/min (100 gpm) are less costly than those that treat 1.14 m³/min (300 gpm). For alternatives treating the same flows, those that use air stripping for TCE removal are less costly than those utilizing UV/Oxidation for the destruction of TCE. A summary of these costs is presented in table 8-4.

9.5 SUMMARY

This section is provided to present a few alternate remedial action plans that address the contaminants at the 1100-EM-1 Operable Unit. The plans presented here do not comprise the entire universe of possibilities available but, rather, were assembled to offer a range of options that leave in place, contain, or treat the different contaminated media, and the range of costs for these options. Table 9-1 evaluates each plan against the criteria described earlier in this chapter. The plans considered are:

PLAN 1--Alternatives S-0 and GW-0.

PLAN 2--Alternatives S-1B and GW-1.

PLAN 3--Alternatives S-5B and GW-1.

PLAN 4--Alternatives S-5D and GW-1.

PLAN 5--Alternatives S-3D and GW-1.

PLAN 6--Alternatives S-3D and GW-2A.

PLAN 7--Alternatives S-3D and GW-3B.

As noted earlier, state and community acceptance are reserved for evaluation in the development of the proposed plan. The proposed plan provides a specific recommended alternative or approach to address the contaminants and associated risks at the site. One of the above plans may be proposed by the site risk managers for the remediation of the site. However, it should be noted that the exclusion of a specific plan in table 9-1 does not preclude its consideration by site risk managers or the public.

TABLE 9-1. EVALUATION OF ALTERNATE REMEDIAL ACTION PLANS (PLAN)

CRITERION	PLAN						
	1	2	3	4	5	6	7
Overall Protection of Human Health and the Environment	✓	✓	✓	✓	✓	✓	✓
Compliance with ARAR's	-	✓	✓	✓	+	+	+
Long-Term Effectiveness and Permanence	✓	+	+	+	+	+	+
Reduction of Toxicity, Mobility, and Volume	-	✓	✓	✓	+	+	+
Short-Term Effectiveness	+	✓	✓	✓	✓	✓	✓
Implementability	+	+	+	+	+	+	+
Cost	\$561,434	\$4,438,050	\$5,513,540	\$8,705,230	\$9,342,760	\$9,954,892	\$11,673,064

Ratings:

- = Low--does not meet all elements of criterion.
- ✓ = Medium--meets all elements of criterion adequately.
- + = High--meets all elements of criterion to the highest degree.

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