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# Final Remedial Investigation/ Feasibility Study-Environmental Assessment Report for the 1100-EM-1 Operable Unit, Hanford

Date Published
December 30, 1992

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Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

United States
Department of Energy
P.O. Box 550
Richland, Washington

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## ACRONYMS

| | |
|---|---|
| ACGIH | American Conference of Governmental Industrial Hygienists |
| ACM | Asbestos Containing Materials |
| amsl | Above Mean Sea Level |
| ANF | Advanced Nuclear Fuels |
| ANSI | American National Standards Institute |
| API | American Petroleum Institute |
| APR | Air Purifying Respirator |
| ARAR | Applicable or relevant and appropriate requirements |
| ARAR's | Legally applicable, or relevant and appropriate, Federal and State environmental standards |
| ASR | Air supplying respirator |
| ASTM | American Society for Testing and Materials |
| AWP | Asbestos work permit |
| BDAT | Best demonstrated available technology |
| BEHP | Bis (2-ethylhexyl) phthalate |
| BETA-HCH | Beta-Hexachlorocyclohexane |
| BISRA | Baseline Industrial Scenario Risk Assessment |
| BRSRA | Baseline Residential Scenario Risk Assessment |
| BWTF | Buried Waste Test Facility |
| CAA | Clean Air Act |
| CAS | Chemical abstracts service |
| CBC | Complete blood count |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CFR | Code of Federal Regulations |
| CFWQC | Chronic freshwater quality criterion |
| CGI | Combustible gas indicator |
| $cm^3$ | Cubic centimeter |
| CNS | Central nervous system |
| $CO_2$ | Carbon dioxide |
| CPC | Chemical protective clothing |
| CPR | Cardiopulmonary resuscitation |
| CRC | Contamination reduction corridor |
| CRQL | Contract Required Quanitfaction Limit |
| CRZ | Contamination reduction zone |
| CWA | Clean Water Act |
| dBA | Decibels on A-weighted scale |
| DHHS | U.S. Department of Health and Human Services |
| DNR | Washington State Department of Natural Resources |
| DOE | United States Department of Energy |
| DOE-RL | United States Department of Energy Field Office, Richland |
| DOL | Department of Labor |
| DOT | Department of Transportation |
| DOW | Washington State Department of Wildlife |
| Ecology | Washington Department of Ecology |
| EIS | Environmental impact statement |

## ACRONYMS
## (Continued)

| | |
|---|---|
| EM | Equipment maintenance |
| EMI | Electromagnetic inductance |
| EPA | United States Environmental Protection Agency |
| ERDA | United States Energy Research and Development Administration |
| ESLI | End-of-service-life indicator |
| FD&CA | Food, Drug, and Cosmetic Act |
| FEF | Forced expiratory flow |
| FID | Flame ionization detector |
| FIFRA | Federal Insecticide, Fungicide, and Rodenticide Act |
| FRC | Functional residual capacity |
| FS | Feasibility Study |
| ft | Foot |
| g | Gram |
| GC | Gas chromatography |
| G/kg | Grams per kilogram |
| g-mole | Gram-mole |
| GMU | Game management unit |
| GPR | Ground-penetrating radar |
| HEHF | Hanford Environmental Health Foundation |
| HEIS | Hanford Environmental Information System |
| HM | Hazardous material |
| HMS | Hanford Meteorological Station |
| HNF | Hanford Nuclear Facility |
| HNU | A photoionization detector manufactured by the HNU Co. |
| HOC's | Halogenated organic compounds |
| HQ | Hazard quotient |
| hr | Hour |
| HRL | Horn Rapids Landfill |
| HRS | Hazard ranking system |
| HSBRAM | Hanford Site baseline risk assessment methodology |
| HSDB | Hazardous substances data base |
| HSP | Health and Safety Plan |
| HSO | Health & Safety Officer |
| HSPA | Hanford Site performance assessment |
| HWP | Hazardous work permit |
| HWO&ER | Hazardous waste operations and emergency response |
| HWOP | Hazardous waste operating permit |
| HWQHC | Human water quality health criterion |
| HWQWC | Human water quality welfare criterion |
| ICR | Incremental cancer risk |
| IDL | Instrument detection limit |
| IDLH | Immediately dangerous to life and health |
| IP | Ionization potential |
| IR | Infrared |

## ACRONYMS
## (Continued)

| | |
|---|---|
| IRIS | Integrated Risk Information System |
| IU | Isolated unit |
| JSA | Job Safety Analysis |
| kg | One thousand grams |
| L | Liter |
| lb | Pound |
| LC | Lethal concentration |
| LD | Lethal dose |
| LDLO | Lethal dose low |
| LDR | Land disposal restriction |
| LD50 | Medium lethal dose |
| LEL | Lower explosive limit |
| LFL | Lower flammable limit |
| LOAEL | Lowest observed adverse effect level |
| LOEL | Lowest observed effect level |
| $m^3$ | Cubic meter |
| MAG | Magnetometer |
| MCL | Maximum contaminant level |
| MCLG | Maximum contaminant level goal |
| MD | Metal detector |
| MEFR | Maximal expiratory flow rate |
| Metals | Mercury, etc. |
| mg | Milligram |
| mg/kg | Milligram per kilogram |
| ML | Milliner |
| MMHG | Milliner of mercury |
| Mrem | Milliroentgen equivalent in man |
| MS | Mass Spectroscopy |
| MSDS | Material safety data sheet |
| MSHA | Mine Safety and Health Administration |
| msl | Mean sea level |
| MSWLF | Municipal and Solid Waste Landfill |
| MTCA | Model Toxics Control Act |
| MVV | Maximal voluntary ventilation |
| NCP | National Oil and Hazardous Substances Pollution Contingency Plan |
| NFPA | National Fire Protection Association |
| NIOSH | National Institute of Occupational Safety and Health |
| NOAA | National Oceanographic and Atmospheric Administration |
| NOAEL | No observed adverse effect level |
| NOEL | No observed effect level |
| NPL | National Priorities List |
| NRC | Nuclear Regulatory Commission |
| NTP | National Toxicology Program |
| $O_2$ | Oxygen |

## ACRONYMS
## (Continued)

| | |
|---|---|
| O&M | Operation and Maintenance |
| ORM | Other regulated materials |
| OSHA | United States Occupational Safety and Health Administration |
| OSWER | Office of Solid Waste and Emergency Response |
| OU | Operable unit |
| OVA | Organic vapor analyzer |
| OVM | Organic vapor meter |
| PAH | Polycyclic aromatic hydrocarbons |
| PAPR | Powered air-purifying respirator |
| PCB | Polychlorinated biphenyl |
| PCE | Tetrachlorethene (perchlorethene) |
| PCP | Pentachlorophenol |
| PDS | Personnel decontamination station |
| PEL | Permissible exposure limit |
| PEST. | Pesticides |
| pH | Hydrogen ion concentration |
| PID | Photoionization detector |
| PNL | Pacific Northwest Laboratory |
| ppb | Parts per billion |
| ppbv | Parts per billion by volume |
| PPE | Personal protective equipment |
| ppm | Parts per million |
| PRC | PRC Consultants |
| PRG | Preliminary remediation goal |
| psi | Pounds per square inch |
| PSPL | Puget Sound Power and Light |
| PTL | Project team leader |
| PVC | Polyvinyl chloride |
| QAPjP | Quality Assurance Project Plan |
| QAPP | Quality Assurance Program Plan |
| QTRC | Quality Training and Resource Center |
| RAD | A unit for the measurement of radioactivity |
| RAM | Radioactive material |
| RAO | Remedial action objective |
| RBC | Red blood count |
| RCRA | Resource Conservation and Recovery Act |
| REL | Recommended exposure limit |
| REM | A measurement of radiation dose meaning roentgen equivalent man. |
| RfD | Reference dose |
| RHO | Rockwell Hanford Operations |
| Phase I RI | Phase I Remedial Investigation |
| Phase II RI | Phase II Remedial Investigation |
| RME | Reasonable maximum exposure |
| RV | Residual volume |

## ACRONYMS
## (Continued)

| | |
|---|---|
| RWP | Radiation Work Plan |
| SAR | Supplied-air respirator |
| SARA | Superfund Amendments and Reauthorization Act |
| SC | Specific conductance |
| SCBA | Self-contained breathing apparatus |
| SCS | United States Soil Conservation Service |
| SDG | Sample delivery group |
| SDWA | Safe Drinking Water Act |
| SF | Slope factor |
| SOP | Standard Operating Procedure |
| SPC | Siemens Power Corporation |
| SQL | Sample quantitation limit |
| STEL | Short-term exposure limit |
| SVOC | Semivolatile organic compound |
| ta | Ambient air temp. |
| ta adj | Adjusted ambient air temp. |
| TAL | Target analyte list |
| TBC | To be considered |
| TC-99 | Technetium-99 |
| TCA | 1,1,1, trichlorethane |
| TCE | Trichloroethene |
| TCL | Target compound list |
| TCLo | Lowest observed toxic concentration |
| TDLo | Lowest observed toxic dose |
| TDS | Total dissolved solids |
| TIC | Tentatively-identified compounds |
| TLC | Total lung capacity |
| TLV | Threshold Limit Value |
| TLV-C | Threshold limit value - ceiling |
| TLV-STEL | Threshold limit value - short-term exposure limit |
| TOC | Total organic carbon |
| TORR | A unit of pressure equal to 1 mm Hg |
| TOX | Total organic halogen |
| TPA | Tri-Party Agreement |
| TSCA | Toxic Substance Control Act |
| TSD | Treatment, storage, or disposal facility |
| TWA | Time-weight average |
| UCL | Upper confidence limit |
| UEL | Upper explosive limit |
| UFL | Upper flammable limit |
| UN | Unplanned and unauthorized release |
| USC | United States Code |
| USCG | United States Coast Guard |
| USDA | United States Department of Agriculture |

## ACRONYMS
## (Continued)

| | |
|---|---|
| USF&WS | United States Fish and Wildlife Service |
| USGS | United States Geological Survey |
| UTL | Upper tolerance limit |
| UV | Ultraviolet |
| VOC | Volatile organic compound |
| WAC | Washington Administrative Code |
| WDOE | Washington Department of Ecology |
| WHC | Westinghouse Hanford Company |
| WIDS | Waste Information Data System |
| WOE | Weight-of-evidence |
| WPPSS | Washington Public Power Supply System |
| WSGMA | Washington State Growth Management Act |
| WSU | Washington State University |

# EXECUTIVE SUMMARY

The final Remedial Investigation/Feasibility Study (RI/FS) - Environmental Assessment (EA) Report presents the results of field and analytical investigations conducted at the 1100-EM-1 Operable Unit at the U.S. Department of Energy (DOE) Hanford Reservation located near the city of Richland in Benton County, Washington. In addition, this report develops and evaluates a range of remedial technologies to address potential threats to human health and the environment.

This document conforms with current guidance for the conduct and preparation of RI and FS of hazardous waste sites pursuant to the National Oil and Hazard Substance Pollution Contingency Plan (NCP) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Also, National Environmental Policy Act (NEPA) values were integrated into the procedural and documentation requirements of the CERCLA process. Table ES-1 provides a directory identifying the location of specific NEPA values in the 1100-EM-1 documents. DOE has not yet approved this document for NEPA content.

Based on the referenced descriptions, there are no cultural resource areas such as archaeologic and/or historic sites; no endangered or threatened species and their critical habitats; nor environmentally important natural resource areas such as floodplains, wetlands, important farmlands, and/or aquifer recharge zones in the areas affected by any potential remedial actions. However, nothing in this or other documents prepared for the investigation, characterization, and assessment of the site are intended to present a statement on the legal applicability of NEPA actions under CERCLA.

This report fulfills DOE's agreed obligation milestone M-15-01B/C as mandated by the Hanford Federal Facility Agreement and Consent Order, commonly referred to as the Tri-Party Agreement.

The 1100-EM-1 Operable Unit is one of four operable units within the 1100 Area. The 1100 Area was placed on the National Priorities List in July 1989. Recent efforts on the part of DOE, the Environmental Protection Agency (EPA), and others to accelerate the characterization and remediation of the entire 1100 Area have led to the initiation of an expedited investigation of the 1100-EM-2, 1100-EM-3, and 1100-IU-1 Operable Units as well. It is anticipated that results of this investigation will be available by spring of 1993 and will be incorporated into this report as an addendum. The Record of Decision developed from this final RI/FS-EA report and addendum will then address the entire 1100 Area.

The bulk of this final RI/FS-EA report, however, focuses on individual subunit or waste disposal areas within the 1100-EM-1 Operable Unit. The three most significant subunits are the Discolored Soil Site, the Ephemeral Pool, and the Horn Rapids Landfill (HRL). Investigation and analysis of contamination, especially groundwater at HRL, has involved coordination with Siemens Power Corporation, who is independently investigating contaminated groundwater beneath its facility. The scope and scheduling of data collection activities for the entire RI has been subject to substantial negotiations based on concerns for and potential impacts to groundwater and the nearby North Richland well field.

Table ES-1. NEPA VALUE LOCATION DIRECTORY

| NEPA VALUE | 1100-EM-1 DOCUMENT | 1100-EM-1 DOCUMENT |
|---|---|---|
| | DOE/RL-90-18 | DOE/RL-92-67 |
| PHYSICAL CHARACTERISTICS | | |
| Operable Unit Vicinity | Section 3.1 | Section 1.4 |
| Meteorology | Section 3.2 | Section 2.1 |
| Hydrology | Section 3.3 | Section 2.3 |
| Geology | Section 3.4 | Section 2.2 |
| ECOLOGICAL CHARACTERISTICS | | |
| Human Ecology | Section 3.7.1 | |
| Land Use | Section 3.7.1.1 | |
| Water Use | Section 3.7.1.2 | |
| Cultural Resources | Section 3.7.1.3 | |
| Wildlife Ecology | Section 3.7.2 | Appendix L |
| Terrestrial Ecology | Section 3.7.2.1 | |
| Aquatic Ecology | Section 3.7.2.2 | |
| Sensitive Environments | Section 3.7.2.3 | |
| IMPACTS OF REMEDIAL ACTIONS | | |
| Compliance with Statutory Law | | Section 9.1.2, Appendix M |
| Short-Term Impacts | | Section 9.1.5 |
| Long-Term Impacts | | Section 9.1.3 |
| Impacts to Resources | | Section 9.1.6, Appendixes G & N |
| Effects to Public Health | | Sections 5.1, 5.2, 7.2, 9.2, Appendix K |
| AGENCIES/PERSONS CONTACTED | | Section 1.2 |
| LAND USE, POLICIES, CONTROLS | | Section 7.2.4, Appendix J |

This final RI/FS-EA report summarizes and evaluates the followup analysis of both the intrusive and nonintrusive activities at the several subunits. The majority of the soil analyses and geophysical surveys were completed in early phases of this investigatory effort. Important new activities completed in the later phases of the RI include the collection of six additional rounds of groundwater samples, and excavation of several exploratory trenches at HRL. Analytical results of these efforts are presented in the appendixes.

Three main areas of concern were identified. These are: 1) approximately 340 cubic meters of contaminated soil at the Discolored Soil Site [bis (2-ethylhexyl) phthalate (BEHP) concentration up to 25,000 parts per million (ppm)]; 2) approximately 250 cubic meters of polychlorinated biphenyls (PCB's) contaminated soil at the Ephemeral Pool (PCB $<$ 42 ppm); and 3) approximately 460 cubic meters of PCB contaminated soils (PCB $\leq$ 100 ppm), the presence of friable asbestos in surface soils, and overlapping groundwater plumes at HRL. The trichloroethene (TCE) (up to 110 ppm) plume is approximately 1.6 kilometers (km) (1 mile) long by 0.3 km (0.2 miles) wide. The nitrate (up to 63 ppm) plume is approximately 2.0 kilometers (km) (1.3 miles) long by 0.8 km (0.5 miles) wide. Contaminants noted at these areas exceed Federal and/or state environmental regulatory criteria, including the Safe Drinking Water Act (SDWA) and the State of Washington's Model Toxics Control Act (MTCA).

Potential risk to human health and the environment were assessed. Incremental cancer risks were evaluated for both industrial and residential scenarios. For industrial use, the risks were determined to be in the range of 2E-5 to 5E-5. For residential use the risks were determined to be in the range of 2E-3 to 3E-3. The 95 percent upper confidence level concentrations for contaminants were used to evaluate and develop the risk ranges.

Identification and analysis of mobility and migration of contaminants was evaluated through the use of both unsaturated and saturated zone flow and transport models. Results from the modelling and analysis activities suggest groundwater contaminants will migrate but attenuate to levels at or below regulatory concern within 12 to 22 years.

A wide range of treatment options were reviewed. These options were screened for technical and practical applicability, and evaluated for effectiveness. Viable and practicable process technologies were then assembled into groups of alternatives to provide for remediation of those contaminants exceeding criteria. Incorporated into the alternatives for the soil contaminants, were processes or technologies including, bioremediation, supercritical $CO_2$ extraction, excavation with offsite disposal, and incineration. For the groundwater contamination, processes involving , extraction, treatment, and infiltration were considered as was an approach relying upon natural attenuation. Additional consideration was given to costs. An estimate was developed for each alternative.

Finally, each of the alternatives that survived the review, screening, and evaluation, including a no action alternative, were considered against evaluation criteria pursuant to the NCP and CERCLA. These evaluations were completed to provide objective comparison of remedial alternatives for the 1100-EM-1 Operable Unit to allow for risk management decisions by the appropriate regulatory agencies.

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9 3 1 2 7 5 4 1 0 3 7

# 1.0 INTRODUCTION

The 1100 Area of the U.S. Department of Energy's (DOE) Hanford Reservation was placed on the National Priorities List (NPL) in July 1989, pursuant to the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, 42 U.S.C. 9601 *et seq*. Based on both documented and undocumented past practices at the 1100 Area, it was determined that pollutants were released to the environment and that those contaminants might present a danger to the public health, welfare, and the environment.

In anticipation of regulatory actions, the U.S. Department of Energy Field Office, Richland (DOE-RL) divided the 1100 Area into four operable units and initiated CERCLA response planning. DOE-RL, the U. S. Environmental Protection Agency (EPA), and the Washington Department of Ecology (Ecology) jointly assigned the 1100-EM-1 Operable Unit the highest priority, within both the 1100 Area and the Hanford Site as a whole.

The Hanford Federal Facility Agreement and Consent Order, also referred to as the Tri-Party Agreement (TPA) issued in May 1989, governs all CERCLA efforts at Hanford. The Remedial Investigation (RI)/Feasibility Study (FS) work plan (DOE/RL-88-23), mandated by the TPA, led to the first phase of the RI, which was completed in the summer of 1990. The Phase I RI report (DOE/RL-90-18) was issued in August 1990, followed by the Phase I and II FS Report (DOE/RL-90-32) issued in December 1990.

The Phase II RI was initiated with the publication of the draft RI Phase II Supplemental Work Plan (DOE/RL-90-37) in October 1990.

According to the TPA, the Phase II RI was due for completion in September 1991. Due to changes in the scope of remedial characterization activities, DOE, EPA, and Ecology renegotiated the Phase II RI milestone, M-15-01B, and combined it with the Phase III FS milestone M-15-01C, to become the combined RI Phase II/Phase III FS milestone M-15-01B/C with the new submittal date of December 1992. This Final RI/FS-EA Report for the 1100-EM-1 Operable Unit, Hanford has been prepared to meet the DOE's obligations for that combined milestone.

## 1.1 PURPOSE OF REPORT

The Phase I RI report concentrated on the initial site characterization for the 1100-EM-1 Operable Unit. This Final Report focuses on more complete site characterization as well as an additional investigation of problematic issues developed during Phase I. These issues included development of more detailed analysis of groundwater contamination, risk assessment and land use at and near the operable unit proper. A description of the activities undertaken is found in the Phase II RI Supplemental Work Plan (Revision II) DOE/RL-90-37. It is noteworthy that some tasks originally planned in early versions of the RI Phase II Work Plan have been deleted while other tasks have been modified or added. Discussions detailing these changes are found in the introduction to the RI Phase II Supplemental Work Plan (Revision II). This Final Report complements the initial characterization, providing a more definitive characterization of the nature and extent of the contaminants and threats to

threats to human health and the environment posed by contaminant releases from the Operable Unit.

This document also presents the Phase III FS results. Included are the review and analysis of appropriate remedial technologies and evaluation of several remedial options for the restoration of the 1100-EM-1 Operable Unit in accordance with pertinent regulatory criteria.

This document is intended to be a self-contained report. It is important to note, however, that to avoid unnecessary duplication, this document will refer frequently to previously published reports on the 1100 Area, especially the Phase I RI and the Phase I/II FS Reports noted above. It is the intent to provide only sufficient redevelopment of older material to allow the reader to follow the logic of the technical discussions presented in this report. Familiarity with previous investigative reports published on the 1100 Area, especially as presented in DOE/RL-90-18 and DOE/RL-90-32, is assumed for a critical review of the findings and recommendations presented in this document. As noted, this document reports primarily on those activities outlined in the Phase II RI Supplemental Work Plan, Revision II.

The TPA identifies a RI Phase II Report as a primary document. As such, regulatory agencies have the opportunity to comment, and the DOE the opportunity to respond to those comments within a certain time period. Revisions and/or modifications to this Final RI/FS-EA Report will follow guidelines as stated in paragraph 9.2.1 of the TPA.

## 1.2 NATIONAL ENVIRONMENTAL POLICY ACT

This report has also been prepared to address the requirements for an environmental assessment as defined in the Council on Environmental Quality regulations for implementing the procedural requirements of the National Environmental Policy Act (NEPA) and the DOE regulations and orders for implementing NEPA. These regulations and orders require an environmental assessment to provide brief discussions of the need for a proposed remedial measure, alternatives considered, the environmental impacts associated with each alternative, and a listing of agencies and persons contacted.

The regulatory authority for the proposed action is discussed above in section 1.0. Table ES-1 provides a directory identifying the location of specific NEPA values in the 1100-EM-1 Operable Unit documents. The affected environment is described in detail in sections 2, 3, and 4. The environmental and human health impacts and the rationale for requisite actions at the site are presented in sections 5 and 6. In sections 7, 8, and 9, remedial alternatives are developed, screened, and assessed. Effectiveness, implementability, and other criteria are also evaluated to determine if protection of human health and the environment are being addressed, and to meet the intent of regulatory criteria.

To date numerous agencies and persons have been contacted including: EPA Region 10, Hanford Project Office; Ecology, Hanford Facility Project Office; Siemens Power Corporation(SPC); the Department of the Interior (DOI); and the National Oceanic and

Atmospheric Administration (NOAA). Additional agencies and persons will be contacted through the public and regulatory review process for this document.

The DOE will use this Final RI/FS-EA Report to determine whether the potential environmental impacts are significant enough to warrant preparation of an Environmental Impact Statement (EIS). A Finding of No Significant Impact will be prepared and published by the DOE if it is determined that the potential environmental impacts from contaminant releases and/or proposed actions are not significant.

## 1.3 NATURAL RESOURCE TRUSTEES

CERCLA and the Clean Water Act (CWA), 33 U.S.C. 1251-1376, provide that natural resource trustees may assess damages to natural resources resulting from a discharge of oil or a release of a hazardous substance covered under CERCLA or the CWA and may seek to recover those damages. To this end, a Preliminary Natural Resource Survey was completed by NOAA.

According to the NCP [section 300.160 (a)(3)] the lead agency shall make available to the trustees of affected natural resources information and documentation that can assist the trustees in the determination of actual or potential natural resource injuries. This RI/FS-EA with its Ecological Assessment and analysis of alternatives is to be used by DOE in lieu of a Preassessment Screen for Natural Resource Damages Assessment (43 CFR 11).

The trustees for natural resources are NOAA, DOE, and the State of Washington. Potential trustees include the following Indian Tribes: Confederated Tribes and Bands of the Yakima Indian Nation, the Nez Perce Indian Tribe , the Confederated Tribes of the Umatilla Indian Reservation, and the Confederated Tribes of Warm Springs Reservation. Copies of this report are to be made available to the trustees and potential trustees for Natural Resources.

## 1.4 REPORT ORGANIZATION

This Final RI/FS-EA Report for the 1100-EM-1 Operable Unit is organized in a format comparable to that recommended by EPA (1988). This document does, however, combine the RI/FS portions under a single cover. The intent is to minimize the repetition of background materials without sacrificing the technical detail necessary to make an informed decision for appropriate remediation of the site. This subsection assists the reader in understanding the presentation format and in locating information of specific interest. This Final RI/FS-EA Report, consists of eight sections in addition to this introduction, the bibliography, and associated appendixes.

- Section 1: Provides a concise site description, general history, and background of the 1100-EM-1 Operable Unit.

- Section 2: Presents a summary of the physical characteristics of the 1100-EM-1 Operable Unit.

- Section 3: Summarizes the data collection activities performed as documented in the RI/FS work plans.

- Section 4: Discusses the nature and extent of contamination at the site.

- Section 5: Presents contaminants of concern along with summaries of human health baseline risk assessments for industrial and residential scenarios and ecological risk assessments posed by hazardous substances released from 1100-EM-1 Operable Unit.

- Section 6: Analyzes the environmental fate and transport of contaminants at the operable unit. Potential operable unit contaminant migration pathways are documented, contaminant characteristics relevant to migration are assessed, and transport modeling is performed to estimate current and future contaminant concentrations in each environmental medium.

- Section 7: Identifies remedial action objectives, general response actions, and screens and evaluates remedial technologies and process options.

- Section 8: Develops and screens remedial alternatives.

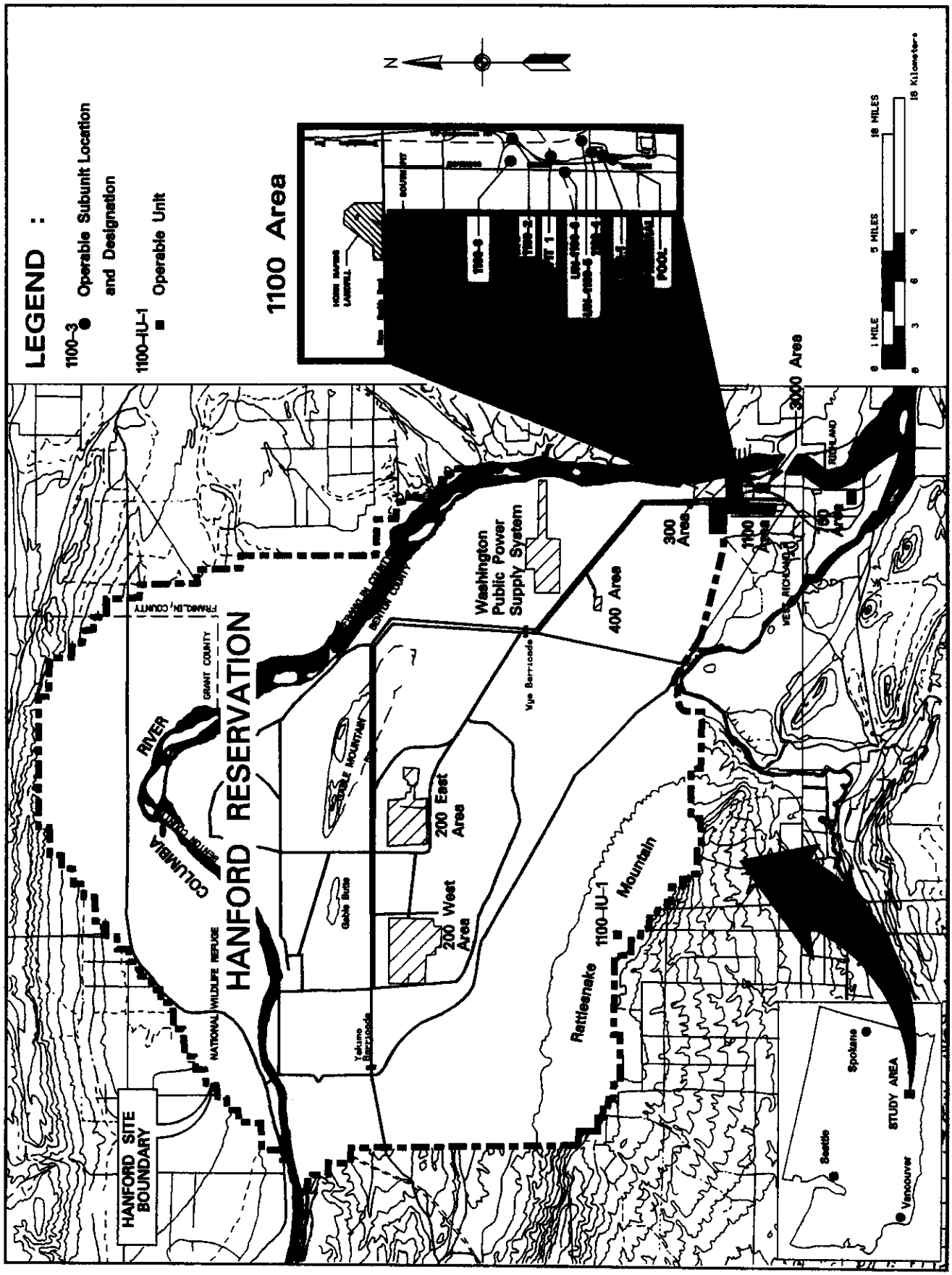
- Section 9: Provides comparison of the alternatives against regulatory evaluation criteria.

- Section 10: Presents references cited in the body of the text.

- Appendixes: Present letters, memoranda, technical data, concise summaries of validated analytical data, and details of technical analyses needed to confirm the findings contained within the text.

## 1.5 1100-EM-1 OPERABLE UNIT BACKGROUND

The 1100 Area is located in the southern-most portion of the Hanford Site, adjacent to the city of Richland in Benton County, Washington (see figure 1-1). As defined by EPA for purposes of site designation, the 1100 Area includes portions of the 600, 700, and 3000 Areas. The 600 Area nominally includes all land within the Hanford site not otherwise within the 100, 200, 300, 400, or 1100 Areas and consists mostly of undeveloped land and some relatively remote facilities. The 700 Area is primarily comprised of administrative buildings and is located outside of the Hanford Reservation proper in downtown Richland; it is centered around the Federal Building on Jadwin Avenue in Richland. The 3000 Area is located outside of, but adjacent to, the Hanford Site; it also is comprised mostly of administrative buildings, but includes some technical support and warehouse storage facilities as well.




Hanford Reservation Location Map

Fig. 1-1

The 1100 Area NPL Site is currently divided into four operable units. The 1100-EM-1, 1100-EM-2, and 1100-EM-3 Operable Units, are shown in figure 1-2. The 1100-IU-1 Operable Unit is located 24 kilometers (km) west of the 1100 Area near Rattlesnake Mountain (see figure 1-1).

Each operable unit is designated with a three-part code. The first part indicates the NPL site affiliation, in this case the 1100 Area NPL Site. The second part provides a shorthand description of the operable unit type: EM indicates "equipment maintenance;" IU indicates "isolated unit." The final portion of the code simply provides a unique numeric designator for each operable unit.

The 1100-EM-1 and 1100-EM-2 Operable Units are comprised of different sets of waste management units that are, for the most part, located within the 1100 Area proper.

The 1100-EM-3 Operable Unit contains the 3000 Area waste management units and is physically separated from the remainder of the 1100 Area by a major thoroughfare, Stevens Drive.

Within the 1100-EM-1 Operable Unit are numerous individual sites or waste disposal areas that are identified as subunits (see figure 1-2). These subunits have been designated with descriptive names (*e.g.*, The Discolored Soil Site) and/or a simple alphanumeric code (*e.g.*, UN-1100-6). This nomenclature will be followed in this report.

Recent efforts on the part of DOE, EPA, and others to expedite the remediation and eventual delisting of the entire 1100 Area have led to the initiation of an expedited investigation of the 1100-EM-2, 1100-EM-3, and the 1100-IU-1 Operable Units. It is anticipated that this investigation will be completed in the spring of 1993 with the results presented as an addendum to this final RI/FS-EA Report.

The Record of Decision developed from this report and addendum is intended to address the entire 1100 Area, a considerable expansion of the original focus on the 1100-EM-1 Operable Unit. This accelerated schedule is intended to provide for more effective utilization of resources.

### 1.5.1 Nearby Properties and Facilities

The North Richland well field has been of particular interest during the course of the 1100-EM-1 investigation. Located 0.8 km east of the 1171 building in the 1100 Area, the well field is still used to supplement city of Richland water supplies (see figure 1-2). Columbia River water is pumped to the well field and allowed to percolate through the soil. This procedure reduces turbidity and improves water quality for industrial and residential usage. Initial concerns focussed on the potential impact of migration of contaminants from the 1100 Area to the well field. The findings of the RI indicate there is no reasonable scenario under which contaminants in groundwater in the 1100-EM-1 Operable Unit would impact the city well fields.

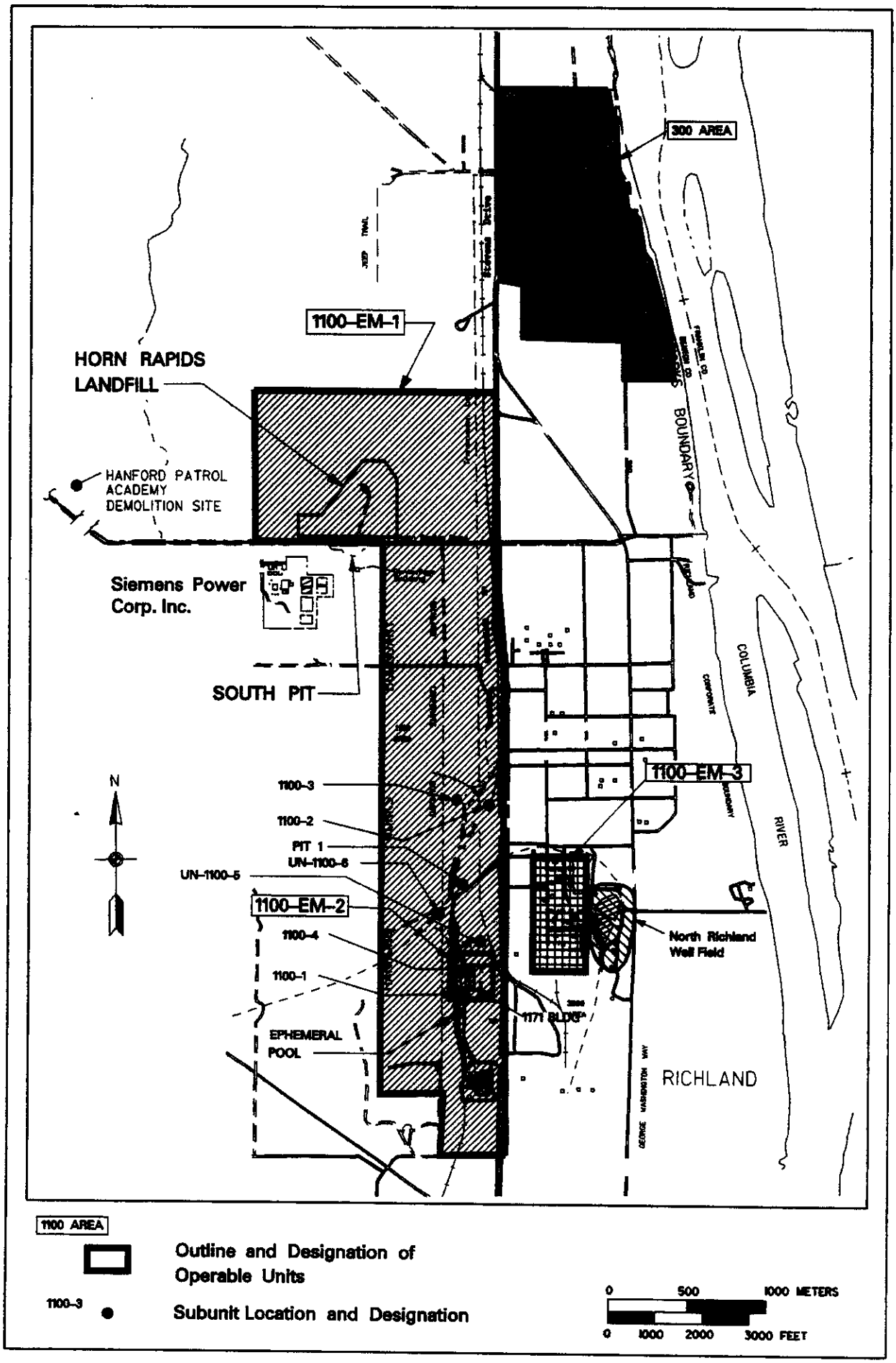



Figure 1-2. 1100 Area Operable Units



9 3 1 2 7 4 0 0 9 4

During the course of this RI for the 1100-EM-1 Operable Unit, agreements were made between DOE, EPA, Ecology, and others to investigate the groundwater at the Horn Rapids Landfill (HRL) and adjacent properties. Currently, SPC owns property which abuts the 1100 Area, specifically near the HRL. The owner and/or corporate entity charged with this property has undergone several name changes even during the course of this investigation. Previous designations include Exxon Nuclear Fuels, Advanced Nuclear Fuels, Siemens Nuclear Power and, as noted above, SPC.

The scope and scheduling of RI activities has been influenced by the participation of the SPC. Coordination with SPC on groundwater data collection and distribution has been ongoing since early 1990. In March 1991, DOE formally briefed SPC on the DOE 1100-EM-1 Operable Unit investigation. SPC's participation in the DOE investigation has continued since this meeting. However, SPC is pursuing their own investigation of groundwater underlying their facility and potential sources of contamination as a separate investigation from DOE's activities at the HRL and 1100-EM-1.

Both DOE and SPC will consider and evaluate data generated by the other party's investigation. Data, as received from SPC, is included in this document, where appropriate.

### 1.5.2 1100-EM-1 Operable Unit Description

The 1100 Area is the central warehousing, vehicle maintenance, and transportation distribution center for the entire Hanford site. A wide range of materials and potential waste products were routinely used at and near the 1100 Area. Table 1-1 lists potential waste products either presumed or known to have been used at the 1100-EM-1 Operable Unit. Known toxic or chemical constituents of these products are presented as well.

The 1100-EM-1 Operable Unit has been divided into several subunits based on the nature of previous use and potential contaminants. The subunits are:

- 1100-1 (The Battery Acid Pit): An unlined dry sump, or french drain, used for disposal of waste acid from vehicle batteries. Historical documents record an estimated 57,000 liters (L) [15,000 gallons (gal)] of battery acid wastes may have been disposed of between 1954 and 1977.

- 1100-2 (The Paint and Solvent Pit): A former sand and gravel pit subsequently used for the disposal of construction debris and reportedly, waste paints, thinners and solvents.

- 1100-3 (The Antifreeze and Degreaser Pit): A former sand and gravel pit used for the disposal of construction debris along with potential disposal of antifreeze and degreasing solutions.

- 1100-4 (The Antifreeze Tank Site): A former underground storage tank used for the disposal of waste vehicle antifreeze. This tank was emptied in 1986, cleaned, and removed due to suspected leakage.

## Table 1-1. Toxic Constituents in 1100-EM-1 Operable Unit Potential Waste Products

| Waste Product | Toxic Element |
|---|---|
| antifreeze | ethylene glycol, propylene glycol |
| automotive cleaners[1] | cresol, ethylene dichloride, sodium chromate, petroleum distillates, 1,1,1-trichloroethane |
| battery acid[2] | lead, sulfuric acid, arsenic, cadmium |
| contact cement[1] | toluene, hexane, methyl ethyl ketone, trichloroethane |
| degreasers | 1,1,1-trichloroethane, trichloroethane |
| gasoline | $C_3$-$C_{12}$ aliphatic hydrocarbons, xylene, benzene |
| hydraulic oils | PCB's |
| industrial lubricants[1] | trichloroethane, lead naphthenate |
| lacquer thinners[1] | ethyl acetate, butyl acetate, butyl alcohol, toluene, xylene, aliphatic hydrocarbons |
| metal cleaners[1] | potassium carbonate, trisodium phosphate, tetrachloroethane, trichloroethane, kerosene[b], chromic acid |
| paints, latex[3] | ethylene glycol, zinc |
| paints, oil-based[4] | linseed oil[c], mineral spirits[d], lead, zinc |
| paints, other[3,4] | toluene, methyl ethyl ketone, chromium, zinc, lead |
| paint removers | dichloromethane, methyl ethyl ketone |
| paint thinners | mineral spirits[d] |
| penetrating oils[1] | kerosene[b], xylene, carbon tetrachloride |
| roof patching sealants[1] | kerosene[b], gasoline, mineral spirits[d] |
| solvents | acetone, carbon tetrachloride, gum turpentine, methanol, 1,1,1-trichloroethane, stoddard solvent[e] |
| stains[1] | mineral spirits[d], aniline dyes |
| undercoating material[1] | aromatic hydrocarbons, aliphatic hydrocarbons, phenolic resins, methyl isobutyl ketone |
| vinyl adhesives[1] | benzene, toluene |
| waste oil[5] | $C_{10}$-$C_{16}$ alkanes, toluene, 1,1,1-trichloroethane, polycyclic aromatic hydrocarbons (PAH's) |

[a] Petroleum distillates are hydrocarbon fractions such as gasoline and kerosene.
[b] Kerosene contains aromatic hydrocarbons and $C_5$-$C_6$ aliphatic hydrocarbons.
[c] Linseed oil contains flaxseed oil and additives such as lead, manganese, and cobalt.
[d] Mineral spirits contains benzene, toluene, hexane, and cyclohexane.
[e] Stoddard solvent contains C9-C12 aliphatic hydrocarbons, naphthalene, and aromatic hydrocarbons.

[1] Gosselin et al. 1984.
[2] Eckroth 1981.
[3] Ash and Ash 1978.
[4] Myers and Long 1975.
[5] EPA 1974.

- UN-1100-5 (The Radiation Contamination Incident): On August 24, 1962, radioactive contamination was discovered on an incoming 1,452 kilograms (kg) (16-ton) shipment cask containing irradiated metal specimens from a facility at the Idaho National Engineering Laboratory. The truck trailer on which the contamination was detected, had offloaded other cargo at another building and was parked in the parking lot northwest of the 1171 Building when the contamination was detected.

- UN-1100-6 (The Discolored Soil Site): The location of an unplanned release onto the ground surface involving an unknown quantity of organic waste liquids.

- The HRL: A solid waste facility used primarily for the disposal of office and construction waste, asbestos, sewage sludge, fly ash, and reportedly, numerous drums of unidentified organic liquids. Classified documents were also incinerated at a burn cage located at the northern edge of the landfill.

- The Ephemeral Pool: An elongate, man-made depression into which parking area runoff water collects and evaporates leaving behind contaminant residues.

- Pit 1: An active gravel/borrow pit north of the 1171 building.

- The South Pit: A "disturbed" area on the south side of Horn Rapids Road, across from HRL. Scattered debris of unknown origin has been found on the ground surface.

- The Hanford Patrol Academy Demolition Site: An ash pit used for the disposal of unstable chemicals by detonation, is located approximately 2 kilometers (km) [1 mile (mi)] to the west of HRL. This demolition site is identified in WHC (1989a) as a potential Resource Conservation and Recovery Act (RCRA), 42 USC 6901 *et seq.*, treatment, storage, or disposal (TSD) waste management unit.

In all of these areas, a number of distinct surveys and/or investigations have been performed. Several of the older surveys and analytical results have been presented in previously published work plans and/or reports and are not repeated here. During the efforts associated with this final phase of the investigation, some of the work was focussed on the particular uses and past practices of a specific subunit, while other studies concentrated on operable unit wide containment issues. Before providing a review of the investigations, surveys and studies undertaken at the entire operable unit, a brief review of the physical characteristics of the 1100 Area is presented in section 2.

# 2.0 PHYSICAL CHARACTERISTICS OF THE 1100-EM-1 OPERABLE UNIT

This chapter provides a summary of important physical parameters and processes that have contributed to the conditions existing at each of the various 1100-EM-1 Operable Unit subunits. Previous reports provided detailed information on these subunits (DOE/RL-90-18). Only those salient items that provide immediate support to the Phase II RI presentation will be repeated in the development of the hypotheses and conclusions made in this document.

## 2.1 METEOROLOGY

Meteorological data is summarized in appendix D of DOE/RL-90-18. Data was obtained from historical records gathered at the Hanford Meteorological Station (HMS), the Hanford 300 Area automated meteorological station, and the Richland, Washington Airport.

The climate of the Hanford Site has been classified as mid-latitude semiarid or mid-latitude desert, depending on the classification scheme employed. Summers are warm and dry with abundant sunshine. Winters are cool with occasional precipitation (Hulstrom, 1992). Average high air temperatures at the HMS reach 37°C (100°F) during the summer, and drop to lows of -5°C (23°F) in winter. Historical extremes are recorded as 46°C (115°F) and -29°C (-20°F). Annual highs are generally reached during July and lows during January.

Rain is the most common form of precipitation, but snowfalls occur regularly during the winter. Hail may fall during the summer thunderstorm season. The greatest volume of precipitation occurs in the winter, usually between the months of October and February. July is the driest month, averaging only 0.5 centimeters (cm) [0.2 inches (in)] of rainfall. The average annual precipitation falling at the Hanford Site is 15.9 cm (6.3 in) (Stone *et. al.*, 1983). This value was derived from HMS data gathered between the years 1912 through 1980.

Windblown dust is commonly associated with strong winds that regularly occur at the Hanford Site. Wind speeds average 10 to 12 km per hour (6 to 7 mi/h) in winter and 13 to 17 km/h (8 to 10 mi/h) during the summer months. The strongest observed winds have speeds measuring up to 130 km/h (80 mi/h). Blowing dust originating on the site itself has been observed at wind speeds greater than 32 km/h (19 mi/h). Dust entrained offsite and carried onto Hanford has been observed at wind speeds as low as 7 km/h (4 mi/h).

The mean annual rate of potential evapotranspiration for the region has been estimated at approximately 74 cm (29 in). The estimated rate of mean annual actual evapotranspiration is approximately 18 cm (7 in) (U.S. Weather Bureau and Soil Conservation Service, 1962). The rate of annual actual evapotranspiration, then, typically approximates the rate of annual precipitation, which is not uncommon for semiarid areas.

## 2.2 GEOLOGY

Regional and local geologic settings are summarized in the following paragraphs. The discussion of local geology emphasizes topics that may have direct bearing on the descriptions of contaminant transport in the environment and on the development of remedial alternatives as presented later in this document. An exhaustive presentation of the regional and local geology can be found in DOE/RL-90-18, and Gaylord and Poeter, 1991.

### 2.2.1 Regional Geology

The Hanford Site is located in the Pasco Basin, a topographic and structural basin situated in the northern portion of the Columbia Plateau. The plateau is divided into three general structural subprovinces: the Blue Mountains; the Palouse; and, the Yakima Fold Belt (Tolan and Reidel, 1989). The Hanford Site is located near the junction of the Yakima Fold Belt and the Palouse subprovinces. A generalized geologic structural map is included as figure 2-1.

The 1100 Area is located along the southeastern margin of the Hanford Site, adjacent to the Columbia River. This area is similar to much of the rest of the site, which consists of a two-tiered stratigraphy of basalt/basalt-related volcanic and sedimentary rocks and suprabasalt sedimentary deposits. The principal units at the Hanford Site are (from oldest to youngest): Miocene Columbia River Basalt Group (CRBG); Miocene Ellensburg formation; Miocene-Pliocene Ringold Formation; the informally defined Plio-Pleistocene clastic sedimentary unit; Pleistocene early "Palouse" soil; Pleistocene pre-Missoula gravels; the Pleistocene Hanford formation; and, Holocene eolian surficial deposits. The CRBG and Ellensburg formation are included within the basalt/basalt-related deposits while all others are included within suprabasalt deposits.

Of the regional stratigraphic units listed above, only the CRBG, the Ringold Formation, the Hanford formation, and the eolian surficial deposits have been identified within the 1100-EM-1 Operable Unit.

### 2.2.2 Local Geology

The interpretation and description of the geology of the 1100-EM-1 Operable Unit is based primarily on previous studies in adjacent areas and on geologic logs of monitoring wells installed during both phases of the RI. Selected geohydrologic and groundwater quality studies of the 300 Area (Lindberg and Bond, 1979; Schalla, *et al.*, 1988; Gaylord and Poeter, 1991) provide descriptions of the suprabasalt stratigraphic units within approximately 1.6 km (1 mi) of HRL. When available, geologic logs for selected previously-existing wells located near the Operable Unit (Newcomb, *et al.*, 1972; Summers and Schwab, 1977; Fecht and Lillie, 1982; CWC-HDR, Inc., 1988; Geology Section, WHC [Technical Memo 81232-90-042 to S. Clark, WHC] May 11, 1990) were also consulted.

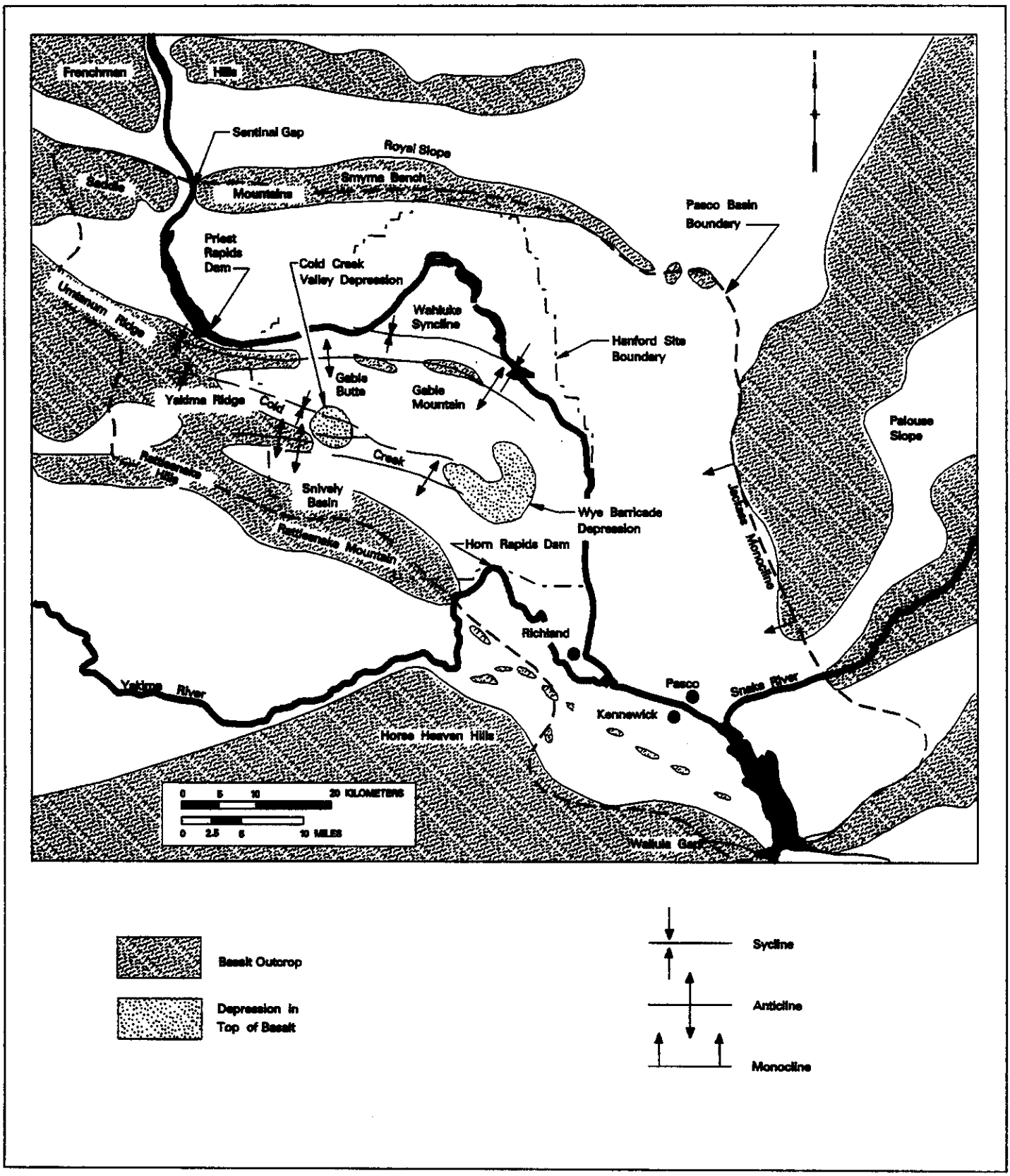



Figure 2-1. Geologic Structures of the Pasco Basin and the Hanford Site.

**2.2.2.1. Structural Geology and Tectonic Setting.** The Columbia Plateau is a part of the North American continental plate and is situated in the back-arc east of the Cascade Range. The plateau is bounded on the north by the Okanogan Highlands, on the east by the Northern Rocky Mountains and Idaho Batholith, and on the south by the High Lava Plains and Snake River Plain.

The Columbia River Basalts within the vicinity of 1100-EM-1, as interpreted by Myers and Price (1979), are folded into a broad, gentle, northwest-trending syncline; the Pasco syncline. The 1100-EM-1 subunits are located near the axis of this syncline, on its gently-sloping western flank. The Pasco syncline slopes gently northwestward toward a flat structural low referred to as the Wye Barricade depression (DOE/RL-88-23), where it loses definition. The geologic structure of the Ringold and Hanford formations has not been identified in the area of the 1100-EM-1 Operable Unit.

**2.2.2.2 Local Stratigraphy.** A generalized stratigraphic column for the 1100-EM-1 Operable Unit is shown in figure 2-2. Information obtained from the drilling of 22 soil borings and 23 groundwater monitoring wells during the 1100-EM-1 Operable Unit RI, and five groundwater monitoring wells installed between the 1100 Area and the North Richland well field in 1988 (Bryce and Goodwin, 1989) was used to develop the idealized stratigraphic column depicted.

The shallow depth of these borings and wells pose substantial limitations on the reliability of the estimates for the actual depth, thickness, and characteristics of the lower portion of the Ringold Formation beneath the 1100-EM-1 Operable Unit. None of the borings extended through the suprabasalt strata to bedrock. The interpretation of the lower stratigraphic units on figure 2-2 is based primarily on a single log for a nearby, previously-existing well that extends to the basalt; 10/28-10G1. This log is published in Newcomb, *et al.*, 1972, and DOE/RL-90-18.

A cross section identification map is provided in figure 2-3. Cross section A-A" (which runs north-south from the HRL to south of the 1171 Building) is shown in figure 2-4. Three east-west cross sections are also provided: B-B" (through HRL) in figure 2-5, and C-C" (near the 1100-2 and 1100-3 subunits) and D-D" (near the 1100-1 and 1100-4 subunits) in figure 2-6.

Geologic logs for the Phase II monitoring well boreholes are included in appendix A. It should be noted that the lithologies shown in the borehole logs are based on visual field estimates of grain-size distribution using the Wentworth grain-size scale, as modified by Folk (1954). Laboratory grain size analyses were not performed during the Phase II investigations. However, comparisons of Phase II field classifications with Phase I laboratory classifications of soil types encountered during monitoring well installations revealed no unusual divergence.

Tables 2-1 through 2-4 list the depths and elevations of the stratigraphic units identified in the borings advanced and wells constructed during both phases of the 1100-EM-1 RI. Locations of Phase I and Phase II monitoring wells are presented on figures 2-7 and 2-8, respectively.

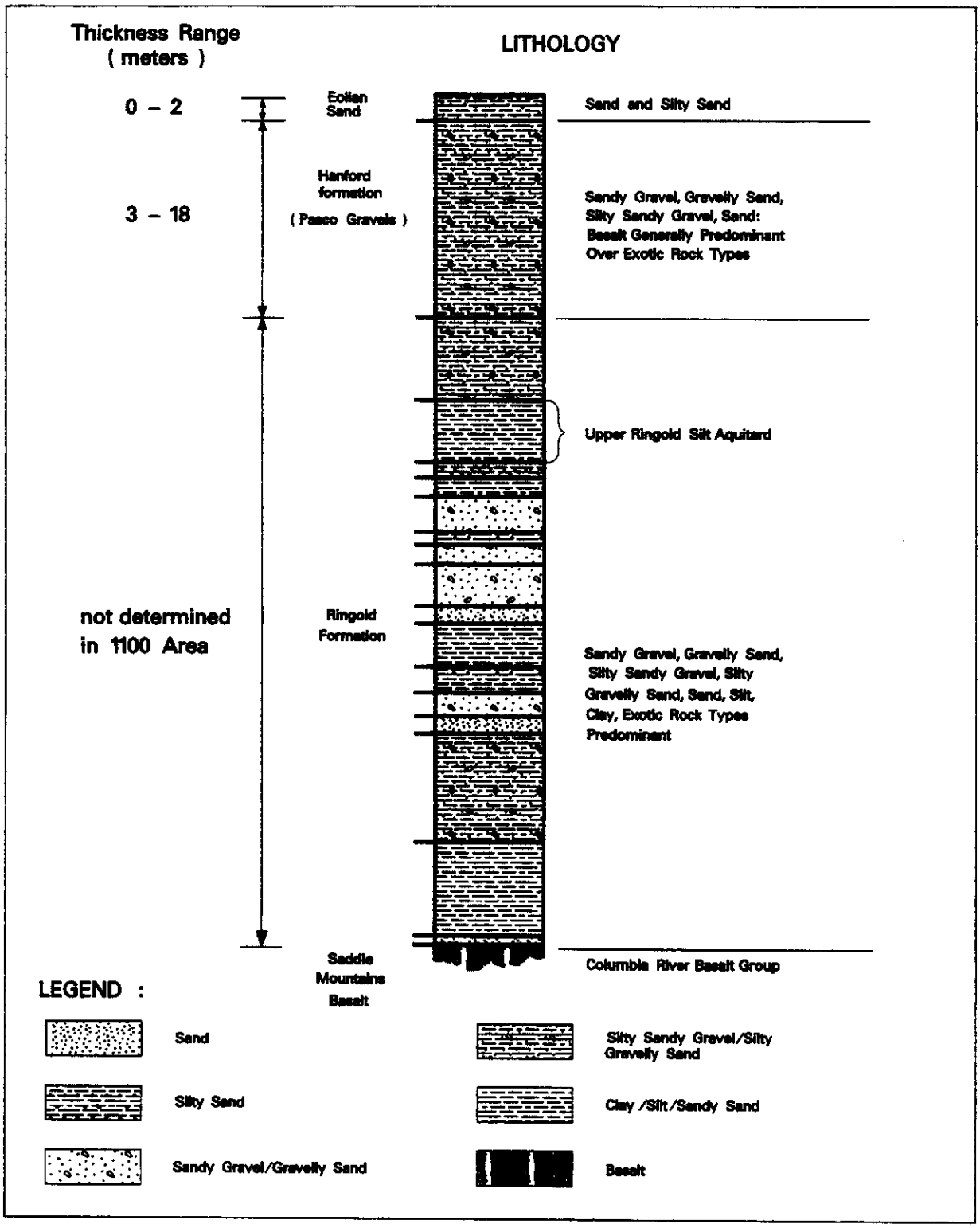
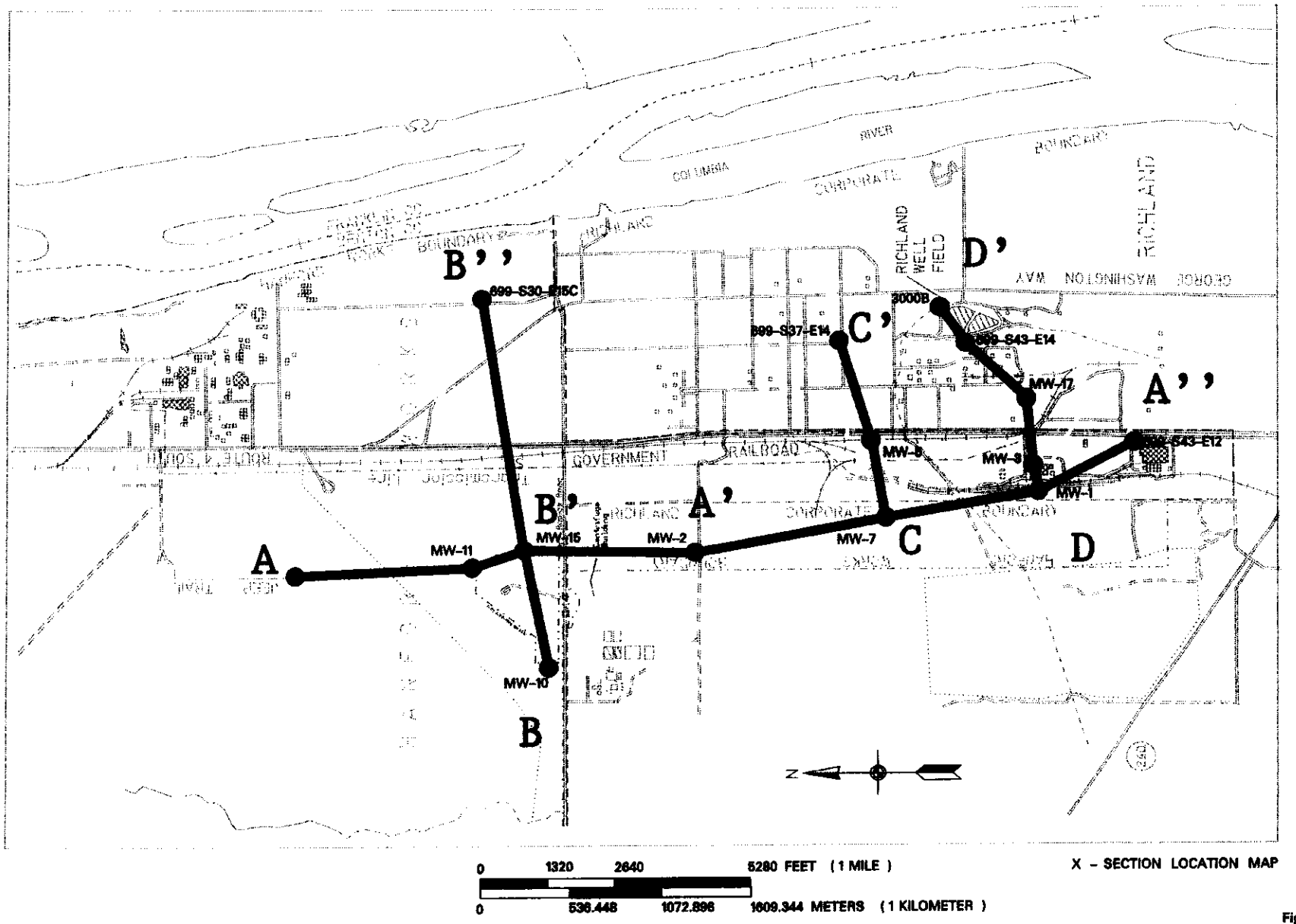
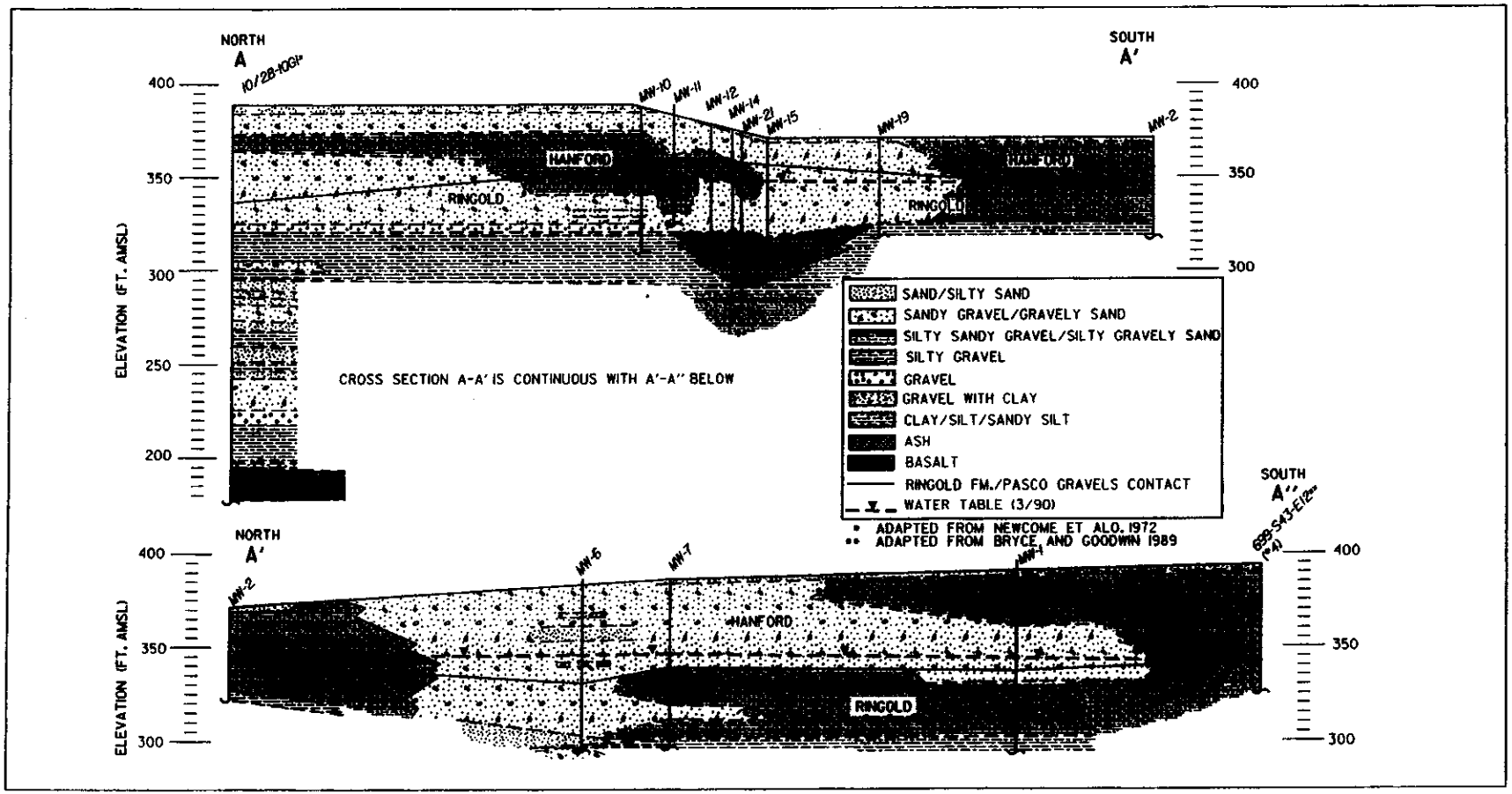



Figure 2–2. Generalized Suprabasalt Stratigraphic Column for the 1100–EM–1 Operable Unit



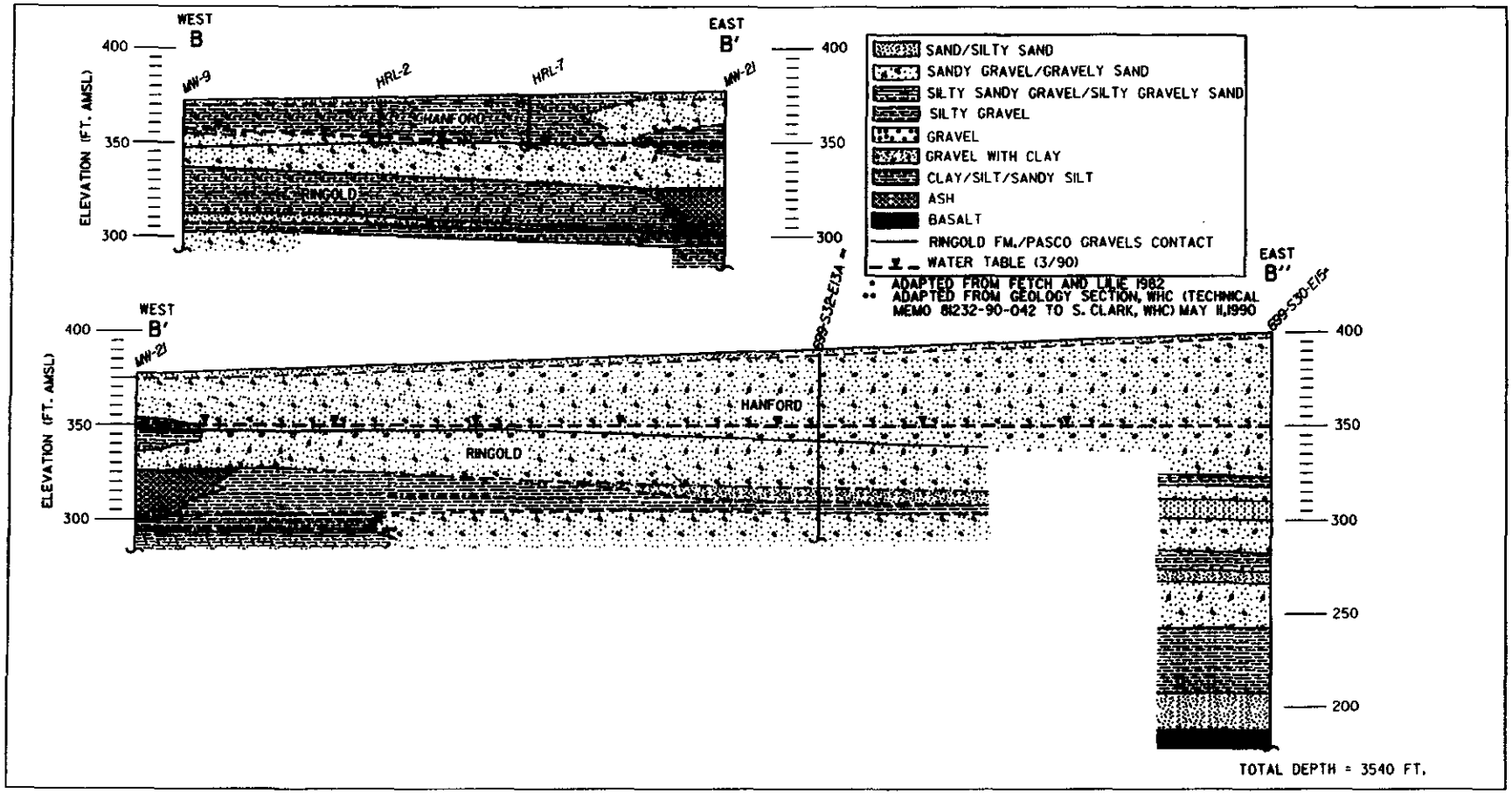

X - SECTION LOCATION MAP

Fig. 2-3




CROSS SECTION A-A''

Figure 2-4




CROSS SECTION B-B''

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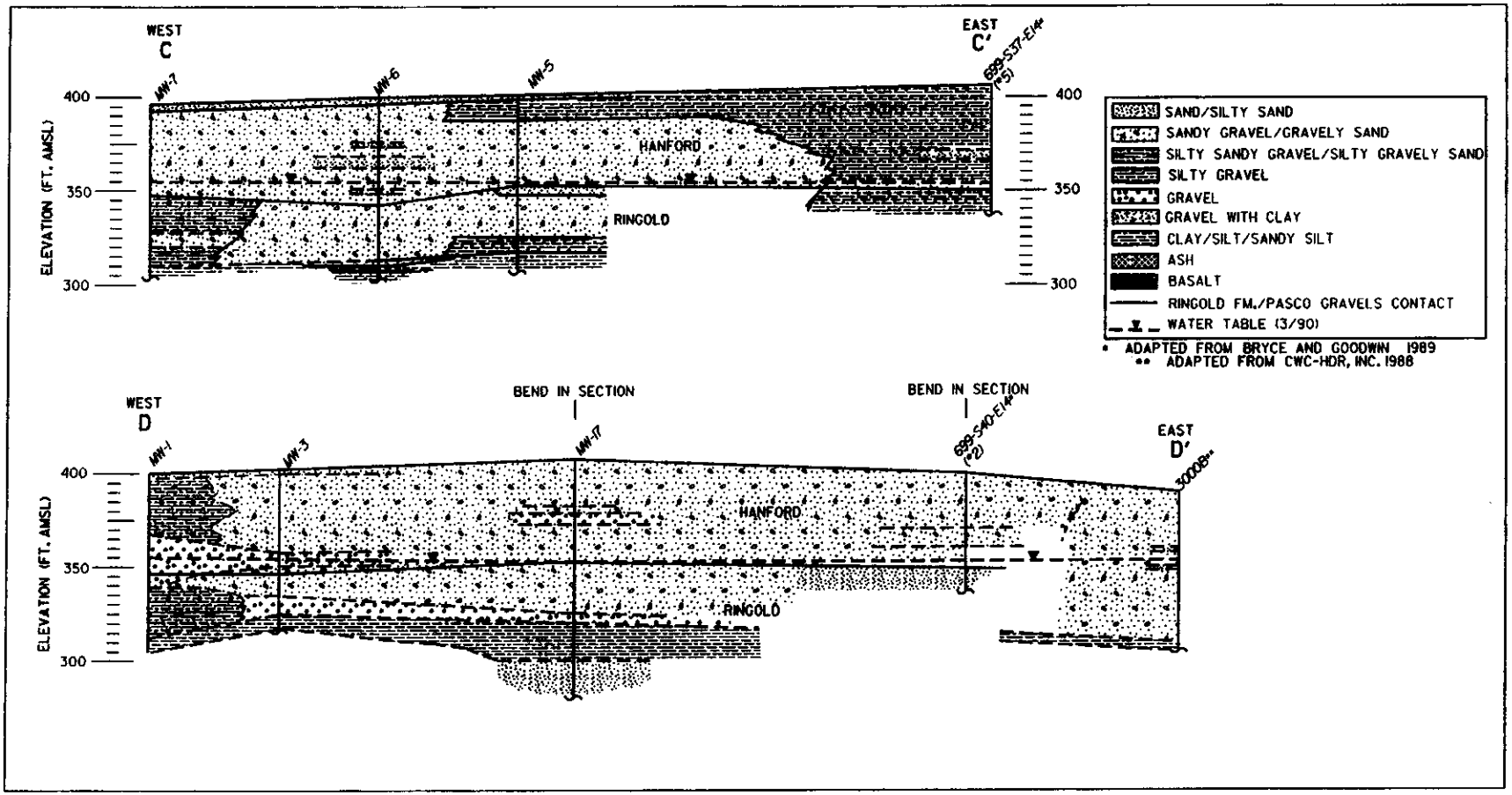
Figure 2-5




CROSS SECTION C-C ' AND D-D '

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Figure 2-6

TABLE 2-1: Stratigraphic Data from Borehole Logs
Battery Acid Pit (1100-1), Antifreeze Tank Site (1100-4), Discolored Soil Site (UN-1100-6), and Ephemeral Pool

| BORING | TOTAL DEPTH m(ft) | BORING ELEV. m(ft) | FILL THICKNESS m(ft) | EOLIAN SAND THICKNESS m(ft) | HANFORD FORMATION THICKNESS m(ft) | DEPTH TO TOP OF RINGOLD FM. m(ft) | TOP OF RINGOLD ELEV. m(ft) | DEPTH TO TOP OF SILT AQUITARD m(ft) | TOP OF SILT AQUITARD ELEV. m(ft) |
|---|---|---|---|---|---|---|---|---|---|
| Vadose Background | | | | | | | | | |
| BAP-2 | 13.88 (45.55) | 121.21 (397.66) | N/A | 0.30 (1.0) | Base of Eolian Sand to EOH | ND | ND | ND | ND |
| Vadose Zone Boring | | | | | | | | | |
| BAP-1 | 6.10 (20.0) | 122.66 (402.42) | 1.83 (6.0) | none | Base of Fill to EOH | ND | ND | ND | ND |
| ATS-1C | 6.71 (22.0) | Not Available | 3.75 * (12.3*) | none | Base of Fill to EOH | ND | ND | ND | ND |
| Monitoring Wells | | | | | | | | | |
| MW-1 | 28.65 (94.0) | 121.44 (398.43) | N/A | 0.58 (1.9) | 16.03 (52.6) | 16.61 (54.5) | 104.83 (343.9) | 26.97 (88.5) | 94.47 (309.9) |
| MW-3 | 25.52 (83.74) | 122.53 (402.0) | N/A | none | 18.33 (60.14) | 18.44 (60.5) | 104.09 (341.5) | 23.96 (78.6) | 98.57 (323.4) |
| MW-17 | 38.10 (125.0) | 124.24 (407.62) | N/A | none | 17.07 (56.0) | 17.07 (56.0) | 107.17 (351.6) | 27.58 (90.5) | 96.66 (317.1) |

NOTES:
1. EOH - End of Hole.
2. N/A - Not Applicable.
3. ND - No Data due to Shallow Depth of Boring.
4. * - 0.11 m (0.35 ft) of Blacktop Asphalt at Ground Surface.

TABLE 2-2: Stratigraphic Data from Borehole Logs
Paint and Solvent Pit (1100-2)

| BORING | TOTAL DEPTH m(ft) | BORING ELEV. m(ft) | FILL THICKNESS m(ft) | EOLIAN SAND THICKNESS m(ft) | HANFORD FORMATION THICKNESS m(ft) | DEPTH TO TOP OF RINGOLD FM. m(ft) | TOP OF RINGOLD ELEV. m(ft) | DEPTH TO TOP OF SILT AQUITARD m(ft) | TOP OF SILT AQUITARD ELEV. m(ft) |
|---|---|---|---|---|---|---|---|---|---|
| Vadose Background | | | | | | | | | |
| DP-7 | 12.50 (41.0) | 119.65 (392.54) | N/A | 0.46 (1.5) | Base of Eolian Sand to EOH | ND | ND | ND | ND |
| Vadose Zone Borings | | | | | | | | | |
| DP-4 | 6.10 (20.0) | 120.15 (394.19) | 2.16 (7.1) | none | Base of Fill to EOH | ND | ND | ND | ND |
| DP-5 | 6.10 (20.0) | 120.22 (394.43) | 4.88 (16.0) | none | Base of Fill to EOH | ND | ND | ND | ND |
| DP-6 | 6.10 (20.0) | 120.31 (394.71) | not identified | none | To EOH | ND | ND | ND | ND |
| DP-9 | 12.13 (39.8) | 119.68 (392.65) | 1.22 (4.0) | none | 10.82 (35.5) | 12.04 (39.5) | 107.64 (353.15) | ND | ND |
| Monitoring Wells | | | | | | | | | |
| MW-4 | 20.51 (67.29) | 122.35 (401.40) | N/A | 1.07 (3.5) | 15.09 (49.5) | 16.15 (53.0) | 106.19 (348.4) | ND | ND |
| MW-5 | 27.02 (88.65) | 122.40 (401.57) | N/A | 0.91 (3.0) | 14.94 (49.0) | 15.85 (52.0) | 106.55 (349.6) | 26.49 (86.9) | 95.91 (314.7) |
| MW-6 | 27.74 (91.0) | 120.70 (396.0) | N/A | 0.55 (1.8) | 16.98 (55.7) | 17.53 (57.5) | 103.17 (338.5) | 25.9 (85.0) | 94.79 (311.0) |
| MW-7 | 27.22 (89.3) | 120.46 (395.20) | N/A | 1.14 (3.75) | 13.91 (45.7) | 15.06 (49.4) | 105.40 (345.8) | 26.06 (85.5) | 94.40 (309.7) |
| MW-18 | 21.06 (69.1) | 121.84 (399.74) | N/A | 0.61 (2.0) | 14.48 (47.5) | 15.09 (49.5) | 106.75 (350.24) | ND | ND |

NOTES:
1. EOH – End of Hole.
2. N/A – Not Applicable.
3. ND – No Data due to Shallow Depth of Boring.

TABLE 2-3: Stratigraphic Data from Borehole Logs
Antifreeze and Degreaser Pit (1100-3)

| BORING | TOTAL DEPTH m(ft) | BORING ELEV. m(ft) | FILL THICKNESS m(ft) | EOLIAN SAND THICKNESS m(ft) | HANFORD FORMATION THICKNESS m(ft) | DEPTH TO TOP OF RINGOLD FM. m(ft) | TOP OF RINGOLD ELEV. m(ft) | DEPTH TO TOP OF SILT AQUITARD m(ft) | TOP OF SILT AQUITARD ELEV. m(ft) |
|---|---|---|---|---|---|---|---|---|---|
| Vadose Background | | | | | | | | | |
| DP-7 | 12.50 (41.0) | 119.65 (392.54) | N/A | 0.46 (1.5) | Base of Eolian Sand to EOH | ND | ND | ND | ND |
| Vadose Zone Borings | | | | | | | | | |
| DP-1 | 6.10 (20.0) | 117.57 (385.74) | not identified | none | To EOH | ND | ND | ND | ND |
| DP-2 | 6.10 (20.0) | 116.99 (383.84) | 1.6 (5.3) | none | Base of Fill to EOH | ND | ND | ND | ND |
| DP-3 | 6.10 (20.0) | 118.13 (387.58) | not identified | none | To EOH | ND | ND | ND | ND |
| DP-6 | 10.36 (34.0) | 117.81 (386.51) | not identified | none | To EOH | ND | ND | ND | ND |
| Monitoring Wells | | | | | | | | | |
| MW-4 | 20.51 (67.29) | 122.35 (401.40) | N/A | 1.07 (3.5) | 15.09 (49.5) | 16.15 (53.0) | 106.19 (348.4) | ND | ND |
| MW-5 | 27.02 (88.65) | 122.40 (401.57) | N/A | 0.91 (3.0) | 14.94 (49.0) | 15.85 (52.0) | 106.55 (349.6) | 26.49 (86.9) | 95.91 (314.7) |
| MW-6 | 27.74 (91.0) | 120.70 (396.0) | N/A | 0.55 (1.8) | 16.98 (55.7) | 17.53 (57.5) | 103.17 (338.5) | 25.9 (85.0) | 94.79 (311.0) |
| MW-7 | 27.22 (89.3) | 120.46 (395.20) | N/A | 1.14 (3.75) | 13.91 (45.7) | 15.06 (49.4) | 105.40 (345.8) | 26.06 (85.5) | 94.40 (309.7) |

NOTES:
1. EOH - End of Hole.
2. N/A - Not Applicable
3. ND - No Data due to Shallow Depth of Boring.

TABLE 2-4: Stratigraphic Data from Borehole Logs
Horn Rapids Landfill (1 of 3)

| BORING | TOTAL DEPTH m(ft) | BORING ELEV. m(ft) | FILL THICKNESS m(ft) | EOLIAN SAND THICKNESS m(ft) | HANFORD FORMATION THICKNESS m(ft) | DEPTH TO TOP OF RINGOLD FM. m(ft) | TOP OF RINGOLD ELEV. m(ft) | DEPTH TO TOP OF SILT AQUITARD m(ft) | TOP OF SILT AQUITARD ELEV. m(ft) |
|---|---|---|---|---|---|---|---|---|---|
| Vadose Background | | | | | | | | | |
| HRL-1 | 5.67 (18.6) | 112.71 (369.78) | N/A | 0.30 (1.0) | Base of Eolian Sand to EOH | ND | ND | ND | ND |
| Vadose Zone Borings | | | | | | | | | |
| HRL-2 | 7.71 (25.3) | 114.34 (375.13) | N/A | 0.91 (3.0) | 6.10 (20.0) | 7.01 (23.0) | 107.33 (352.1) | ND | ND |
| HRL-3 | 7.80 (25.6) | 114.63 (376.07) | N/A | 0.61 (2.0) | Base of Eolian Sand to EOH | ND | ND | ND | ND |
| HRL-4 | 7.77 (25.5) | 114.48 (375.56) | not identified | none | To EOH | ND | ND | ND | ND |
| HRL-5 | 7.80 (25.6) | 114.40 (375.33) | not identified | none | To EOH | ND | ND | ND | ND |
| HRL-6 | 8.47 (27.8) | 114.95 (377.12) | not identified | none | To EOH | ND | ND | ND | ND |
| HRL-7 | 7.92 (26.0) | 114.31 (375.04) | not identified | none | 6.92 (22.7) | 6.92 (22.7) | 102.39 (352.3) | ND | ND |
| HRL-8 | 8.63 (28.3) | 114.73 (376.40) | red brick frags. 6.31 to 6.95 (20.7 to 22.8) | none | Base of Fill to EOH | ND | ND | ND | ND |
| HRL-9 | 8.23 (27.0) | 114.16 (374.54) | not identified | none | 3.32 (10.9) | 3.32 (10.9) | 110.84 (363.6) | ND | ND |

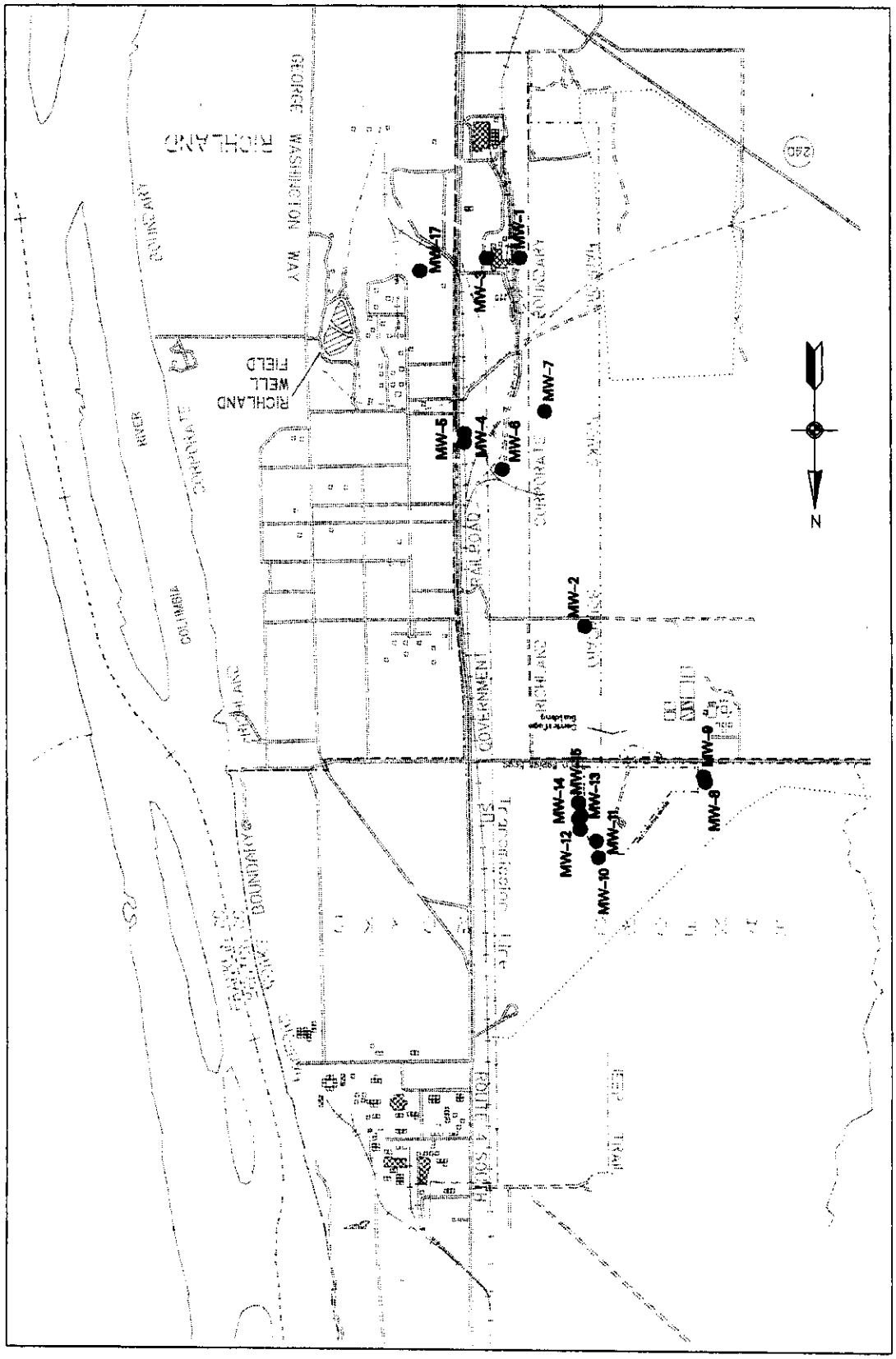
TABLE 2-4: Stratigraphic Data from Borehole Logs
Horn Rapids Landfill (2 of 3)

| BORING | TOTAL DEPTH m(ft) | BORING ELEV. m(ft) | FILL THICKNESS m(ft) | EOLIAN SAND THICKNESS m(ft) | HANFORD FORMATION THICKNESS m(ft) | DEPTH TO TOP OF RINGOLD FM. m(ft) | TOP OF RINGOLD ELEV. m(ft) | DEPTH TO TOP OF SILT AQUITARD m(ft) | TOP OF SILT AQUITARD ELEV. m(ft) |
|---|---|---|---|---|---|---|---|---|---|
| Vadose Zone Borings continued | | | | | | | | | |
| HRL-10 | 10.5 (34.5) | 116.24 (381.37) | discoloration @ 5.28 (19.1) | none | Base of Fill to EOH | ND | ND | ND | ND |
| Monitoring Wells | | | | | | | | | |
| MW-8 | 10.39 (34.08) | 113.27 (371.62) | N/A | 1.07 (3.5) | 6.86 (22.5) | 7.92 (26.0) | 105.34 (345.6) | ND | ND |
| MW-9 | 24.8 (81.4) | 113.34 (371.86) | N/A | 1.07 (3.5) | 7.59 (24.9) | 8.66 (28.4) | 104.69 (343.5) | 10.73 (35.3) | 102.61 (336.7) |
| MW-10 | 20.57 (67.5) | 118.59 (389.09) | N/A | 0.61 (2.0) | 10.06 (33.0) | 10.67 (35.0) | 107.93 (354.1) | 19.51 (64.0) | 99.09 (325.1) |
| MW-11 | 17.83 (58.5) | 118.47 (388.69) | N/A | 0.82 (2.7) | 12.28 (40.3) | 13.11 (43.0) | 105.37 (345.7) | ND | ND |
| MW-12 | 18.04 (59.17) | 116.17 (381.14) | N/A | 1.22 (4.0) | 6.40 (21.0) | 7.62 (25.0) | 108.55 (356.1) | 17.37* (57.0*) | 98.8* (324.1*) |
| MW-13 | 13.41 (44.0) | 115.78 (379.85) | N/A | none | 7.62 (25.0) | 7.62 (25.0) | 108.16 (354.9) | ND | ND |
| MW-14 | 18.44 (60.5) | 115.83 (380.01) | N/A | 0.15 (0.5) | 6.55 (21.5) | 6.71 (22.0) | 109.12 (358.0) | 16.34* (53.6*) | 99.49* (326.4*) |
| MW-15 | 16.60 (54.47) | 115.04 (377.43) | N/A | 0.30 (1.0) | 6.40 (21.0) | 6.71+ (22.0+) | 108.34+ (355.4+) | 15.82* (51.9*) | 99.22* (325.5*) |
| MW-19 | 16.46 (54.0) | 117.21 (384.56) | N/A | 0.61 (2.0) | 7.92 (26.0) | 8.53 (28.0) | 108.68 (356.56) | 15.85 (52.0) | 101.36 (332.56) |

TABLE 2-4: Stratigraphic Data from Borehole Logs
Horn Rapids Landfill (3 of 3)

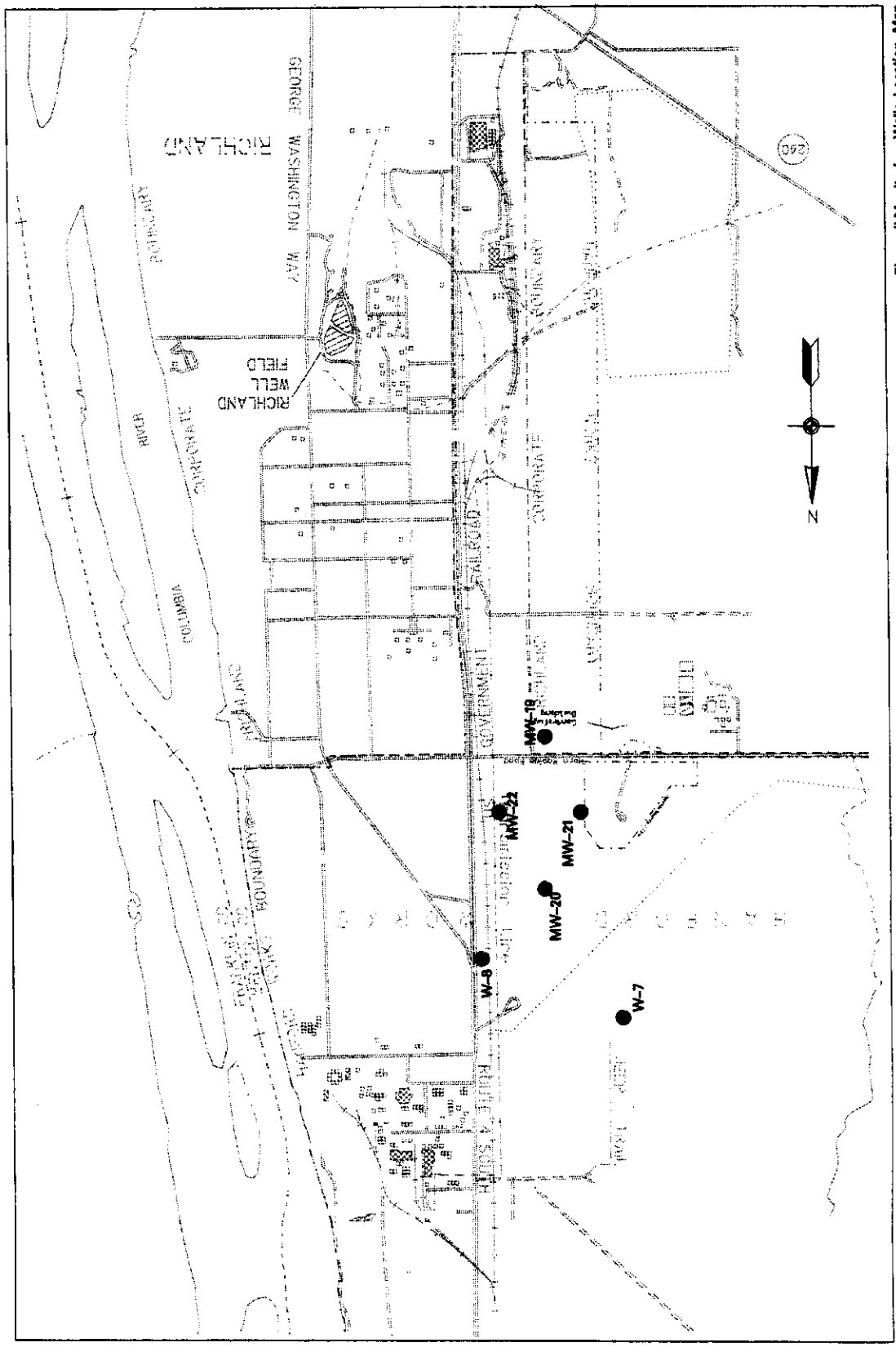
| BORING | TOTAL DEPTH m(ft) | BORING ELEV. m(ft) | FILL THICKNESS m(ft) | EOLIAN SAND THICKNESS m(ft) | HANFORD FORMATION THICKNESS m(ft) | DEPTH TO TOP OF RINGOLD FM. m(ft) | TOP OF RINGOLD ELEV. m(ft) | DEPTH TO TOP OF SILT AQUITARD m(ft) | TOP OF SILT AQUITARD ELEV. m(ft) |
|---|---|---|---|---|---|---|---|---|---|
| Monitoring Wells | | | | | | | | | |
| MW-20 | 20.64 (67.7) | 116.88 (383.45) | N/A | 1.68 (5.5) | 6.86 (22.5) | 8.53 (28.0) | 108.34 (355.45) | 20.12* (66.0*) | 96.76* (317.45*) |
| MW-21 | 29.26 (96.0) | 115.66 (379.45) | N/A | 0.91 (3.0) | 9.30 (30.5) | 10.21 (33.5) | 105.45 (345.95) | 23.62 (77.5) | 92.03 (301.95) |
| MW-22 | 19.20 (63.0) | 117.37 (385.07) | N/A | 0.61 (2.0) | 10.52 (34.5) | 11.13 (36.5) | 106.24 (348.57) | 17.68* (58.0*) | 99.69* (327.07*) |
| W-7A | 17.77 (58.3) | 118.26 (388.00) | N/A | 0.61 (2.0) | 9.51 (31.2) | 10.12 (33.2) | 108.14 (354.80) | ND | ND |
| W-8A | 16.70 (54.8) | 117.71 (386.19) | N/A | 1.22 (4.0) | 12.50 (41.0) | 13.72 (45.0) | 103.99 (341.19) | ND | ND |

NOTES:
1. EOH – End of Hole.
2. N/A – Not Applicable.
3. ND – Not Determined due to shallow depth of boring.
4. + – Ringold contact based on visual examination of physical samples in the WHC Sample Library.
5. * – Measurement on top of volcanic ash layer.




Phase I Monitoring Wells Location Map

Fig. 2-7.




Phase II Monitoring Wells Location Map

Fig. 2-8.

**2.2.2.2.1 Columbia River Basalt Group**--The CRBG is characterized by a thick sequence of tholeiitic, continental flood basalts of Miocene age. These flows cover an area of more than 163,700 $km^2$ (63,000 $mi^2$) in Washington, Oregon, and Idaho, and have an estimated volume of about 174,356 $km^3$ (40,800 $mi^3$) (Tolan *et al.*, 1989). Isotopic age determinations indicate basalt flows were erupted from approximately 17 to 6 million years before present, with >98 percent of this volume extruded between 17 and 14.5 million years before present (Reidel *et al.*, 1989).

The Columbia River basalt flows were erupted from north to northwest trending fissures or linear vent systems in north-central and northeastern Oregon, eastern Washington, and western Idaho (Swanson *et al.*, 1979). The CRBG is formally subdivided into five formations (from oldest to youngest): Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Of these, only the Picture Gorge Basalt is not known to be present in the Pasco Basin. The Saddle Mountains Basalt is divisible into the Ice Harbor, Elephant Mountain, Pomona, Esquatzel, Asotin, Wilbur Creek, and Umatilla members and forms the uppermost basalt across most of the Pasco Basin. The Elephant Mountain member is the uppermost flow beneath most of the Hanford Site except north of the 200 Area where erosion has removed most of the younger flows down to the Umatilla Member, and near the 300 Area where the topmost unit is the Ice Harbor Basalt. Erosion has also exposed the Wanapum and Grande Ronde Basalts on the anticlinal ridge crests bounding the Pasco Basin.

Bedrock geology was not considered during the development of remediation alternatives for this project and will not be discussed further.

**2.2.2.2.2 Ringold Formation**--The Ringold Formation consists of semi-indurated clay, silt, pedogenic mud, fine- to coarse-grained sand, cobbles, and gravel that usually are divided into: (1) gravel, sand, and paleosols of the basal unit; (2) clay and silt of the lower unit; (3) gravel of the middle unit; (4) mud and lesser sand of the upper unit; and (5) basalt detritus of the fanglomerate unit (Newcomb, 1958; Newcomb, *et al.*, 1972; Myers and Price, 1979; Bjornstad, 1984; DOE/RL-88-23). Ringold strata also have been divided on the basis of facies types (Tallman, *et al.*, 1981) and fining-upwards sequences (PSPL, 1982). All of these stratigraphic divisions are of limited use as they are too generalized to account for marked local stratigraphic variations or are defined sufficiently only for small areas (Lindsey and Gaylord, 1990).

Data available for the characterization of the Ringold Formation in the vicinity of the 1100-EM-1 Operable Unit are limited. Of the monitoring wells installed and soil borings sampled during the RI, 27 penetrated the Ringold Formation to depths ranging from 7.7 to 38 meters (m) [25.3 to 125 feet (ft)] below the ground surface. The data show the upper portion of the Ringold Formation in the vicinity of the Operable Unit to consist primarily of interfingering sandy gravels, gravelly sands, silty sandy gravels, and silty gravelly sands, with discontinuous sand lenses. Data from the deeper monitoring wells show that these coarse-grained sediments are underlain by finer-grained facies comprised of silt, clay, sandy silt, and sand.

Gravels and sands in the upper portion of the Ringold Formation underlying the 1100-EM-1 Operable Unit are poorly to moderately consolidated, and are calcareous in some wells. Sorting of the gravelly horizons is generally poor, whereas the sand units are typically well sorted. Sands are commonly angular to subangular, micaceous, and quartzitic. The gravels and sands are generally brown-gray to gray-brown, with olive grays and olive browns occurring locally. The lithologies of gravel clasts indicate that they were derived from granitic and metamorphic rocks located outside the Pasco Basin. Within the gravel horizons; however, basaltic gravels and sands predominate locally, reflecting upstream erosion in basaltic terrain traversed by the Columbia River.

The fine-grained sediments underlying the coarse-grained facies are moderately consolidated, and clayey horizons are generally plastic. The uppermost fine-grained unit consists of a brown to yellow-brown to olive silt-to-clay horizon that was encountered at most of the monitoring wells installed throughout the 1100-EM-1 Operable Unit. In the few wells where the entire silty unit was penetrated, the thickness varies. In monitoring well (MW)-9 and MW-21, at the HRL, and in MW-17, east of the 1171 Building, the silty unit is approximately 10, 1, and 5.5 m (33, 3.4, and 18 ft) thick, respectively. This silty layer acts as an aquitard within the 1100-EM-1 Operable Unit, separating the upper unconfined aquifer from the lower confined aquifer.

The elevation of the top of the uppermost fine-grained Ringold Formation facies (the silt unit of the previous paragraph) varies across the Operable Unit. As shown in north-south cross section A-A" (see figure 2-4), the fine-grained facies decreases in elevation southward, from approximately 99 to 103 m (324 to 337 ft) at HRL to approximately 94 m (310 ft) in the vicinity of monitoring well MW-1, west of the 1171 Building. There is a 7 m (23 ft) decrease in elevation of the top of the silt between MW-2, where the elevation is 101 m (333 ft), and MW-6 and MW-7 to the south, where the elevations are approximately 94 m (310 ft). As shown in east-west cross section D-D" (see figure 2-6), there is a 4 m (13 ft) increase in elevation of the top of the silt between MW-1, west of the 1171 Building, and MW-3, located approximately 168 m (550 ft) to the east.

The clayey silt unit in the vicinity of the 1100-EM-1 Operable Unit has been tentatively identified as a paleosol, based on the absence of bedding fabric, the massive appearance, a pattern of disaggregation typical of paleosols in the Ringold Formation throughout the Hanford Site, and the mixing of silt- and clay-sized grains which suggests bioturbation. Based on current knowledge of the Ringold depositional system, this paleosol is inferred to have formed in an overbank setting where muds deposited by floods were subjected to pedogenic alteration. Similar fine-grained facies are reported in the Ringold Formation in many borehole logs for existing wells in and near the Operable Unit. In well 10/28-10G1, north of HRL, an uppermost clay horizon is approximately 5 m (17 ft) thick (Newcomb *et al.*, 1972). However, the quality of many of the existing borehole logs is such that the fine-grained sediments noted can not be definitively correlated with those present in the monitoring wells constructed for the 1100-EM-1 RI.

Available data precludes determining whether the fine-grained Ringold sediments are laterally continuous over a broad area. Because of its considerable thickness in MW-9, MW-17, and 10/28-10G1, the fine-grained facies is interpreted to be laterally continuous

within and near the Operable Unit (see figure C-2). However, the fine-grained facies appears have been locally eroded prior to deposition of the overlying Ringold Formation gravels, creating an irregular erosional surface at the top, and the silt unit may have been completely eroded in some areas not investigated by soil borings.

The probable depositional environment of the Ringold Formation beneath the 1100-EM-1 Operable Unit is fluvial, in which the coarse-grained facies are interpreted to be high-energy, meandering river channel deposits, and the fine-grained facies are interpreted to be overbank and lacustrine floodplain deposits.

In MW-12, MW-14, MW-15, MW-21, and MW-22, east of HRL, a distinctive ash layer was encountered at an approximate depth of 99 m (325 ft) (see figures 2-3 and 2-4). The ash was microscopically examined and shown to consist of white, angular-to-subangular, glassy, silt-sized grains showing no evidence of alteration other than mechanical breakage. Dark accessory mineral grains, probably heavy minerals and other mafic grains, constitute less than 1 percent of the ash. Some of the ash grains appear to be fragments of bubble--walls (glass containing gas bubbles entrapped during solidification). With the exception of a few very-thin layers of fine sand or of staining, bedding is indiscernible in core barrel and split spoon samples.

A thickness of 7.04 m (23.1 ft) of ash was penetrated in MW-21. Because all other wells that encountered the ash were completed prior to reaching the base of the unit, the overall geometry of the deposit is uncertain. No ash of a comparable thickness or in a similar stratigraphic position has been reported from the Ringold Formation elsewhere beneath the Hanford Site. The lateral extent of the ash appears to be very limited, in that the three closest wells to the south, west, and north (MW-2, MW-9, and MW-10, respectively) contained massive, brown-to-tan silt and clay comprising the silt aquitard horizon mentioned above (see figures 2-3 and 2-4, and figure C-4) at the same elevation as the ash. Ash is not reported to occur in the same stratigraphic position to the northeast in the 300 Area (Lindberg and Bond, 1979; Schalla *et al.*, 1988), and available existing borehole logs to the east and southeast do not report an ash unit in this stratigraphic position.

The depositional environment of the ash interval is unclear. The subangularity of the ash grains, the lack of abundant bubble-wall shards, and the presence of minor sand stringers or staining suggests that some reworking by fluvial processes has occurred subsequent to deposition, presumably by air fall. However, the generally massive bedding and the lack of nonvolcanic material, as well as the absence of chemically weathered grains, suggests that reworking was not extensive.

The most-favored hypothesis to interpret the relationships between the environment of deposition of the ash and the apparently laterally continuous clayey silt paleosol is that they are separated by an erosional surface (disconformity). The clayey silt is tentatively interpreted to be a paleosol formed in an overbank setting where muds deposited by floods subsequently underwent pedogenic alteration. The absence of chemical weathering in the ash precludes it from being correlative with the paleosol. The ash unit is tentatively interpreted to be an air fall ash deposit of limited extent that was subsequently reworked by a fluvial system on a local erosional surface capping the clayey silt paleosol. The ash may have been

transported to its present location by a nearby drainage, possibly the ancestral Yakima River, that drained the volcanic Cascade terrain. A relatively close source could account for the purity of the ash and the lack of major mechanical erosion resulting in only minor reworking of the ash.

The shallow depth of the monitoring wells constructed during the 1100-EM-1 RI precludes determining the nature and thickness of the lower portion of Ringold Formation beneath the 1100-EM-1 Operable Unit. Therefore, the overall thickness of the Ringold Formation has been estimated based on the assumption that the approximate of depth to the top of basalt is 59 m (195 ft) (Myers and Price, 1979), and that elevation of the top of the Ringold Formation ranges from 103 to 111 m (337 to 364 ft) (see figure C-1). Using these assumptions, the thickness of the Ringold Formation beneath the Operable Unit is estimated to range from approximately 44 to 52 m (142 to 169 ft). This thickness is consistent with the thickness of the Ringold Formation in the North Richland well field area, which is reported by CWC-HDR, Inc. (1988) to range from 30 to 46 m (100 to 150 ft). Total thickness of the Ringold Formation in test well 10/28-10G1, located approximately 1.3 km (0.7 mi) north of HRL, is reported by Newcomb *et al.*, (1972) to be approximately 44 m (144 ft). In the 300 Area, approximately 1.9 km (1 mi) northeast of HRL, the Ringold Formation is approximately 46 m (150 ft) thick (Lindberg and Bond, 1979).

The lithologic units in the upper portion of the Ringold Formation beneath the 1100-EM-1 Operable Unit, as recorded in the borehole logs for the groundwater monitoring wells constructed for the RI, are tentatively interpreted to be equivalent to the middle Ringold textural facies of Newcomb (1958) and Myers and Price (1979). It is also proposed that, based on the elevation of the middle and upper Ringold units exposed east of the Operable Unit along the Columbia River near White Bluffs, the upper portion of the middle Ringold unit and the upper Ringold unit of Newcomb (1958) and Myers and Price (1979) are not present beneath the Operable Unit, and have most likely been removed by erosion.

**2.2.2.2.3 Hanford Formation**--The informally defined Hanford formation is composed of uncemented pebble to boulder conglomerate and less commonly of fine- to coarse-grained sand, silt, and silty clay. The bulk of these sediments were derived during Pleistocene Missoula floods, though some are also attributed to pre-Missoula flood episodes (PSPL, 1982).

Extensive scouring associated with the Missoula flood deposits was responsible for the erosion of an approximately north-south oriented paleochannel that cuts across the western side of the 300 area, immediately northeast of the 1100-EM-1 Operable Unit (Lindberg and Bond, 1979). This channel, which was filled with coarse-grained, dominantly gravel detritus during Hanford time, merges with the modern Columbia River north of and at the extreme southern margin of the 300 Area.

The Pasco gravels are the dominant facies of the Hanford formation in the vicinity of the 1100-EM-1 Operable Unit. The distinction between the Pasco gravels and the Ringold Formation is generally made on the basis of mineralogy, grain size, weathering of basalt clasts, and cementation. Pasco gravels have a higher percentage of basaltic materials, and

are generally coarser-grained and uncemented. Pasco gravel basalt clasts are commonly less weathered than basalt clasts in the Ringold Formation.

The Pasco gravels unconformably overlie the Ringold Formation at the 1100-EM-1 Operable Unit and consist of a variable mixture of boulders, cobbles, pebbles, sands, and silts. Most of the Pasco gravels can be classified as moderately to poorly sorted, unconsolidated sandy gravels to gravelly sands and silty sandy gravels. Sand lenses up to 2 m (7 ft) thick are present locally. The gravels are composed primarily of subrounded to rounded, unweathered basalt clasts with lesser amounts of mixed granitic and metamorphic lithologies. Calcium carbonate rinds occur on some gravel clasts and reworked caliche clasts are present locally . The sand fraction is angular to rounded and medium to coarse-grained, and contains from 20 to 90 percent basalt. The color ranges primarily from dark grays to dark browns, with lighter-brown materials locally present near the ground surface.

Within the 1100-EM-1 Operable Unit, the Pasco gravels range in thickness from approximately 7.6 m (25 ft) at HRL to 17 m (56 ft) in the vicinity of the 1171 Building. Within the groundwater monitoring wells constructed east of the 1100 Area, the thickness of the Pasco gravels was identified as approximately 15 m (50 ft) (Bryce and Goodwin, 1989).

The Pasco gravels were deposited during multiple Pleistocene glaciofluvial flood events on an irregular erosional surface of the Ringold Formation. The predominantly coarse-grained facies present beneath the 1100-EM-1 Operable Unit indicate that the area was within a main channel of these floods.

Lindberg and Bond (1979) have identified two cycles of graded bedding within the Pasco gravels at the 300 Area. They interpret each fining-upward sequence to represent deposition of coarse sediments during initial surges of flood waters. The finer sediments were deposited later as each flood surge diminished. The finer portion of the second, or upper, cycle is not present in the 300 Area, and Lindberg and Bond (1979) suggest that it may have been removed by erosion. These fining-upward sequences in the Pasco gravels were not recognized in the vicinity of the 1100-EM-1 Operable Unit.

**2.2.2.2.4 Holocene Eolian Surficial Deposits**--Holocene eolian deposits locally form a veneer that generally overlies the Hanford formation within the 1100-EM-1 Operable Unit. This veneer ranges from less than 0.3 m (1 ft) to more than 1.8 m (6 ft) in thickness. The deposits consist of wind-transported sand that was derived from reworked Hanford formation sediments. In some portions of the 1100-EM-1 Operable Unit, these sands form dunes with amplitudes exceeding 3 m (10 ft); the dune bordering UN-1100-6 subunit to the south has an amplitude of approximately 6 m (20 ft).

These sands are generally composed of brown, very fine to medium -grained sand or silty sand. They are moderately to well sorted, contain from 10- to 80-percent mafic constituents, and commonly contain root hairs and plant material.

## 2.3 SURFACE WATER HYDROLOGY

A detailed characterization of surface water hydrology, regionally within the Pasco Basin and locally in the vicinity of the 1100-EM-1 Operable Unit, was presented in DOE/RL-90-18. With few exceptions, little new information is presented in this report to change the previous findings. Of note is the description and characterization of the Ephemeral Pool (see paragraph 3.6).

The 1100 Area is clearly not in the 100-year floodplain of either the Columbia or Yakima Rivers (Hanford Site National Environmental Policy Act (NEPA) Characterization, C.E. Cushing, PNL-6415 Revision 4, 1991). Based on the probable maximum flood (PMF) floodplain delineation in the referenced document and the relative magnitudes of the PMF and 500-year floods, the HRL and other subunits in the 1100 Area will not be inundated by floods having return periods less than 500 years. Although the floodplain of the 500-year event has not been formally defined for the Hanford area, predicted flows for the PMF and the 500-year flood are 40,000 cubic meters per second (cms) [1.4 million cubic feet per second (cfs)] and 15,000 cms (0.5 million cfs), respectively (Water Control Manual for McNary Lock and Dam, Columbia River, Oregon and Washington, U.S. Army Corps of Engineers, August 1989). The PMF floodplain delineation shows the low areas near the HRL being inundated, while the main body of the landfill and the subunits along Stevens Drive were not predicted to be within the PMF floodplain. The 500-year flood, being less than half as large as the PMF floodplain, would, therefore, not flood these same areas.

The topography within the 1100-EM-1 Operable Unit is generally flat, with no obvious drainage channels or ponds. The lack of well defined drainages, and the arid to semiarid climate, lead to the infiltration and evapotranspiration of moisture from virtually all surface waters. However, manmade ponds do exist near the 1100-EM-1 Operable Unit. To the southwest of HRL is the SPC facility. The lined ponds located at SPC are used for pretreatment of waste water. Two miles southeast of the HRL and to the east of the 1171 Building is the North Richland well field. The unlined ponds operated in the city well field are specifically intended to recharge the unconfined groundwater table with water pumped from the Columbia River. Water filtered in this manner is then extracted to satisfy seasonal and peak municipal demands.

## 2.4 HYDROGEOLOGY

A detailed description of the 1100-EM-1 Operable Unit hydrogeology was presented in DOE/RL-90-18 and is summarized, with updated information, in the following paragraphs. Pertinent additional information gathered subsequent to Phase I RI report, relating to the well inventory, observed groundwater levels, and hydraulic parameters for the saturated and unsaturated zone are discussed.

9 3 1 2 7 4 0 1 2 0

### 2.4.1 Monitoring Well Inventory

Twenty three groundwater monitoring wells were installed during the 1100-EM-1 RI. These wells were installed to provide additional groundwater sampling stations; to define geological and hydrogeological characteristics of the Operable Unit; and, in two instances (MW-3 and MW-8A), to define further the nature and extent of contamination in the soil column.

**2.4.1.1 Phase I Monitoring Wells.** A total of 16 wells were installed during the Phase I RI. Well installation occurred from November 1989 through February 1990. The cabletool drilling method was used to advance borings designated to receive well assemblies. All wells were constructed with stainless steel screens and casing. Well construction was performed in accordance with Washington State standards for resource protection wells [Washington Administrative Code (WAC )173-160-500]. Phase I well locations are presented on figure 2-7.

Laboratory analyses were conducted for the following soil physical parameters: grain-size distribution, moisture content of soils located above the local water table, and, in a few select cases, vertical permeability. Soil samples collected for chemical analysis were obtained only at MW-3. These samples were analyzed for Target Analyte List (TAL) and Target Compound List (TCL) parameters.

Drill cuttings and soil samples from each boring were logged by a professional geologist who noted details on stratigraphy, drilling method and characteristics, well construction, types and locations of downhole samples, and visual soil characteristics. Soil samples collected for physical analysis, and chemical analysis in the case of MW-3, were obtained at approximately 1.5-m (5-ft) intervals and at changes in soil composition. A detailed summary of the distribution of downhole soil samples; a summary of well completion information; summary borehole logs for each monitoring well installation; results of physical analyses of soil samples; and, soil chemical analytical results are contained in the appendixes of DOE/RL-90-18.

**2.4.1.2 Phase II Monitoring Wells.** Seven additional groundwater monitoring wells were installed during the Phase II RI. Well installation took place from January through July 1991. As during the Phase I installations, cabletool drilling was exclusively used to advance borings designated to receive well assemblies. Wells were constructed with stainless steel screens and casing. All construction was again performed according to Washington State standards for installation of resource protection wells (WAC 173-160-500). Location of the Phase II wells are provided on figure 2-8.

Laboratory analyses for the determination of physical soil parameters were not conducted during the Phase II RI. Soil samples collected for chemical analysis were obtained from well MW-8A. These samples were analyzed for TAL and TCL parameters.

Drill cuttings and soil samples from each boring were logged by a professional geologist who noted details on stratigraphy, drilling method and characteristics, well construction, types and locations of downhole samples, and visual soil characteristics.

Soil samples collected for chemical analysis were obtained at approximately 1.5 m (5 ft) intervals and at changes in soil composition. The distribution of downhole soil samples is provided on summary borehole logs provided in appendix A. A summary of well completion information is contained in table 2-5. Soil chemical analytical results are provided in appendix D.

### 2.4.2 Groundwater Levels

The more detailed definition of site hydrogeology provided by the Phase II RI data and the larger well inventory, confirms the basic description of groundwater occurrence and flow found in DOE/RL-90-18. Monthly potentiometric surface maps for March 1991 to June 1992 are found in appendix B. Groundwater level elevations are provided in table 2-6. Additional maps for January 1990 through February 1991 were previously presented in the "Interim Groundwater Data Summary Report for the 1100-EM-1 Operable Unit for 1990," prepared for Westinghouse Hanford Company by Golder Associates, Inc., September 20, 1991, (Doc. No.903-1215) and are not included herein. All of these maps were prepared for the 1100-EM-1 Operable Unit from water level measurements taken in monitoring wells during the course of the RI. The purpose of these constructions was to refine the interpretation of groundwater flow directions, groundwater surface fluctuations, and relative groundwater flow velocities, discussed in DOE/RL-90-18. The maps include data gathered from the 300 Area and the SPC area (see paragraph 3.7).

The potentiometric surface maps show, for the observed period, the direction of groundwater flow in the unconfined aquifer and the range of groundwater level fluctuations. The direction of flow is from high pressure (high potentiometric head) towards the adjacent lower pressure (lower potentiometric head). On the maps, this is orthogonal to the contours in the down-gradient direction. Site groundwater flow and water table fluctuations are discussed in paragraph 2.4.3.2.

### 2.4.3 Hydrostratigraphy

The hydrostratigraphy within the 1100-EM-1 Operable Unit consists of the unsaturated vadose zone, an unconfined (water table) aquifer, a clayey silt aquitard, a confined aquifer, and a lower clayey silt to silty clay unit which essentially overlies bedrock. This basic hydrostratigraphy was used in the development of the groundwater model described in paragraph 6.4 and in appendix H. A generalized depiction of the hydrostratigraphic column is presented in figure 2-9.

**2.4.3.1 Vadose Zone.** The vadose zone consists predominantly of unsaturated interlayered sandy gravel, gravelly sand, and silty sandy gravel of the Hanford formation between the ground surface and the water table. It is the zone through which natural and anthropogenic recharge waters may migrate toward the groundwater.

**Table 2–5: Completion Summary for the Phase II Monitoring Wells**

| Well ID | Installation Date (mo/yr) | Ground Surface Elevation (ft amsl) | Top of Screen Elevation (ft amsl) | Screen Length (ft) | Sand Pack Interval (ft amsl) | Screen Type | Aquifer |
|---|---|---|---|---|---|---|---|
| MW–7A | 5/91 | 388.00 | 355.50 | 20.00 | 356.20 – 331.70 | a | Unconfined |
| MW–8A | 5/91 | 386.19 | 351.19 | 20.30 | 327.79 – 354.69 | a | Unconfined |
| MW–18 | 1/91 | 399.74 | 357.74 | 20.00 | 333.44 – 360.44 | a | Unconfined |
| MW–19 | 6/91 | 388.56 | 354.66 | 20.98 | 330.26 – 358.76 | a | Unconfined |
| MW–20 | 6/91 | 383.45 | 359.35 | 20.00 | 294.75 – 338.45 | a | Unconfined |
| MW–21 | 6/91 | 379.45 | 290.95 | 10.10 | 280.95 – 298.95 | a | Confined |
| MW–22 | 6/91 | 385.07 | 355.07 | 20.40 | 295.07 – 328.07 | a | Unconfined |

NOTES:
1. a – 0.010 slot, stainless steel, wire wound screen
2. A similar completion summary for the Phase I monitoring wells is provided in Chapter 2 of the Phase I RI report (DOE/RL 90–18).

## Table 2-6: 1100-EM-1 Operable Unit Monitoring Well Groundwater Levels

DATES

| Well ID | 2/90 | 6/90 | 9/90 | 3/91 | 4/91 | 5/91 | 6/91 | 7/91 | 8/91 | 9/91 | 10/91 | 11/91 | 12/91 | 1/92 | 2/92 | 3/92 | 4/92 | 5/92 | 6/92 | 7/92 | 8/92 | 9/92 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Groundwater Elevations (m) | | | | | | | | | | | | | | | | | | | | | |
| 11-34-13 | 107.35 | 107.29 | 107.56 | 107.15 | 107.16 | 107.25 | 107.38 | 107.62 | 107.72 | 107.86 | 107.86 | 107.77 | 107.70 | 107.47 | 107.33 | 107.23 | 107.20 | 107.23 | 107.284 | 107.23 | 107.20 | 107.16 |
| 11-41-13C | 107.30 | 107.62 | 107.72 | 106.75 | 107.15 | 108.38 | 108.53 | 108.59 | 108.66 | 108.75 | 108.46 | 107.96 | 107.41 | 106.96 | 107.02 | 106.99 | 107.10 | 107.36 | 107.253 | 107.34 | 107.15 | 107.50 |
| 30-45-16 | 105.80 | 106.41 | 106.06 | 105.34 | 105.61 | 106.33 | 106.54 | NA | 108.12 | NA | NA | NA | NA | 106.06 | 106.06 | 106.07 | 106.97 | 106.06 | 107.515 | 107.24 | 107.05 | 107.22 |
| 30-47-18B | 104.42 | 105.57 | 103.40 | 104.63 | 105.29 | 105.36 | 105.19 | 104.85 | 105.00 | 104.08 | 104.44 | 104.02 | 104.02 | 103.94 | 103.66 | 103.91 | 103.80 | 104.43 | 104.483 | 103.69 | 103.34 | 103.42 |
| S27-E14 | 104.67 | 105.52 | 103.88 | 104.79 | 105.36 | 105.61 | 105.35 | 104.58 | 104.43 | 103.98 | 104.12 | 104.14 | 104.52 | 104.17 | 103.92 | 104.05 | 104.39 | NA | NA | NA | NA | NA |
| S29-E11 (MW-20) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 105.87 | 105.77 | 105.70 | NA | 105.56 | 105.64 | 105.741 | 105.76 | 106.31 | 105.25 |
| S29-E12 | 105.36 | 105.86 | 105.42 | 105.35 | 105.40 | 105.24 | 105.79 | 105.73 | 105.65 | 105.60 | 105.60 | 106.32 | 105.47 | 105.33 | 105.24 | NA | 105.21 | 105.29 | 105.406 | 105.33 | 105.25 | NA |
| S30-E10A (MW-10) | 106.24 | 106.28 | 106.34 | 106.30 | 106.26 | 106.29 | 106.32 | 106.43 | 106.46 | 106.53 | 106.56 | 106.57 | 106.60 | 106.50 | 106.42 | 106.37 | 106.28 | 106.27 | 106.324 | 106.38 | 106.37 | 106.34 |
| S30-E10B (MW-11) | 106.40 | 106.39 | 106.49 | 106.42 | 106.40 | 106.42 | 106.45 | 106.55 | 106.60 | 106.68 | 106.71 | NA | 106.73 | 106.66 | 106.60 | 106.50 | 106.45 | 106.43 | 106.485 | 106.54 | 106.54 | 106.52 |
| S30-E15A | 104.67 | 105.65 | 103.84 | 104.76 | 105.21 | 105.39 | 104.88 | 104.83 | 104.96 | 104.17 | 104.34 | 104.26 | 104.39 | 104.26 | 103.96 | 103.97 | 104.22 | 104.62 | 104.729 | 104.14 | 103.65 | 103.64 |
| S31-E10A (MW-12) | 106.12 | 106.16 | 106.22 | 106.12 | 106.11 | 106.16 | 106.21 | 106.34 | 106.38 | 106.46 | 106.51 | 106.49 | 106.48 | 106.36 | 106.27 | 106.16 | 106.11 | 106.13 | 106.193 | 106.25 | 106.23 | 106.20 |
| S31-E10B (MW-13) | 106.34 | 106.34 | 106.43 | 106.34 | 106.31 | 106.35 | 106.38 | 106.51 | 106.56 | 106.56 | 106.70 | 106.70 | 106.69 | 106.59 | 106.51 | 106.41 | 106.36 | 106.35 | 106.415 | 106.47 | 106.46 | 106.44 |
| S31-E10C (MW-14) | 106.31 | 106.92 | 107.01 | 106.31 | 106.29 | 106.32 | 106.36 | 106.49 | 106.54 | 106.63 | 106.68 | 106.67 | 106.64 | 106.57 | 106.50 | 106.38 | 106.32 | 106.33 | 106.394 | 106.44 | 106.43 | 106.41 |
| S31-E10D (MW-15) | 106.28 | 106.28 | 106.37 | 106.28 | 106.26 | 106.29 | 106.34 | 106.46 | 106.51 | 106.60 | 106.65 | 106.65 | 106.64 | 106.52 | 106.43 | 106.34 | 106.29 | 106.30 | 106.354 | 106.41 | 106.40 | 106.37 |
| S31-E10E (MW-21) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 106.50 | 106.42 | 106.32 | NA | 106.16 | 106.19 | 106.269 | 106.33 | 106.32 | 106.31 |
| S31-E11 (MW-22) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 105.82 | 105.64 | 105.51 | NA | 105.51 | 105.72 | 105.827 | 105.74 | 105.68 | 106.22 |
| S31-E13 | 105.41 | 106.00 | 105.55 | 105.34 | 105.49 | 105.76 | 106.03 | 105.92 | 105.92 | 105.86 | 105.86 | 105.64 | 105.50 | 105.32 | 105.19 | 105.13 | 105.30 | 105.66 | 105.717 | 105.51 | 107.59 | 105.50 |
| S31-E8 (MW-8) | 107.64 | 107.60 | 107.69 | 107.72 | 107.70 | 107.69 | 107.69 | 107.77 | 107.82 | 107.92 | 107.97 | 107.99 | 108.02 | 107.99 | 107.95 | 107.91 | 107.89 | 107.85 | 107.884 | 107.94 | 107.94 | 107.97 |
| S32-E11 (MW-19) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 107.01 | 106.89 | 106.71 | 106.61 | 106.51 | 106.59 | 106.695 | 106.73 | 106.69 | 106.70 |
| S32-E13B | 107.15 | 106.08 | 105.75 | 105.46 | 105.59 | 105.84 | 106.12 | 106.08 | 106.06 | 106.06 | 106.06 | 105.83 | 105.70 | 105.52 | 105.41 | 105.27 | 105.55 | 105.88 | 105.879 | 105.71 | 105.65 | 105.73 |
| S32-E8 (MW-9) | NA | NA | 109.44 | 109.40 | 109.39 | 109.39 | 109.39 | 109.44 | 109.49 | 109.59 | 109.63 | 109.66 | 109.76 | 109.83 | 109.73 | 109.59 | 109.67 | 109.67 | 108.786 | 109.75 | 109.75 | 109.80 |
| S34-E10 (MW-2) | 107.55 | 107.43 | 107.70 | 107.39 | 107.31 | 107.46 | 107.64 | 107.95 | 108.02 | 108.16 | 108.18 | 107.78 | 108.03 | 107.81 | 107.65 | 107.55 | 107.51 | 107.58 | 107.643 | 107.66 | 107.66 | 107.70 |
| S36-E12B | 107.13 | 107.39 | 107.56 | 106.46 | 106.93 | 108.02 | 105.21 | 108.28 | 108.30 | 108.50 | 108.27 | 107.80 | 107.30 | 106.79 | 106.81 | 106.76 | 106.92 | 107.21 | 107.089 | 107.14 | 106.95 | 107.33 |
| S36-E13A | 107.07 | 107.38 | 107.51 | 106.41 | 106.92 | 107.96 | 108.18 | 108.18 | 108.36 | 108.38 | 108.16 | 107.70 | 107.22 | 106.74 | 106.78 | 106.70 | 106.87 | 107.18 | 107.098 | 107.14 | 106.96 | 107.29 |
| S36-E13B | 107.15 | NA | NA | NA | NA | NA | NA | NA | 108.37 | NA | NA | NA | 107.37 | 106.81 | 106.79 | 106.88 | 106.93 | 107.77 | 107.076 | 107.09 | 106.96 | 107.27 |
| S37-E11 (MW-6) | 107.32 | 107.42 | 107.71 | 106.74 | 106.99 | 107.98 | 108.27 | 108.40 | 108.53 | 108.60 | 108.40 | 107.99 | 107.61 | 107.11 | 109.43 | 106.99 | 107.11 | 107.31 | 107.265 | 107.29 | 107.15 | 107.45 |
| S37-E12 (MW-18) | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 107.38 | NA | 106.94 | NA | 107.04 | 107.30 | NA | 107.34 | 107.09 | 107.43 |
| S37-E14 | 107.04 | 107.41 | 107.17 | 106.41 | 106.98 | 108.18 | 108.34 | 108.31 | 108.49 | 108.48 | 108.18 | 107.61 | 107.09 | 106.55 | 106.74 | 106.72 | 106.83 | 107.11 | 107.009 | 107.08 | 106.90 | NA |
| S38-E11 (MW-7) | 107.60 | 107.56 | 107.89 | 107.20 | 107.27 | 107.90 | 108.20 | 108.45 | 108.52 | 108.69 | 108.54 | 108.26 | 107.97 | 107.61 | 107.48 | 107.40 | 107.46 | 107.57 | 107.585 | 107.57 | 107.50 | 107.69 |
| S38-E12A (MW-4) | 107.26 | 107.56 | 107.68 | 106.61 | 107.10 | 108.30 | 108.48 | 108.52 | 108.63 | 108.68 | 108.40 | 107.89 | 107.38 | 106.89 | 106.97 | 106.93 | 107.04 | 107.32 | 107.226 | 107.28 | 107.11 | 107.45 |
| S38-E12B (MW-5) | 107.26 | 107.56 | 107.68 | 106.61 | 107.10 | 108.30 | 108.48 | 108.53 | 108.69 | 108.69 | 108.40 | 107.89 | 107.39 | 106.90 | 106.97 | 106.92 | 107.04 | 107.31 | 107.232 | 107.28 | 107.11 | 107.46 |
| S40-E14 | 107.34 | 0.00 | 108.02 | 106.52 | 107.59 | 109.08 | 109.25 | 109.17 | 109.44 | 109.15 | 108.59 | 107.96 | 107.15 | 106.88 | 107.12 | 107.05 | 107.33 | 107.54 | 107.415 | 107.44 | 107.36 | 107.73 |
| S41-E11 (MW-1) | 107.84 | 107.63 | 107.88 | 107.56 | 107.54 | 107.86 | 108.05 | 108.28 | 108.45 | 108.59 | 108.53 | 108.35 | 108.20 | 107.95 | 107.81 | 107.73 | 107.72 | 107.73 | 107.72 | 107.70 | 107.67 | 107.83 |
| S41-E12 (MW-3) | NA | 107.42 | 107.73 | 107.05 | NA | 107.78 | 107.95 | 108.23 | 108.31 | 108.48 | 108.35 | 108.04 | 107.65 | 107.35 | 107.57 | 107.53 | 107.52 | 107.61 | 107.585 | 107.57 | 107.51 | 107.68 |
| S41-E13A | 107.43 | 107.84 | 107.88 | 106.77 | 107.38 | 108.68 | 108.77 | 108.87 | 109.07 | 108.97 | 108.73 | 108.09 | 107.56 | 107.02 | 107.16 | 107.11 | 107.22 | 107.51 | 107.406 | 107.47 | 107.31 | 107.65 |
| S41-E13B | 107.43 | 107.85 | 107.88 | 106.76 | 107.38 | 108.69 | 108.79 | 108.88 | 109.16 | 108.98 | 108.60 | 108.08 | 107.51 | 107.01 | 107.15 | 107.10 | 107.21 | 107.52 | 107.406 | 107.46 | 107.31 | 107.65 |
| S41-E13C (MW-17) | 107.73 | NA | NA | 106.76 | 107.40 | 108.54 | 108.94 | 108.74 | 108.94 | 108.83 | 108.51 | 108.04 | 107.45 | 106.96 | 107.16 | 107.09 | 107.18 | 107.46 | 107.348 | 107.39 | 107.31 | 107.60 |
| S43-E12 | 107.73 | 107.58 | 107.83 | 107.48 | 107.45 | 107.73 | 107.91 | 108.14 | 108.25 | 108.47 | 108.40 | 107.60 | 108.10 | 107.84 | 107.72 | 107.62 | 107.59 | 107.60 | 107.595 | 107.59 | 107.56 | 107.62 |
| MW-7A | NA | NA | NA | NA | NA | | | | | | | | 106.05 | | 106.02 | 106.00 | | | | | | |
| MW-8A | NA | NA | NA | NA | NA | | | | | | | | | 104.99 | 104.96 | 104.85 | | | | | | |

BLANK – Measurements have been obtained but not yet entered into HEIS
NA – Measurements are not recorded in HEIS database

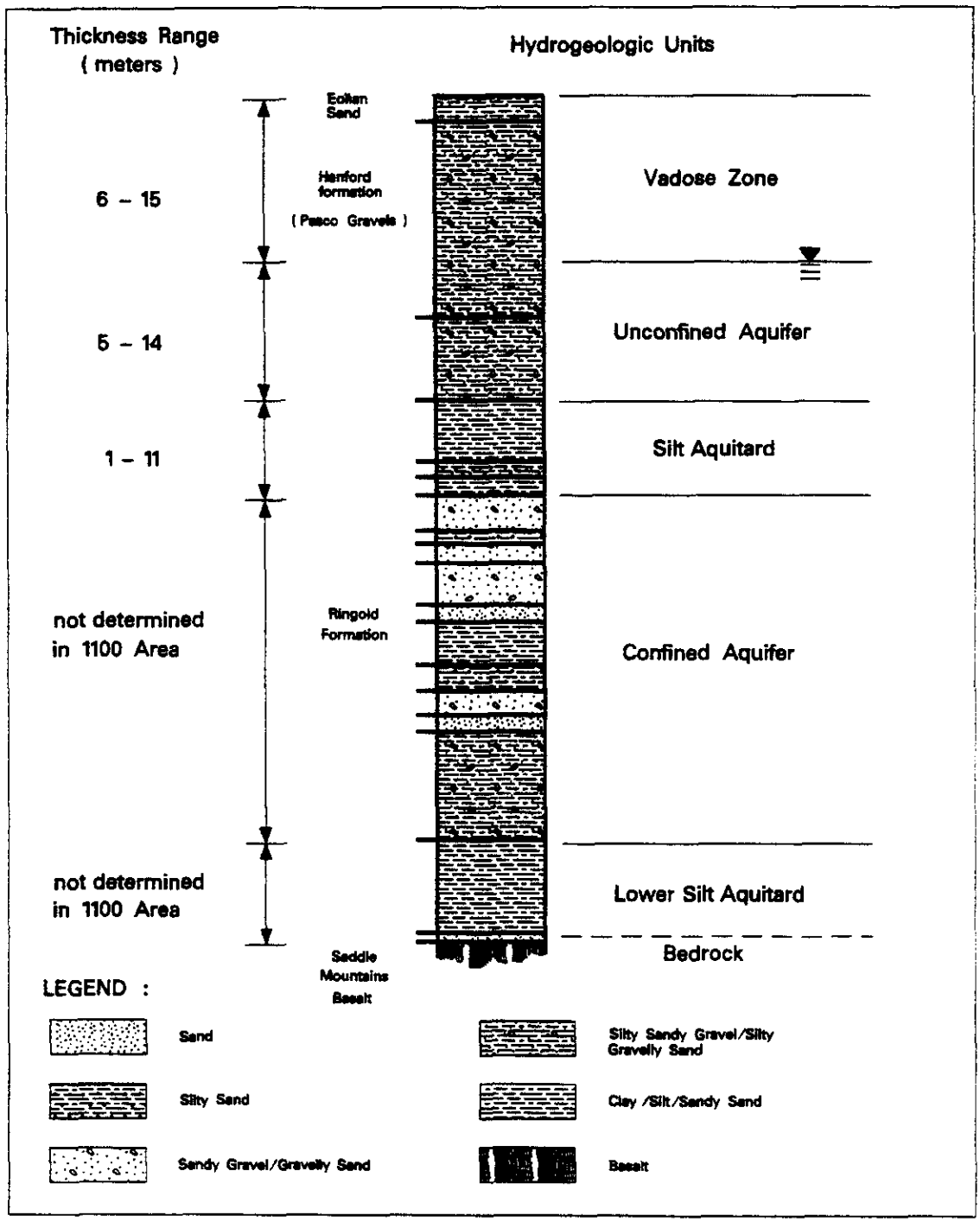



Figure 2-9. Generalized Hydrostratigraphic Column for the 1100-EM-1 Operable Unit

Below the 1100-EM-1 Operable Unit, the thinnest portion of the vadose zone occurs on the west side of HRL, where it is only 6 m (20 ft) to the water table (see figure 2-5). East and south of the landfill, the vadose zone thickness gradually increases by 6 to 8 m (20 to 25 ft). Below the 1100-2 and 1100-3 subunits, it is about 15 m (50 ft) to groundwater, and about 14 to 15 m (45 to 50 ft) to groundwater below subunits 1100-1, 1100-4, UN-1100-6, and the Ephemeral Pool.

Hydraulic testing and surface mapping to evaluate vadose zone recharge to groundwater was not conducted during the 1100-EM-1 RI. The Hanford Site Performance Assessment (HSPA) project; however, has collected data at several locations on drainage and moisture in the vadose zone (Rockhold *et al.*, 1990). Two of these locations are within 16 km (10 mi) of the 1100-EM-1 Operable Unit. The information from these locations can be generally applied to the vadose zone underlying the Operable Unit.

The two HSPA sites located nearest to the 1100-EM-1 Operable Unit are the Buried Waste Test Facility (BWTF) Site and the Grass Site (Rockhold *et al.*, 1990). They are located about 16 km (10 mi) and 8 km (5 mi) north of the Operable Unit, respectively. The sites are instrumented to monitor in-situ water content of the sediments and cumulative drainage volumes. At the BWTF Site, lysimeters and caissons were installed using locally derived, repacked sieved sediments passing a 1.3 cm (0.5 in) mesh with about 3-percent silt and clay. At the Grass Site, neutron probe access tubes were installed in undisturbed sediments consisting of 74 percent sand, 21 percent silt, and about 5 percent clay. These sediments are similar to those occurring in the vadose zone of the 1100-EM-1 Operable Unit, but are lacking in the very coarse fraction which includes large gravel, cobbles, and small boulders.

Water-balance calculations, completed for the period from 1985 to 1989, have provided cumulative drainage volumes for the BWTF Site. The calculations were performed on data collected from two weighing lysimeters (north and south) and a caisson. Cumulative drainage volumes over the 4-year (yr) study ranged from 0.0 to 10.6 cm (0.0 to 4.5 in) for the vegetated south weighing lysimeter, 3.1 to 10.0 cm (1.3 to 4.0 in) at the unvegetated north weighing lysimeter, and 4.0 to 11.1 cm (1.7 to 4.5 in) at the unvegetated south caisson, which is deeper than either the north or south weighing lysimeters (Rockhold *et al.*, 1990). The south caisson extends to a depth of 7.6 m (25 ft), whereas the north and south weighing lysimeters extend to only 1.5 m (4 ft) below ground surface.

In general, the vegetated south weighing lysimeter had 3 to 6 cm (1.3 to 2.5 in) less drainage than the north weighing lysimeter and the south caisson from 1986 to 1989. The drainage rate in the south caisson was also reported to be more regular due to its greater depth, as compared to both the north and south weighing lysimeters, which were observed to show seasonal fluctuations (Rockhold *et al.*, 1990).

Fewer data are available to evaluate drainage from the Grass Site. A computed recharge rate for the Grass Site, based on the unit gradient principle and the average field-measured saturated hydraulic conductivity, was estimated at 0.44 cm/yr (0.17 in/yr) (Rockhold *et al.*, 1990). The unit gradient was generally observed in the field moisture

9 3 1 2 7 4 0 1 2 6

content data. The smaller recharge rate at the Grass Site was attributed to the finer-grained vegetated sediments.

Computer modeling of the water table aquifer recharge rate from surface infiltration was performed during the Phase II investigation. A discussion of the modeling is provided in paragraph 6.3 of this report. Groundwater recharge within the 1100-EM-1 Operable Unit, as determined through the modeling effort, was computed as averaging 1.04 cm/yr (0.41 in/yr) for vegetated areas and 3.46 cm/yr (1.36 in/yr) for unvegetated areas. Both values are well within the ranges measured by field investigations described above.

**2.4.3.1.1 Vadose Zone Properties**--Soil grain-size distribution and moisture content were the only two physical properties determined for vadose zone sediments during the 1100-EM-1 Operable Unit Phase I investigation. Neither property was measured during the Phase II investigation. A detailed summary and discussion of vadose zone parameters are presented in paragraph 6.1. Tables presented there provide a compilation of the soil samples obtained for physical analyses, the borehole/well from which the samples were obtained, the depths of the samples, a summary of their grain-size composition, the measured soil-moisture contents, and the Wentworth Classification of the soil based on laboratory gradation analysis results.

Gradation percentages and classifications presented in these tables may differ from field data entered on the boring logs. Field data was based entirely on visual estimation of soil grain size and composition and, therefore, subject to the classifier's judgement. Based on the arithmetic averaging of 168 test results, the overall soil gradation within the vadose zone consists of 50-percent gravel sized particles, 42-percent sand, and 8-percent silt-sized or finer grains. Soil moisture averages 0.06 $cm^3/cm^3$.

**2.4.3.2 Unconfined Aquifer.** The unconfined aquifer below the 1100-EM-1 Operable Unit occurs between the water table and the underlying silt aquitard, approximately 95 to 107 m (310 to 350 ft) above mean sea level (amsl). The aquifer occurs within the lower Hanford formation and the upper portion of the middle Ringold Formation.

**2.4.3.2.1 Aquifer Thickness**--Below the 1100-EM-1 Operable Unit, the unconfined aquifer thickness gradually increases south from HRL to a trough, which occurs in the vicinity of the 1100-2 and 1100-3 subunits. Directly south from these two subunits, toward the 1100-1 subunit, the thickness does not appear to change. Southeast from the 1100-2 and 1100-3 subunits and east from the 1100-1 subunit, the thickness decreases slightly. The maximum thickness observed is 13 m (44 ft), in the vicinity of the 1100-1, 1100-2, 1100-3, and UN-1100-6 subunits. The minimum observed thickness is 5 m (16 ft) and occurs on the west side of HRL.

Outside of the 1100-EM-1 Operable Unit, fewer data are available to map the unconfined aquifer thickness. In general, the thickness appears to increase toward the Columbia River.

**2.4.3.2.2 Recharge**--Groundwater recharge to the unconfined aquifer below the 1100-EM-1 Operable Unit is primarily from the Yakima River located several miles west and southwest of the site. The river appears to discharge directly to the unconfined aquifer along the Horn

Rapids Reach below Horn Rapids Dam (Freshley *et al.*, 1989). Irrigation losses from farmland west of the Operable Unit is likely a minimal contributor to the westward groundwater inflow volume.

Within the boundaries of the 1100-EM-1 Operable Unit, groundwater recharge also may occur as a result of natural precipitation. The volume of recharge from infiltrating precipitation is anticipated to be small relative to the westward groundwater inflow volume.

To the east of the 1100-EM-1 Operable Unit, the North Richland well field artificially recharges the unconfined aquifer to provide treatment of turbid Columbia River water and enhance the well field capacity (see figure 1-2 for well field location). This is a major source of recharge to the aquifer and causes groundwater mounding that extends west to the vicinity of the 1100-1, 1100-4, UN-1100-6, and Ephemeral Pool subunits. However, because the well field is recharged intermittently, the mound may dissipate between periods of recharge. Monthly totals for recharge at the well field during 1988 and 1989 ranged from about 75,000,000 L (20,000,000 gal) to 1,500,000,000 L (400,000,000 gal).

**2.4.3.2.3 Water Table Surface Fluctuations**--Groundwater surface fluctuations near the 1100 Area occur due to Columbia River stage fluctuations and variable recharge at the North Richland well field. Of the observed data sets, the June 1990 and the April 1992 water surfaces (shown in figures B-1 and B-17) have, respectively, the highest and lowest surfaces due to river fluctuations. Comparing these data sets, the influence of the major (seasonal) river stage fluctuations in the northern part of the area extends inland to about the down-gradient boundary of the HRL. In the southern part of the area, the extent of the river influence does not reach as far inland, because of the steepness of the surface gradient in this area. Its exact extent could not be determined because of the variable influence of the North Richland well field recharge.

As noted, recharge from the North Richland well field causes groundwater mounding in the southern part of the area as shown on the groundwater level maps. Of the observed data sets, the greatest and least amount of mounding occurred in August 1991 (figure B-9) and March 1991 (figure B-4), respectively. In the SPC/HRL area, the maximum observed northward extent of the recharge influence was to the area approximately 1,500 m south of Horn Rapids Road. The recharge mounding has not been observed to have a significant effect on groundwater levels or gradient directions within the SPC/HRL area. Well field recharge data from 1983 to the present indicates reasonably consistent yearly recharge volumes and mode of operation (*Ground-water Modeling Investigation of North Richland Well Field and the 1100 Area*, PNL Letter Report, M.D. Freshley, March, 1989).

**2.4.3.2.4 Groundwater Flow**--The groundwater flow direction was determined from groundwater potential measurements in monitoring wells within and adjacent to the 1100-EM-1 Operable Unit as reported in table 2-6 and the potentiometric surface maps discussed in paragraph 2.4.2.

The potentiometric surface maps indicate consistent northeasterly groundwater flow in the vicinity of the HRL and that groundwater passing through the SPC area flows to the HRL. HRL wells containing the highest concentrations of contaminants (paragraph 4.8.2)



9 3 1 2 7 4 0 1 2 8

are directly down-gradient from the SPC facility. No reasonable scenario was found that would allow for groundwater flow from the SPC/HRL area to the North Richland well field.

The potentiometric maps also confirm the Phase I RI observation that local groundwater flow originating north of latitude 46°20'N (near wells MW-7 and MW-5) does not flow to the North Richland well field. Therefore, based on the 1990 to 1992 observations, it is not possible for unconfined aquifer groundwater contamination originating at the SPC/HRL area to flow directly to the North Richland well field.

The maps also show that groundwater passing beneath the southern portion of the 1100-EM-1 Operable Unit flows eastward toward the North Richland well field when it is not obstructed by recharge mounding, and westward when mounding occurs. Examination of the 29 months of available data revealed that, for 13 months, flow was from the 1100-EM-1 eastward towards the well fields while, for 16 months, flow was reversed due to well recharge mounding. The average local surface gradients were approximately equivalent for those two conditions. Therefore, for the localized area west of the well field, the 1990 to 1992 data indicates that the recharged water dominates the direction of flow, that flow is towards the west more than towards the east, and that, if the observed recharge pattern is continued indefinitely, the natural groundwater beneath the southern portion of the 1100-EM-1 Operable Unit will not flow into the North Richland well field.

**2.4.3.2.5 Discharge**--Groundwater discharge from the unconfined aquifer occurs primarily into the Columbia River and to wells in the North Richland well field, depending on well field operations. Hydraulic connection between the aquifer and the river is shown by the continuity of the formation materials toward the river, and the similarity between river stage and the observed groundwater potential in the unconfined aquifer near the river.

This hydraulic connection was further demonstrated by the response of many monitoring wells to a 0.3-m (1-ft) decline in Columbia River stage from March 2 to 5, 1990. During this period, groundwater potential measured in monitoring wells nearest the river also declined approximately 0.3 m (1 ft).

**2.4.3.2.6 Hydraulic Properties**--Hydraulic properties for the unconfined aquifer were determined from previous investigations at this and nearby sites, and from recent pump tests performed at the SPC facility, and at a location west of Stevens Drive near the 300-FF-5 Operable Unit. Pump tests were not performed at the HRL because of concerns expressed by regulators regarding the pumping of potentially contaminated groundwater to the surface. The SPC pump test was performed close to the area of immediate concern and mainly evaluated properties of the Hanford formation. The two 300-FF-5 Operable Unit tests, at wells 7T and 4T, were located about 1/2 and 1 mile from the HRL boundary, respectively, and reflect properties of the middle Ringold Formation (figure 2-6).

Pump test results were used as the representative data for site hydraulic conductivity instead of the slug tests results reported in the Phase I RI report. This was determined after review of other hydraulic property investigations (see appendix B), discussions with the U.S. Geological Survey (USGS) concerning unpublished hydraulic property testing in the vicinity (personal communication between M. Johansen, U.S. Army Corps of Engineers, and Ward

Staubitz, USGS), and the conventional understanding that pump test results are more representative than slug test data because a larger area of the aquifer is stressed. There were also concerns reported in the Phase I RI and in the 300-FF-5 aquifer test report about the accuracy of the slug test results for wells with small screen mesh sizes (10 to 20 slot at the 1100 Area and 30 slot at the 300-FF-5 Area) and accompanying screen packing material.

The SPC pump test was conducted April 27 through 30, 1992, by pumping well TW-1 (located near SPC monitoring well GM-5 as shown in figure 6-13) at approximately 154 gallons per minute (gpm) for a period of 72 hours; a time period sufficient for test stabilization (see appendix F). The pumping rate was determined from a previously performed step-drawdown test. The driller's log for well PW-1 shows the base of the screen to be located a few feet above the silt aquitard layer with the screen extending 15 feet upward to the vicinity of the water table. The contact between the Hanford and Ringold Formations is interpreted as occurring approximately at the midpoint of the screened interval with slightly more length screened in the Pasco gravels of the Hanford formation. The pump test largely evaluated the properties of the Hanford formation since most of the pumped water was likely derived from the more permeable Pasco gravels. Based on test results, the estimated transmissivity of the unconfined aquifer in the vicinity of the pumping well was approximately 2,460 to 3,140 $m^3$/d-m (180,000 to 230,000 gallons per day per foot). Corresponding horizontal hydraulic conductivities range from 400 to 520 meters per day (m/d) (1,320 to 1,700 feet per day [ft/d]). The information is preliminary and is to be finalized and presented in an RI report for SPC scheduled for release in the spring of 1993.

Aquifer testing at the 300-FF-5 sites was conducted from January to May of 1992 in 10-inch-diameter wells equipped with 30-slot, wire-wrap screens (WHC, 1992c). The two test wells were screened entirely within the middle Ringold Formation with screen lengths for wells 4T and 7T being 20.2 and 30.5 feet, respectively. Three observation wells were constructed for each test well and several different slug and pump tests were performed. The slug test results were reported as unrepresentative of aquifer properties because of the effects of the fine filter pack material required by the 30-slot size screens. The pump test results were horizontal conductivities of 10 - 72 m/d (33 to 236 ft/d) vertical conductivities of 2 to 5 m/d (6.6 to 16 ft/d), and a storage coefficient of 0.01 - 0.58 ($S_y$). The constant discharge tests (Neuman analysis) were reported to provide the best estimate of the unconfined aquifer properties with results of 37 to 49 m/d (121 to 161 ft/d) ($K_h$), 2 to 5 m/d (6.6 to 16 ft/d) ($K_v$), and 0.02 - 0.37 ($S_y$).

The SPC and 300-FF-5 pump tests reviewed provided the best estimates of aquifer properties in the HRL vicinity. However, additional information concerning the hydraulic properties of the unconfined aquifer near the river was for use in groundwater modeling. The water table contour maps (appendix B) show that the groundwater surface near the 300 Area is consistently and distinctly flatter than the up-gradient surface near the HRL. According to the governing principles of groundwater flow, this decrease in the slope indicates the presence of relatively high aquifer hydraulic conductivities in this area. The upgradient pump tests results were, therefore, not extrapolated into this area. The best available hydraulic property information for this area were $K_h$ measurements of 3,350 - 15,000 m/d (10,991 to 49,215 ft/d) for the local Hanford formation [RI/FS Work Plan for the 300-FF-5 Operable Unit, Hanford Site, Richland, Washington (DOE/RL-89-14)].



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An earlier pumping test completed at the North Richland well field provided a single hydraulic conductivity estimate of 457 m/d (1E+03 ft/d), which is more typical for the unconfined aquifer. At the well field, the unconfined aquifer occurs within both the Hanford formation and middle Ringold Formation. During this test, water was withdrawn from the aquifer at a rate of 5,070 l/min (1,340 gal/min). Although the test continued for a total of 98 hours, all observed drawdown occurred in the first 24 hours. A total drawdown of 1.2 m (4 ft) was measured in the pumping well. In an observation well 107 m (350 ft) away, the total drawdown was only 0.20 m (0.66 ft). These results are consistent with those of the SPC test.

Table 2-7 summarizes the estimated hydraulic properties for the hydrogeologic units at the site. Those values not taken from the information reported above, were estimates and observations taken from DOE/RL-90-18 and other investigations at Hanford as reported in appendix B. Where no previous site-specific data was available, the estimated value, or range, was extrapolated from the nearest available measured value (*i.e.*, some vertical hydraulic conductivity estimates were derived from measured horizontal conductivity values by using a 1 to 10 ratio).

**2.4.3.3 Silt Aquitard.** A silt aquitard was identified during drilling throughout the 1100-EM-1 Operable Unit, and is also recognized in the drill logs of previous workers in the general vicinity. See appendix C for further details and maps defining stratigraphic characteristics, thicknesses, and areal extent of the silt aquitard. The aquitard was encountered within the interval from 91 to 102 m (299 to 333 ft) amsl. Wells drilled to elevations lower than 91 m (299 ft) amsl invariably intercepted the aquitard. There is, however, uncertainty regarding the continuity of this layer. A possibility exists for the aquitard to be discontinuous due to erosion that may have occurred before the overlying sediments were deposited.

**2.4.3.3.1 Aquitard Thickness and Extent**--The reported thickness of the silt aquitard ranges from 1.04 to 10.1 m (3.4 to 33 ft) (see table C-1). The thickness of only 1.04 m (3.4 ft) was observed in MW-21. This unit is overlain by a 7.04 m (23.1 ft) thick volcanic ash layer (see appendix C). The ash appears to have been alluvially deposited in an isolated depression on the top of the silt. On the west side of HRL, at MW-9, the silt aquitard thickness is measured to be 10.1 m (33 ft). A short distance west of the North Richland well field, in MW-17, the aquitard is 5.5 m (18 ft) thick. Within the North Richland well field, no wells extended through the silt aquitard; however, several logs indicate a silt or clay interval being intercepted at the bottom of the borehole.

The change in thickness of the aquitard is interpreted to reflect undulations in its upper surface. This surface likely was subject to erosion based on the high-energy sand and gravel deposits that overlie it and the apparent geometry of the ash deposit previously described. The lower surface of the silt appears to be relatively flat (based on six data points), varying in elevation by less than 3 m (10 ft) over a 6 km (3 mi) north-south transect passing through the 1100-EM-1 Operable Unit (see cross section A-A", figure 2-4).

The uniformity and gradation in elevation of the lower silt surface, as observed, suggest the aquitard may be a continuous stratum; however, the undulating upper surface

indicates the potential for complete erosion of the silt in localized areas. Below the 300 Area, a silt aquitard, which occurs at about the same elevation as that below the 1100-EM-1 Operable Unit, pinches out near the Columbia River channel, an indication of complete erosion in this area (see figure C-2). However, it is not clear that these two silt horizons are absolutely correlative.

The uppermost Ringold silt layer present within the 1100-EM-1 Operable Unit is, at least partially, discontinuous to the east, adjacent to the Columbia River. This is evident in the head differences obtained from two well clusters (MW-8 and 9 located along the western edge of HRL and wells 7A, 7B, and 7C located within the 300-FF-5 Operable Unit), which indicated upward pressure head differences of 2.0 and 0.3 m (6.6 and 1.0 ft), respectively. If the silt layer were continuous, the head differences would be approximately the same across the site or might even increase closer to the river.

MW-21, which penetrates the confined aquifer at the eastern edge of HRL, presents an anomaly to this trend. Water level measurements indicate that a slightly lower potentiometric surface exists in the confined aquifer versus the unconfined aquifer at this location. Water level elevation differences average 0.13 m (0.43 ft) with a maximum difference of 0.18 m (0.59 ft) and a minimum of 0.10 m (0.33 ft); the water level elevation in the lower confined aquifer being lower than that in the upper unconfined aquifer. A preliminary check of the top-of-casing elevation listed for well MW-21 suggests the anomaly may be the result of survey error. Alternately, the well seal may be compromised. An elevation survey of 1100 Area wells is underway. This anomaly will be re-evaluated when the new survey data becomes available.

**2.4.3.3.2 Hydraulic Properties**--Ten samples of the silt aquitard were used to measure the vertical hydraulic conductivity of this confining layer. The hydraulic conductivity results ranged from 2.5E-05 to 4.3E-02 m/d (8E-04 to 1E-01 ft/d) (DOE/RL-90-18). These values were several orders of magnitude lower than in the overlying unconfined aquifer. The laboratory test results may not, however, be representative of the true hydraulic conductivities of the sediments due to sampling disturbances.

The confining ability of the aquitard is shown by comparison of the groundwater potentials in monitoring wells MW-8 and MW-9 on the west side of HRL. MW-9 is screened entirely within sediments underlying the silt aquitard and has groundwater potentials approximately 1.9 m (6.3 ft) greater than those in MW-8, which is screened above the aquitard. Under these conditions, an upward hydraulic gradient across the aquitard exists.

At MW-17 the groundwater potential difference across the aquitard was essentially zero. The absence of a potential gradient at MW-17 may be attributed to the occurrence of a window through the aquitard, mounding effects caused by recharge at the well field, a change in the depositional or diagenetic facies of the aquitard, or poor well construction. In general, an easterly decline in the hydraulic gradient across the aquitard is anticipated, as the aquitard likely pinches out in this direction, thereby allowing the unconfined aquifer to equilibrate with the aquifer below.

**2.4.3.4 Confined Aquifer.** The upper confined aquifer occurs immediately below the silt aquitard. Information on this aquifer is limited, as the 1100-EM-1 RI hydrogeological investigation focused primarily on the vadose zone and unconfined aquifer.

The upper confined aquifer is monitored by wells MW-9, MW-17, and MW-21. The groundwater potentials measured in these wells indicate that flow is apparently toward the east. There is also flow upward into the silt aquitard that occurs above the confined aquifer, with the possible exception of MW-21 as discussed in paragraph 2.4.3.3.1. It is presently unknown if North Richland well field operations have significant affects on the flow observed in this aquifer, although minor fluctuations observed in water levels measured in well MW-17 indicate that at least some minor effect is likely.

The sediments encountered in the confined aquifer ranged from silty sand to sandy gravel of the middle Ringold Formation. Rising head slug tests conducted in MW-9 and MW-17 yielded hydraulic conductivity estimates of .34E-01 m/d (1.0 ft/d) and 0.086 m/d (0.30 ft/d), respectively, indicating that at least in these two locations the hydraulic conductivity is generally lower than in the unconfined aquifer.

The horizontal and vertical extent of the upper confined aquifer is not well defined. Lindberg and Bond (1979) show the upper confined aquifer merges with the unconfined aquifer near the Columbia River within the 300 Area, and Newcomb *et. al.*, (1972) report on a well drilled through the upper confined aquifer southwest of the 300 Area. During drilling for the initial phase of the 1100-EM-1 RI, the upper confined aquifer was identified at HRL at MW-9, and to the south at MW-6 and MW-17. The vertical thickness of the upper confined aquifer may vary from a few meters up to 10 m (30 ft), depending on the continuity of silt strata in the middle Ringold unit. During the RI, no explorations penetrated the full thickness of the upper confined aquifer below the 1100-EM-1 Operable Unit.

**2.4.3.5 Lower Silt Aquitard.** A clayey silt to silty clay unit is assumed to overlie the bedrock surface below the 1100-EM-1 Operable Unit except where separated by a thin sand unit. There are no wells within the Operable Unit that extend deep enough to confirm this assumption. Well log data in the 300 Area show that the aquitard is separated from bedrock by a thin sand that is likely irregular and discontinuous. Based on remote well data, it is assumed that the lower silt aquitard, in places, may not be in direct contact with bedrock below the Operable Unit (DOE/RL-89-14).

This fine-grained unit serves as the major aquitard separating water-bearing units in the basalt bedrock from water-bearing strata of the suprabasalt sedimentary sequence. In the 1100-EM-1 groundwater model, the lower silt aquitard is assigned the role of lower bounding unit for the geometric block of sediments of which the model is composed.

Table 2-7. Measured and Estimated Saturated Zone Hydraulic Properties

| Hydrogeologic Unit | Horizontal Hydraulic Conductivity (m/d) | Vertical Hydraulic Conductivity (m/d) | Storage Coefficient | Porosity (effective) |
|---|---|---|---|---|
| Unconfined Aquifer | | | | |
| Hanford Formation (near HRL) | 400 - 520 | 40 - 50* | .02 - .37* | .20 - .33* |
| Hanford Formation (near 300 Area) | 3350 - 15000 | 330 - 1500* | .02 - .37* | .20 - .33* |
| Ringold Formation | 10 - 72 | 2 - 5 | .02 - .37 | .11 - .30* |
| Silt Aquitard | .001 - .03 | .0001 - .003* | | .20 - .33* |
| Confined Aquifer | 10 - 72 | 2 - 5 | | .11 - .30* |

* Value, or range, is based on general reported values at the Hanford site (appendixes B and F) or extrapolated from nearest available value.

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## 3.0 SITE INVESTIGATIONS

Investigations completed for the 1100-EM-1 Operable Unit RI will be summarized in the following sections. Subunits will be discussed in the sequence: 1100-1, Battery Acid Pit; 1100-2, Paint and Solvent Pit; 1100-3, Antifreeze and Degreaser Pit; 1100-4, Antifreeze Tank Site; UN-1100-6, Discolored Soil Site; Ephemeral Pool; and, HRL. Subunits UN-1100-5, Radiation Contaminant Incident; Pit No. 1; and, the Hanford Patrol Academy Demolition Site were eliminated from further consideration for remediation during the Phase I portion of the RI (DOE/RL-90-18). Of these three sites eliminated, the first two were deleted from further consideration due to a lack of substantive contamination detected at the sites. It is anticipated that the Hanford Patrol Academy Demolition Site will be addressed separately, if necessary, under Ecology's RCRA authority.

The discussion of site investigations will begin with a general description of each subunit. Following the site description, details of individual investigations completed at each subunit will be presented including soil sampling and analysis, soil-gas sampling efforts, and geophysical investigations. Then, a summary of all subunit soil investigations, and screened contaminants will be presented. Finally, groundwater investigations will be discussed on an Operable Unit-wide basis in the last paragraph of this section.

Soil [0 to 0.7 m (0 to 2.0 ft)] contaminants detected within the 1100-EM-1 Operable Unit are presented in table 3-1. Subsurface [> 0.7 m (2 ft)] contaminants detected at the 1100-EM-1 Operable Unit are presented in table 3-2. Table entries highlight those substances detected in concentrations above Upper Tolerance Limits (UTL) (see appendix K). The UTL is used as the project-specific background level and contaminants are defined as those analytes detected at concentrations above UTL. Phase I analytical parameters for soils consisted of EPA TAL and TCL parameters (EPA, 1989a and 1989b, respectively). Phase II analytical parameters were more restrictive in that Phase II analyses focused on contaminants of potential concern identified during the Phase I investigation (DOE, 1990).

Surface radiation surveys were conducted at all 1100-EM-1 Operable Unit subunits. All radiation surveys were negative. These will not be considered further.

### 3.1 BATTERY ACID PIT-1100-1

The Battery Acid Pit was an unlined, sand filled sump/french drain excavated in native soil deposits approximately 30 m (100 ft) from the southwest corner of the 1171 Building (figure 3-1) . During the period between 1954 to 1977, an estimated volume of 57,000 l (15,000 gal) of waste battery acid from vehicle maintenance activities was deposited in the pit. Information gathered through interviews with former site workers suggest that other substances including waste oil, waste antifreeze, and spent solvents were also deposited in the pit. No documentation exists to support these claims. Periodically, during the operation of this facility, the acid-laden sand lining was removed and deposited at an undetermined location and fresh sand fill installed. The pit dimensions during its use as a disposal facility are reported to have been roughly 1.8 m (6 ft) in diameter by 1.8 m (6 ft) in depth. The Battery Acid Pit is no longer visible at the site. When withdrawn from service,

**Table 3-1** Maximum Concentrations for Detected Compounds, Compared to UTL's for Surface Soils (0 to 2 Feet) from Phase I and II Data (Sheet 1 of 4)

| Parameter | Surface Soil UTL | Max Value 1100-1 | Max Value 1100-2 | Max Value 1100-3 | Max Value 1100-4 | Max Value 1100-6 | Max Value HRL | Max Value EP |
|---|---|---|---|---|---|---|---|---|
| INORGANIC COMPOUNDS (mg/kg) | | | | | | | | |
| Aluminum | 9708.79 | 7130 | 8300 | **9770** | 7320 | 8680 | **15800**[b] | 5810 |
| Antimony | 3.70 | ND | ND | ND | ND | ND | **15.6**[b] | ND |
| Arsenic | 3.99 | 3.2 | 2.3 | 3.4 | 2.6 | 2.7 | 3.6 | 2.6 |
| Barium | 120.10 | 80.8 | 91.5 | 106 | 80.9 | 99.2 | **1320** | 72.3 |
| Beryllium | 0.74 | ND | 0.51 | 0.44 | 0.25 | 0.4 | **1.3** | 0.26 |
| Cadmium | 0.70 | ND | ND | ND | ND | ND | **2** | ND |
| Calcium | 5129.25 | **8690** | **6480** | **6810** | **9710** | 4180 | **86700** | 3030 |
| Chromium | 12.94 | 10.6 | **16.8** | 14 | 11.3 | 10.9 | **17.1** | 7.7 |
| Cobalt | 17.74 | 13.2 | 13.9 | 14.1 | 11.4 | 12.2 | 15.9[b] | 10.3 |
| Copper | 19.11 | **37.9** | **24.4** | **22.8** | 14.4 | 16.2 | **58.6** | 15.2 |
| Iron | 31110.42 | 21100 | 26600 | 25500 | 23300 | 23500 | 29800 | 18900 |
| Lead | 12.64 | **266** | **94.6** | **26.4** | 5 | **22.1** | **482** | 54.2 |
| Magnesium | 6523.59 | 6430 | 5210 | 6170 | 4650 | 4840 | **25000** | 4250 |
| Manganese | 552.27 | 464 | 365 | 436 | 330 | 383 | 423 | 354 |
| Mercury | 0.10 | **0.22** | ND | ND | ND | ND | **1.3** | ND |
| Nickel | 19.00 | **20.9** | 15 | 14.9 | 9.8 | 12.9 | **174** | 12.5 |
| Potassium | 1909.71 | 850 | **2060** | 1730 | 1210 | **1950** | **2230** | 1140 |
| Selenium | 0.39 | ND | ND | ND | ND | ND | **0.97**[b] | ND |
| Silver | 2.44 | ND | ND | ND | ND | ND | **4.5** | ND |
| Sodium | 241.52 | **479** | **374** | **495** | **413** | 143 | **5140**[b] | 216 |
| Thallium | 0.39 | ND | **0.48** | **.40** | ND | ND | **.42** | ND |
| Vanadium | 83.93 | 32.5 | 73.4 | 70.2 | 61.8 | 60.8 | **87.3** | 44.4 |
| Zinc | 62.20 | **92** | 56.6 | 59 | 45.9 | 111 | **408** | **67.5** |
| Cyanide | 0.52 | ND | ND | ND | ND | ND | **0.56** | ND |

**Table 3-1** Maximum Concentrations for Detected Compounds, Compared to UTL's for Surface Soils (0 to 2 Feet) from Phase I and II Data (Sheet 2 of 4)

| Parameter | Surface Soil UTL | Max Value 1100-1 | Max Value 1100-2 | Max Value 1100-3 | Max Value 1100-4 | Max Value 1100-6 | Max Value HRL | Max Value EP |
|---|---|---|---|---|---|---|---|---|
| VOLATILE ORGANIC COMPOUNDS (μg/kg) | | | | | | | | |
| 1,1,1-trichloroethane | 5 | ND | 2 | ND | ND | 35 | ND | ND |
| 1,1-dichloroethene | 5 | ND | 5 | ND | ND | ND | ND | ND |
| 2-butanone | 11 | ND | 10[a] | 17[a] | ND | 69[a] | 35[a,b] | ND |
| 2-hexanone | 11 | ND | ND | ND | ND | 53 | ND | ND |
| Acetone | 43 | ND | 19[a] | 92[a] | 6[a] | 190[a] | ND | ND |
| Chlorobenzene | 5 | ND | 6 | ND | ND | ND | ND | ND |
| Methylene chloride | 5 | ND | 42[a] | 120[a] | ND | 20[a] | 43[a] | 4[a] |
| Tetrachloroethene | 5 | ND | 35 | ND | ND | ND | 5 | ND |
| Toluene | 5 | ND | 11[a] | 6[a] | ND | 8[a] | 16[a] | ND |
| Trichloroethene | 5 | ND | 6 | ND | ND | ND | ND | ND |
| Xylene | 5 | ND | 6 | ND | ND | ND | ND | ND |
| SEMI-VOLATILE ORGANIC COMPOUNDS (μg/kg) | | | | | | | | |
| 1,2,4-trichlorobenzene | 690 | ND | 120 | ND | ND | 83 | ND | ND |
| 1,3-dichlorobenzene | 690 | ND | 120 | ND | ND | ND | ND | ND |
| 1,4-dichlorobenzene | 690 | ND | 120 | ND | ND | 86 | ND | ND |
| 2-chlorophenol | 690 | ND | 230 | ND | ND | 170 | ND | ND |
| 2-methylnaphthalene | 690 | ND | ND | ND | ND | ND | 7100 | ND |
| 2,6-dinitrotoluene | 690 | ND | ND | ND | ND | ND | 210[b] | ND |
| 4-chloro-3-methylphenol | 690 | ND | 190 | ND | ND | 95 | ND | ND |
| 4-nitrophenol | 3300 | ND | ND | ND | ND | ND | 3800 | ND |
| Acenaphthene | 690 | ND | 110 | ND | ND | 77 | ND | ND |
| Anthracene | 690 | ND | ND | ND | ND | ND | 70[b] | ND |

**Table 3-1 Maximum Concentrations for Detected Compounds, Compared to UTL's for Surface Soils (0 to 2 Feet) from Phase I and II Data (Sheet 3 of 4)**

| Parameter | Surface Soil UTL | Max Value 1100-1 | Max Value 1100-2 | Max Value 1100-3 | Max Value 1100-4 | Max Value 1100-6 | Max Value HRL | Max Value EP |
|---|---|---|---|---|---|---|---|---|
| SEMI-VOLATILE ORGANIC COMPOUNDS (μg/kg) (continued) | | | | | | | | |
| Benzoic acid | 2790 | ND | ND | ND | ND | ND | 220[a] | ND |
| Benzo(a)anthracene | 690 | ND | ND | 120 | ND | ND | 180 | ND |
| Benzo(a)pyrene | 690 | ND | 110 | 150 | ND | ND | 200 | ND |
| Benzo(b)fluoranthene | 690 | 150 | 79 | 180 | ND | ND | 250 | ND |
| Benzo(g,h,i)perylene | 690 | ND | 330 | 230 | ND | ND | 150 | ND |
| Benzo(k)fluoranthene | 690 | ND | 120 | 160 | ND | ND | 190 | ND |
| Bis(2-ethylhexyl)phthalate | 690 | 390[a] | 290[a] | 940[a] | ND | 2.5E+07 | ND | ND |
| Butylbenzylphthalate | 690 | ND | ND | ND | ND | ND | 99[a] | ND |
| Chrysene | 690 | 100 | ND | 170 | ND | ND | 240 | ND |
| Dibenzofuran | 690 | ND | ND | ND | ND | ND | 130 | ND |
| Dibenz(a,h)anthracene | 690 | ND | 300 | 110 | ND | ND | ND | ND |
| Di-n-butyl phthalate | 690 | ND | ND | ND | ND | ND | 65[b] | ND |
| Di-n-octyl phthalate | 690 | ND | 67[a] | ND | ND | 46000 | ND | ND |
| Fluoranthene | 690 | 110 | ND | 220 | ND | ND | 180 | ND |
| Indeno(1,2,3-cd)pyrene | 690 | ND | 300 | 230 | ND | ND | 170 | ND |
| Naphthalene | 690 | ND | ND | ND | ND | ND | 1100 | ND |
| N-nitroso-di-n-propylamine | 690 | ND | 110 | ND | ND | 78 | ND | ND |
| Pentachlorophenol | 3300 | ND | ND | 99 | ND | ND | 980[b] | ND |
| Phenanthrene | 690 | ND | ND | 130 | ND | ND | 380[b] | ND |
| Phenol | 38100 | ND | 94 | ND | ND | ND | ND | ND |
| Pyrene | 690 | 97 | 120 | 250 | ND | 94 | 220 | ND |

**Table 3-1** Maximum Concentrations for Detected Compounds, Compared to UTL's for Surface Soils (0 to 2 Feet) from Phase I and II Data (Sheet 4 of 4)

| Parameter | Surface Soil UTL | Max Value 1100-1 | Max Value 1100-2 | Max Value 1100-3 | Max Value 1100-4 | Max Value 1100-6 | Max Value HRL | Max Value EP |
|---|---|---|---|---|---|---|---|---|
| PESTICIDES/PCB's (μg/kg) | | | | | | | | |
| 4,4"-DDE | 33 | 6.8 | **42** | ND | ND | **170** | **1200** | ND |
| 4,4'-DDD | 33 | ND | 3.6 | ND | ND | ND | **260** | ND |
| 4,4'-DDT | 33 | ND | **57** | ND | ND | ND | **520**[b] | ND |
| Aldrin | 17 | ND | 9.6[a] | 1.1[a] | ND | 9.6[a] | 11[b] | ND |
| Alpha-chlordane | 170 | 6.5 | ND | ND | ND | **1000** | **770**[b] | **1100**[b] |
| Total PCB's | 1510 | 290 | 300 | 150 | ND | ND | **100550** | **42000** |
| Aroclor 1248 | 170 | ND | ND | ND | ND | ND | **100000**[b] | ND |
| Aroclor 1260 | 330 | 290 | 300 | 150 | ND | ND | 260 | **42000**[b] |
| Aroclor-1254 | 330 | ND | ND | ND | ND | ND | 290 | ND |
| Beta-BHC | 17 | ND | ND | ND | ND | ND | **94**[b] | ND |
| Delta-BHC | 14 | ND | ND | ND | ND | 13 | ND | ND |
| Dieldrin | 33 | ND | 1.3 | ND | ND | 2.3 | **1200**[b] | ND |
| Endosulfan II | 33 | ND | ND | ND | ND | ND | **110**[b] | 160 |
| Endosulfan sulfate | 33 | ND | ND | ND | ND | ND | 19 | ND |
| Endrin | 33 | ND | ND | ND | ND | ND | **280**[b] | **39** |
| Endrin ketone | 33 | ND | 2 | ND | ND | 1.3 | **140**[b] | ND |
| Gamma-BHC(Lindane) | 17 | ND | ND | ND | ND | 0.77 | 1.9 | ND |
| Gamma-chlordane | 158 | 6.2 | ND | ND | ND | **860** | 82 | **1700**[b] |
| Heptachlor | 17 | ND | 1.2 | ND | ND | **65** | ND | 29 |
| Methoxychlor | 170 | ND | ND | ND | ND | ND | 140[b] | ND |

ND - Contaminant not detected
UTL - Upper tolerance limit
[a]Concentration less than detection limit after blank-adjustment
[b]Phase II data

**Table 3-2 Maximum Concentrations for Detected Compounds, Compared to UTL's for Subsurface Soils (> 2 Feet) from Phase I and II Data (Sheet 1 of 3)**

| Parameter | Sub-surface Soil UTL | Max Value 1100-1 | Max Value 1100-2 | Max Value 1100-3 | Max Value 1100-4 | Max Value 1100-6 | Max Value HRL | Max Value EP |
|---|---|---|---|---|---|---|---|---|
| INORGANICS (mg/kg) | | | | | | | | |
| Aluminum | 6236 | 5860 | 7470 | 7400 | 6680 | NS | 17800[b] | NS |
| Antimony | 3.1 | ND | 3 | ND | ND | NS | 15.6[b] | NS |
| Arsenic | 2.92 | 3.2 | 1.8 | 1.8 | 5.8 | NS | 6.6 | NS |
| Barium | 236 | 85.9 | 96.6 | 85.9 | 98.7 | NS | 511[b] | NS |
| Beryllium | 0.27 | ND | ND | ND | 0.93 | NS | 1.1[b] | NS |
| Cadmium | 0.36 | ND | ND | ND | ND | NS | 2.4[b] | NS |
| Calcium | 7830 | 6240 | 13000 | 9080 | 10600 | NS | 44800[b] | NS |
| Chromium | 47.3 | 14.6 | 10.3 | 13.6 | 13.2 | NS | 1250 | NS |
| Cobalt | 16.8 | 11.8 | 15.3 | 17.8 | 16.5 | NS | 42.5 | NS |
| Copper | 19.5 | 25 | 23.6 | 31.7 | 19.8 | NS | 1280[b] | NS |
| Cyanide | 0.51 | ND | ND | ND | ND | NS | 0.56 | NS |
| Iron | 29400 | 25800 | 27100 | 31700 | 26700 | NS | 35200 | NS |
| Lead | 5 | 191 | 45.9 | 4.7 | 5.7 | NS | 854[b] | NS |
| Magnesium | 4680 | 3860 | 4620 | 5290 | 4630 | NS | 7640[b] | NS |
| Manganese | 355 | 249 | 366 | 381 | 329 | NS | 501[b] | NS |
| Mercury | 0.1 | 0.39 | ND | ND | ND | NS | 0.44 | NS |
| Nickel | 26 | 9.5 | 13.8 | 11.3 | 10.7 | NS | 557 | NS |
| Potassium | 966 | 4880 | 1200 | 878 | 1030 | NS | 3820[b] | NS |
| Selenium | 0.41 | ND | ND | ND | ND | NS | 0.36 | NS |
| Silver | 0.54 | ND | ND | ND | 2 | NS | 7.7 | NS |
| Sodium | 419 | 808 | 458 | 999 | 726 | NS | 2360[b] | NS |
| Thallium | 0.41 | ND | ND | ND | 0.48 | NS | 0.46 | NS |
| Vanadium | 115 | 118 | 80.2 | 103 | 82.4 | NS | 101 | NS |
| Zinc | 50.4 | 100 | 54.9 | 60 | 63.8 | NS | 3160[b] | NS |

**Table 3-2 Maximum Concentrations for Detected Compounds, Compared to UTL's for Subsurface Soils (> 2 Feet) from Phase I and II Data (Sheet 2 of 3)**

| Parameter | Sub-surface Soil UTL | Max Value 1100-1 | Max Value 1100-2 | Max Value 1100-3 | Max Value 1100-4 | Max Value 1100-6 | Max Value HRL | Max Value EP |
|---|---|---|---|---|---|---|---|---|
| VOLATILE ORGANIC COMPOUNDS (μg/kg) | | | | | | | | |
| 2-butanone | 11 | 9[a] | 8[a] | 11[a] | ND | NS | 23[a] | NS |
| Acetone | 22 | 26[a] | 28[a] | 29[a] | 9[a] | NS | 200 | NS |
| Benzene | 5 | ND | ND | ND | ND | NS | 0.3[b] | NS |
| Ethylbenzene | 5 | ND | 2 | ND | ND | NS | ND | NS |
| Methylene chloride | 5 | ND | 61[a] | 16[a] | ND | NS | 5[a] | NS |
| Tetrachloroethene | 5 | ND | 16[b] | ND | ND | NS | 4[b] | NS |
| Toluene | 5 | ND | 3[a] | ND | ND | NS | ND | NS |
| SEMI-VOLATILE ORGANIC COMPOUNDS (μg/kg) | | | | | | | | |
| 1,2,4-trichlorobenzene | 350 | ND | ND | ND | ND | NS | 230[b] | NS |
| 1,4-dichlorobenzene | 350 | ND | ND | ND | ND | NS | 170 | NS |
| 2-chlorophenol | 350 | ND | ND | ND | ND | NS | 240[b] | NS |
| 2,4-dinitrotoluene | 350 | ND | ND | ND | ND | NS | 92 | NS |
| 4-chloro-3-methylphenol | 350 | ND | ND | ND | ND | NS | 290 | NS |
| 4-nitrophenol | 1700 | ND | ND | ND | ND | NS | 310 | NS |
| Acenaphthene | 350 | ND | ND | ND | ND | NS | 320[b] | NS |
| Benzoic Acid | 1700 | ND | ND | ND | ND | NS | 160[a,b] | NS |
| Benzo(b)fluoranthene | 350 | 74 | ND | ND | ND | NS | ND | NS |
| Bis(2-ethylhexyl) phthalate | 350 | ND | 3600[a] | 950[a] | ND | NS | 1000[a] | NS |
| Di-n-butylphthalate | 350 | ND | 37 | ND | ND | NS | ND | NS |
| Di-n-octylphthalate | 350 | ND | ND | ND | ND | NS | 270[a,b] | NS |
| Fluoranthene | 350 | 110 | ND | ND | ND | NS | ND | NS |
| N-nitro-di-n-propylamine | 350 | ND | ND | ND | ND | NS | 170 | NS |
| Pentachlorophenol | 1700 | ND | ND | ND | ND | NS | 260 | NS |
| Phenol | 350 | ND | ND | ND | ND | NS | 330[b] | NS |
| Pyrene | 350 | 84 | 290 | ND | ND | NS | 270[b] | NS |

**Table 3-2 Maximum Concentrations for Detected Compounds, Compared to UTL's for Subsurface Soils (> 2 Feet) from Phase I and II Data (Sheet 3 of 3)**

| Parameter | Sub-surface Soil UTL | Max Value 1100-1 | Max Value 1100-2 | Max Value 1100-3 | Max Value 1100-4 | Max Value 1100-6 | Max Value HRL | Max Value EP |
|---|---|---|---|---|---|---|---|---|
| PESTICIDES (μg/kg) | | | | | | | | |
| Aldrin | 17 | ND | 16[a] | ND | ND | NS | 5.5[a,b] | NS |
| Alpha-chlordane | 170 | 1.3 | ND | ND | ND | NS | 13[b] | NS |
| 4,4'-DDE | 34 | ND | **39** | ND | ND | NS | 14 | NS |
| 4,4'-DDT | 34 | ND | **121** | ND | ND | NS | ND | NS |
| Beta-BHC | 17 | ND | ND | ND | ND | NS | 1.2[b] | NS |
| Dieldrin | 34 | ND | ND | ND | ND | NS | **90**[b] | NS |
| Endrin | 34 | ND | ND | ND | ND | NS | **120**[b] | NS |
| Endrin ketone | 34 | ND | 22 | ND | ND | NS | ND | NS |
| Heptachlor | 17 | ND | ND | 0.58 | ND | NS | ND | NS |
| Total PCB's | 1530 | ND | 160 | ND | ND | NS | **2640** | NS |
| Aroclor 1248 | 170 | ND | ND | ND | ND | NS | **640** | NS |
| Aroclor 1254 | 340 | ND | ND | ND | ND | NS | **2000**[b] | NS |
| Aroclor 1260 | 340 | ND | 160 | ND | ND | NS | ND | NS |

Notes:
ND: Contaminant not detected
UTL: Upper tolerance limit
NS: No subsurface samples collected for analysis
[a]Concentration less than detection limit after blank - adjustment
[b]Phase II data

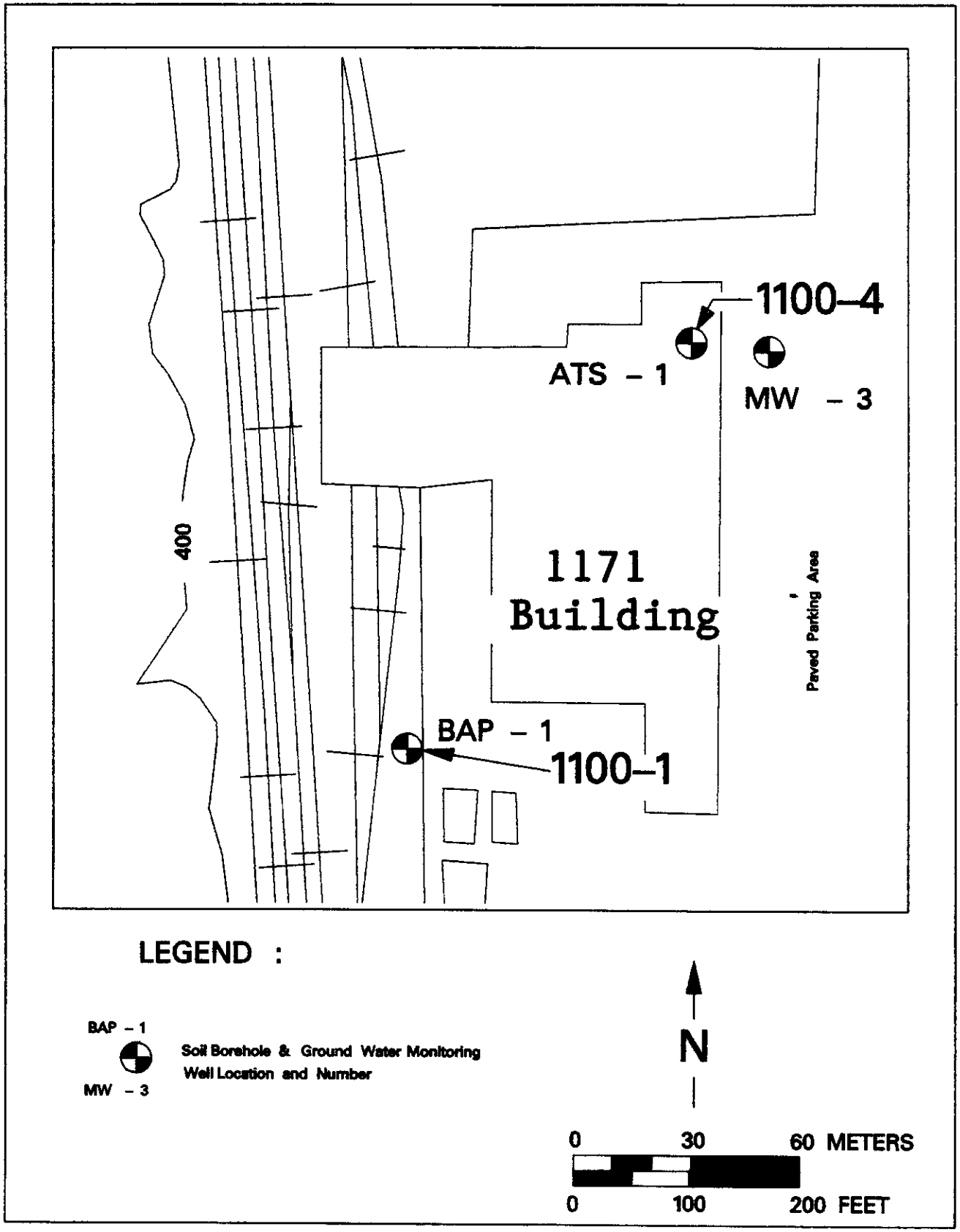


Figure 3–1. 1100–1 and 1100–4 Operable Subunits Soil Sampling Locations.

the pit was filled with locally derived sands and gravels and graded to match the surrounding ground surface.

### 3.1.1 Vadose Zone Sampling

A single borehole was advanced during the Phase I RI at the 1100-1, Battery Acid Pit subunit. This borehole yielded one sample from the surface and seven from the subsurface strata. Sampling and analysis were performed as described in DOE/RL-90-18. Inorganic contaminants were found in surface and subsurface samples. No organic contaminants were detected at this site. Contaminants identified in surface soil samples collected during the Phase I investigation included:

Inorganic Contaminants

| | | | |
|---|---|---|---|
| Calcium | Copper | Lead | Magnesium |
| Mercury | Nickel | Sodium | Zinc |

Organic Contaminants
(None encountered)

Contaminants identified in subsurface samples collected during the Phase I investigation included:

Inorganic Contaminants

| | | | |
|---|---|---|---|
| Arsenic | Copper | Lead | Mercury |
| Potassium | Sodium | Vanadium | Zinc |

Organic Contaminants
(None encountered)

No soil samples were collected at the 1100-1, Battery Acid Pit subunit during the Phase II RI.

### 3.1.2 Geophysical Investigation

A single geophysical survey was performed at the Battery Acid Pit during the Phase I investigation. Geophysical methods employed included Electromagnetic Induction (EMI), Magnetometry (MAG), Metal Detection (MD), and Ground Penetrating Radar (GPR). The geophysical investigation was conducted during the months of January through April 1989 and covered an area of approximately 390.2 square meters (4,200 square feet). Its purpose was to identify the physical location of the former waste disposal site, and to locate any underground utilities adjacent to the pit so they could be avoided during subsequent site investigations.

Survey lines were spaced at close intervals [0.76 m (2.5 ft)] because of the small size of the disposal pit [1.83 meters square (6 feet square)]. GPR signal returns were complex

and difficult to interpret. As noted above, the entire site appears to have been excavated and subsequently backfilled resulting in the complex GPR returns. It was difficult to accurately locate the pit based on geophysical data because of the disturbed nature of the area. A best-guess location map was prepared based on the geophysical data and was used to site soil-gas probes installed in the next phase of the initial characterization activities. A single water supply line was identified at a depth of 1.2 m (4 ft) extending from the 1171 Building to a shower facility located immediately north of the Battery Acid Pit. Two unidentified cables or pipelines were discovered to the west of the Battery Acid Pit (Sandness *et.al.*, 1989).

Geophysical surveys were not performed during the 1100-EM-1 Phase II investigations at the 1100-1, Battery Acid Pit subunit.

### 3.1.3 Soil-Gas Investigation

Five temporary soil-gas probes were installed at the Battery Acid Pit in June, 1989, as part of the Phase I investigation. One probe was placed in the approximate center of the Battery Acid Pit as located from measurements obtained through interviews with past area employees and by ground penetrating radar surveys. One probe was placed immediately west of the pit center, and the remaining three located along a north-south line to the east of the former disposal site. No contamination was detected during the analyses of the soil-gas samples (Evans, 1989).

Soil-gas investigations were not performed during Phase II RI of the 1100-EM-1 Operable Unit at this subunit.

### 3.1.4 Summary of Investigations

Site investigations at the 1100-1 subunit, Battery Acid Pit, detected inorganic contaminants in soils. Geophysical surveys detected the presence of an underground water line in the vicinity of the subunit and two questionable finds that may represent underground cables or pipelines. Soil-gas investigations failed to identify contaminants at the subunit.

## 3.2 PAINT AND SOLVENT PIT-1100-2

The Paint and Solvent Pit is a semicircular depression located approximately 1.6 km (1 mile) north of the 1171 Building (figure 3-2). Originally a sand and gravel pit, the site was used during the period between 1954 through 1985 for the disposal of construction debris generated during demolition of Hanford Site facilities. Principal components of the waste include concrete rubble, asphalt, and wood debris. Undocumented disposal of waste paint, solvent, and paint thinner is also reported to have occurred at this site. The pit has an approximate diameter of 108 m (354 ft) and a depth of 1.2 to 1.8 m (4 to 6 ft).

The Paint and Solvent Pit is filled with between 1.2 and 4.9 m (4 to 16 ft) of backfill mixed with asphalt debris derived from the construction of a nearby highway. A side spur of



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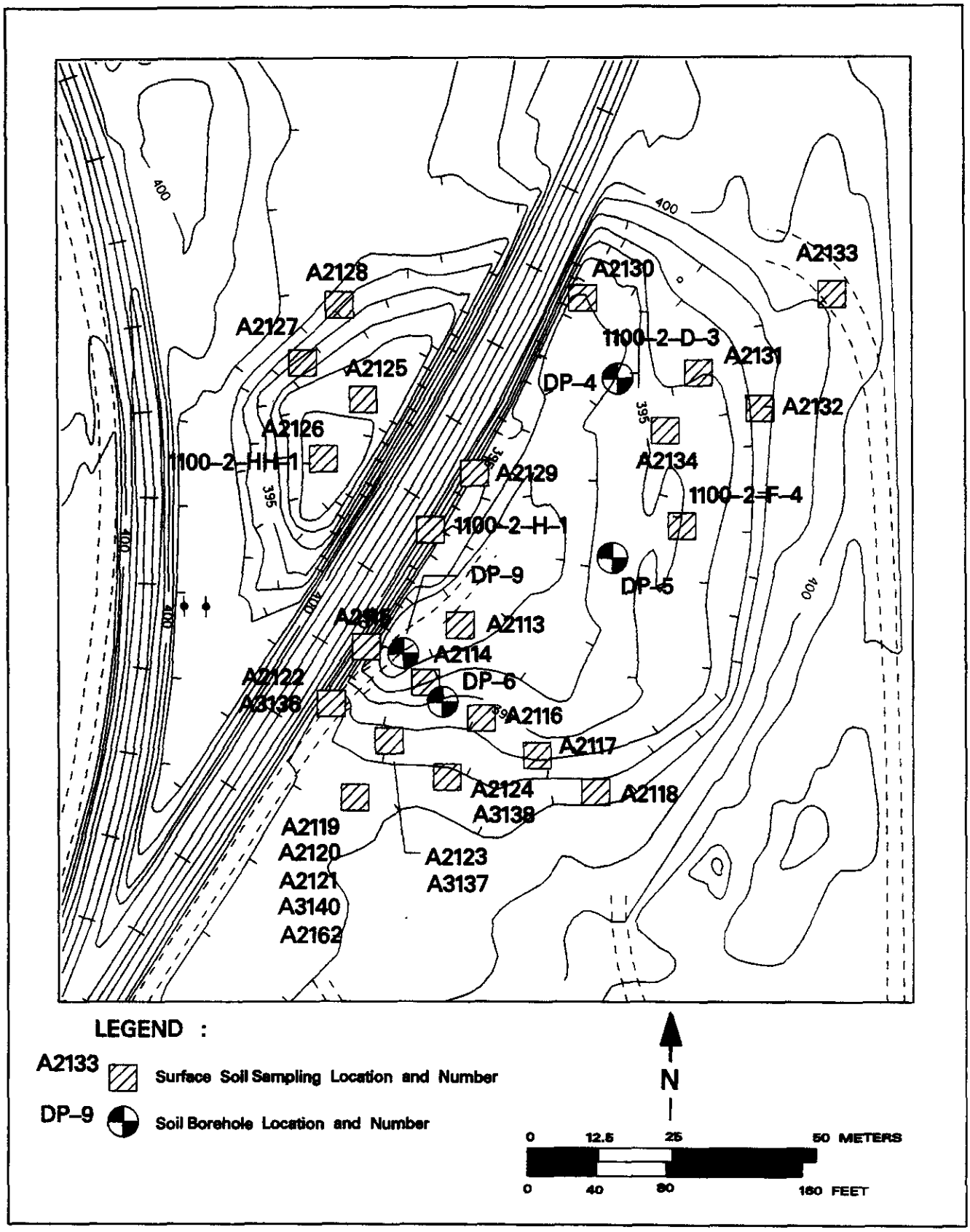


Figure 3-2. 1100-2 Paint and Solvent Pit - Operable Subunit Soil Sampling Locations.

the Hanford Rail Line traverses the pit in a southwest-northeast direction isolating the northwest third of the pit from the remainder of the disposal site.

### 3.2.1 Vadose Zone Sampling

Four boreholes drilled at this site during the Phase I RI yielded 4 surface samples and 29 subsurface soil samples. In addition, soil samples were obtained at 20 surface locations within the 1100-2, Paint and Solvent Pit subunit (figure 3-2). Inorganic, organic and pesticide contamination was detected in surface and subsurface samples. Sampling and analysis methodologies and results are presented in the Phase I RI report (DOE/RL-90-18). Contaminants identified in surface soil samples collected during the Phase I investigation included:

<u>Inorganic Contaminants</u>

| | | | |
|---|---|---|---|
| Calcium | Chromium | Copper | Lead |
| Potassium | Sodium | Thallium | |

<u>Organic Contaminants</u>

| | | |
|---|---|---|
| Chlorobenzene | Tetrachlorethene | Trichloroethene |
| 1,1-dichloroethene | Xylene | |

Contaminants identified in subsurface samples collected during the Phase I investigation included:

<u>Inorganic Contaminants</u>

| | | | |
|---|---|---|---|
| Calcium | Copper | Lead | Magnesium |
| Manganese | Potassium | Sodium | Zinc |

<u>Organic Contaminants</u>

| | | |
|---|---|---|
| 4,4'-DDE | 4,4'-DDT | Tetrachloroethene |

Soil sampling was not performed at the 1100-2, Paint and Solvent Pit subunit during the Phase II RI.

### 3.2.2 Geophysical Investigation

One geophysical survey was performed at the Paint and Solvent Pit during the Phase I investigation. Geophysical methods employed included EMI, MAG, MD, and GPR. The geophysical investigation covered an area of approximately 1.09 hectares (2.7 acres) during the months of January through April, 1989. The purpose was to obtain information regarding waste materials buried at the site, information regarding the location of waste disposal structures (pits and trenches), identification of any underground utilities that may cross the site, and identification of any other waste disposal-related features existing within the depression.



9 3 1 2 7 4 0 1 4 8

Waste materials identified within the Paint and Solvent Pit are concentrated in the eastern portion of the subunit. No waste deposits were evident in the portion of the pit west of the railroad tracks. A GPR reflector located at a depth of approximately 3.05 m (10 ft) appears to mark the bottom of the original pit. Based on surface observations, waste material consists predominantly of concrete and asphalt debris. Geophysical signatures indicating the presence of metals can be explained by the presence of reinforcing steel (rebar) within concrete blocks. None of the geophysical data suggest the presence of steel drums within the subunit. Waste deposits are covered by 0.61 to 1.52 m (2 to 5 feet) of soil. The only other features identified at the site were several abandoned metal irrigation pipes. Portions of these pipes are visible on the ground surface (Sandness *et. al.*, 1989).

No geophysical investigations were performed at the 1100-2, Paint and Solvent Pit during the Phase II RI.

### 3.2.3 Soil-Gas Investigation

Sixty-two temporary soil-gas probes were installed, sampled, and analyzed during the Phase I investigation, in February and March, 1989. One area of relatively high readings of tetrachloroethene (PCE) was found in the southwest corner of the site close to the end of a service road which extends back toward a railroad storage yard located immediately north of the Paint and Solvent Pit site. Concentration values peaked at 727 $\mu$g/L PCE with values steeply dropping in all directions away from the high. Areal distribution of the positive soil-gas readings suggested the potential for an isolated, shallow accumulation or small surface spill of solvent within the pit. However, no PCE was identified in any soil sample for this subunit. No other volatile contaminants were detected during the soil-gas survey (Evans, 1989).

Phase II investigations did not include any additional soil-gas monitoring at the 1100-2, Paint and Solvent Pit subunit.

### 3.2.4 Summary of Investigations

Site investigations at the 1100-2 subunit, Paint and Solvent Pit, detected inorganic, organic, and pesticide contamination in site soils. Geophysical surveys located several abandoned waterlines within and adjacent to the Paint and Solvent Pit. Other geophysical returns can be ascribed to reinforcing steel (rebar) within concrete blocks at the site. Geophysical data did not reveal the presence of buried drums. Soil-gas investigations detected an isolated area of PCE contamination in the southwest corner of the pit. However, no PCE was identified in any soil sample for this subunit.

## 3.3. ANTIFREEZE AND DEGREASER PIT-1100-3

The 1100-3, Antifreeze and Degreaser Pit is a shallow, roughly circular depression located approximately 1.6 km (1 mile) north of the 1171 Building on the west side of the

Hanford Rail Line (figure 3-3). Originally a sand and gravel source for construction activities on the Hanford Site, it was used during the period of 1979 to 1985 as a disposal site for waste construction material, principally roofing and concrete rubble. The pit is approximately 76 m (250 ft) in diameter and 1.8 to 2.4 m (6 to 8 ft) deep. Occasional disposal of waste antifreeze and degreasing solutions from the 1171 Building is suspected, but not documented, at this location.

### 3.3.1 Vadose Zone Sampling

Twenty-three surface samples were collected and twenty-four subsurface samples were obtained from four boreholes at the 1100-3, Antifreeze and Degreaser Pit during the Phase I RI as outlined in DOE/RL-90-18 (figure 3-3). Inorganic contaminants were found in surface and subsurface samples. No organic contaminants were detected at the 1100-3 subunit. Contaminants identified in surface soil samples collected during the Phase I investigation included:

<u>Inorganic Contaminants</u>

| | | | |
|---|---|---|---|
| Aluminum | Calcium | Chromium | Copper |
| Lead | Sodium | Thallium | |

<u>Organic Contaminants</u>
(None encountered)

Contaminants identified in subsurface samples collected during the Phase I investigation included:

<u>Inorganic Contaminants</u>

| | | | |
|---|---|---|---|
| Aluminum | Calcium | Cobalt | Copper |
| Iron | Magnesium | Manganese | Sodium |
| Zinc | | | |

<u>Organic Contaminants</u>
(None encountered)

No Phase II soil samples were taken at the 1100-3, Antifreeze and Degreaser Pit.

### 3.3.2 Geophysical Investigation

One geophysical survey was completed at the Antifreeze and Degreaser Pit during the Phase I investigation. Geophysical methods employed included EMI, MAG, MD, and GPR. The geophysical investigation, undertaken during the months of January through April 1989, covered an area of approximately 1.5 hectares (3.7 acres). The purpose was to obtain



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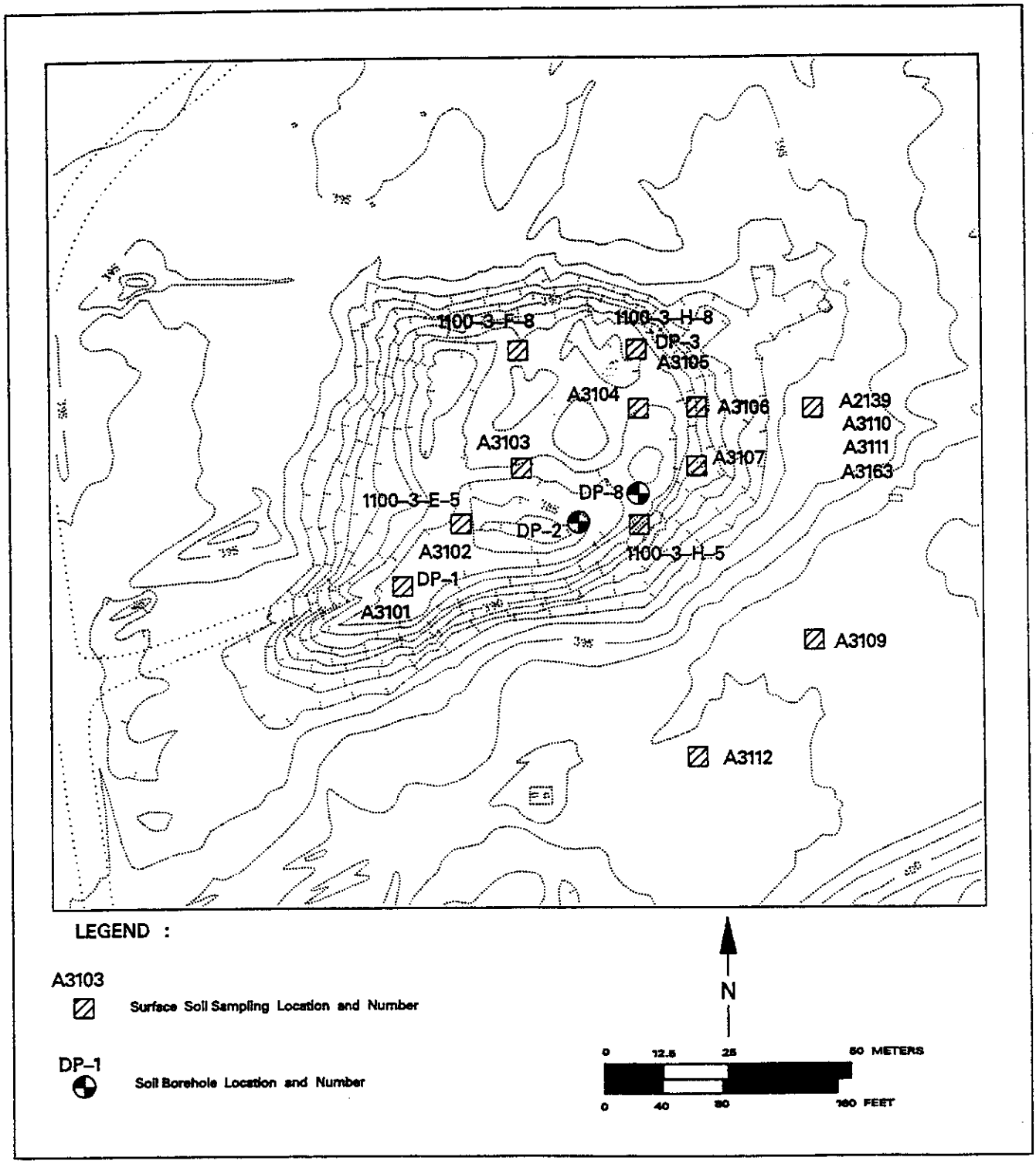



Figure 3-3 1100-3 Antifreeze and Degreaser Pit – Operable Subunit Soil Sampling Locations.

information regarding waste materials buried at the site, to locate waste disposal structures (pits and trenches), to identify any underground utilities crossing the site, and to identify any other waste disposal-related features existing within the depression.

Waste materials within the Antifreeze and Degreaser Pit are concentrated in one large body and two smaller satellite bodies. The material appears to consist predominantly of concrete debris. As with the Paint and Solvent Pit, large metal signatures identified at the site likely result from reinforcing steel (rebar) within the concrete. None of the signatures indicate the presence of steel drums. Further conclusions regarding waste deposits at this site could not be made. A single abandoned tile pipe was identified in the vicinity of the pit (Sandness *et. al.*, 1989).

No geophysical investigations were performed at the 1100-3, Antifreeze and Degreaser Pit subunit during Phase II RI activities.

### 3.3.3 Soil-Gas Investigation

Forty-three soil-gas samples were collected during the Phase I RI from the Antifreeze and Degreaser Pit. Sample collection occurred during the months of May and June 1989. All sampling probes were temporary and were removed after the initial round of sampling was completed. No contaminants were detected during the soil-gas investigation (Evans, 1989).

Soil-gas sampling was not undertaken during the Phase II investigations of the 1100-EM-1 Operable Unit at 1100-3, the Paint and Solvent Pit.

### 3.3.4 Summary of Investigations

Site investigations at the 1100-3 subunit, Paint and Solvent Pit, detected inorganic contaminants in site soils. Geophysical investigations did not provide evidence for the presence of buried drums, however, a single abandoned tile pipe was detected. Soil-gas sampling failed to detect any contaminants at the 1100-3, Antifreeze and Degreaser Pit subunit.

## 3.4 ANTIFREEZE TANK SITE - 1100-4

The Antifreeze Tank Site is located beneath the concrete floor of the northern-most portion of the 1171 Building (figure 3-1). It is the former location of a 19,000 L (5,000 gal) steel, underground waste antifreeze storage tank. The tank was installed in 1976 and removed in 1986 due to suspected leakage. No evidence of leakage was detected during the removal operation.

### 3.4.1 Vadose Zone Sampling

During tank removal, three soil samples were collected from the base of the excavation. No detectable levels of antifreeze were identified. In November 1989, a hole was cut through the concrete floor of stall 89 inside the 1171 Building to allow sampling of the waste site. Thirteen vadose zone samples were collected and analyzed for the full suite of chemical analyses (TCL and TAL) including ethylene glycol. Only a single sample detected ethylene glycol at a concentration of 2.6 parts per million (ppm). Other than this single exception, only inorganic contaminants were detected at this site. Sample analysis results are reported in the Phase I RI report (DOE/RL-90-18). Contaminants identified in subsurface samples collected during the Phase I investigation included:

Inorganic Contaminants

| | | | |
|---|---|---|---|
| Aluminum | Arsenic | Beryllium | Calcium |
| Copper | Lead | Potassium | Silver |
| Sodium | Thallium | Zinc | |

Organic Contaminants

Ethylene glycol

No surface data or soil samples were collected at the 1100-4, Antifreeze Tank Site during the Phase II investigations.

### 3.4.2 Summary of Investigations

Site investigations at the 1100-4 subunit, Antifreeze Tank Site, detected inorganic contaminants and a single organic contaminant in subunit soils.

## 3.5 DISCOLORED SOIL SITE - UN-1100-6

The Discolored Soil Site was identified during the RI Phase I scoping process as a patch of oily, dark stained soil located in the eastern end of an elongate east-west oriented depression approximately 610 m (2,000 ft) northwest of the 1171 Building on the west side of the Hanford Rail Line (figure 1-2). The depression extends over an area of approximately 0.2 hectares (0.4 acres); the actual area of discolored soil covering an area of perhaps 1.8 by 3.1 m (6- by 10 ft).

The southern boundary of the triangular-shaped depression consists of a steep slope apparently excavated in a natural sand dune. The northern boundary is defined by a similar steep slope comprised of material excavated during the construction of a northeast-southwest trending, concrete lined irrigation canal located immediately to the north of the bounding slope. The short eastern boundary of the Discolored Soil Site consists of the raised bed of a native-surfaced road that parallels the western edge of the Hanford Rail Line. The discoloration is located immediately adjacent to the eastern site boundary at the base of the road fill slope.

The source of the soil discoloration is conjectured to be the isolated, unauthorized disposal of contents of one or more containers of liquid material to the ground surface. No record exists that identifies the nature or origin of the waste of the material deposited at the site.

### 3.5.1 Vadose Zone Sampling

Fifteen surface samples were obtained from this site during the Phase I RI (figure 3-4). Analyses were for TAL and TCL parameters as described and reported in the Phase I RI report (DOE/RL-90-18). No subsurface sampling was performed. Inorganic, organic, and pesticide contamination was detected at this site. Contaminants identified in surface soil samples collected during the Phase I investigation included:

<u>Inorganic Contaminants</u>
Lead Potassium Zinc

<u>Organic Contaminants</u>
Alpha-chlordane Gamma-chlordane 4,4'-DDE BEHP
Heptachlor 2-hexanone di-n-octyl phthalate
1,1,1-trichloroethane

No soil samples were collected from the UN-1100-6, Discolored Soil Site during the Phase II investigations.

### 3.5.2 Soil-Gas Investigation

Soil-gas sampling was not performed during the RI Phase I investigation of the UN-1100-6, Discolored Soil Site subunit.

Fourteen temporary soil-gas probes were installed at the Discolored Soil Site to depths ranging between 0.46 and 1.22 m (1.5 and 4 ft) during the Phase II investigation. The purpose was to investigate the possibility of a vadose zone source for contaminants identified during surface soil sampling/analysis. The installations occurred in November and December 1990. Target compounds were not detected in any of the soil-gas samples (WHC, 1991b).

### 3.5.3 Summary of Investigations

Inorganic, organic, and pesticide contaminants were detected in soils of the UN-1100-6, Discolored Soil Site subunit at concentrations above UTL's.

Target compounds were not detected during the soil-gas investigation.

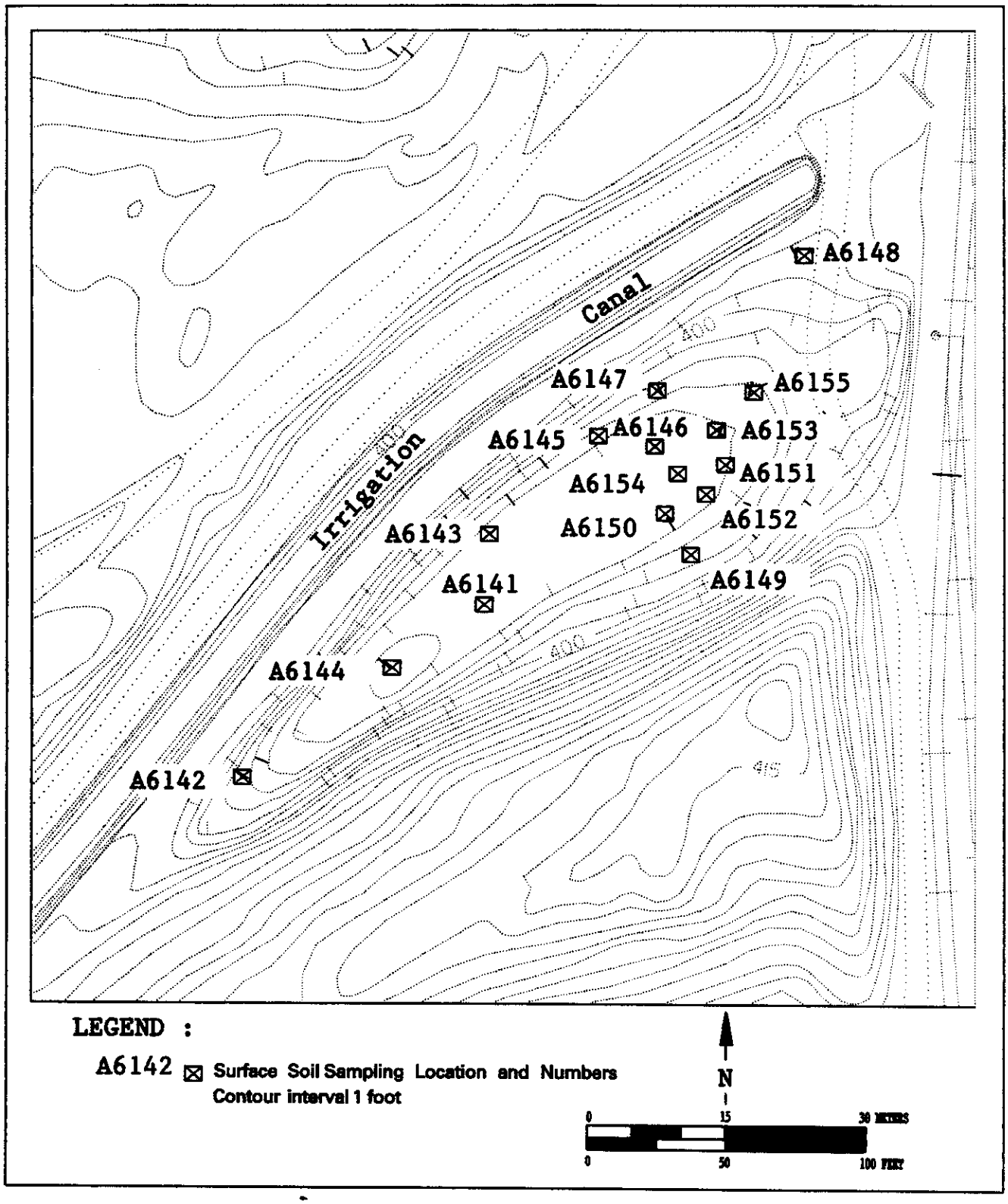



Figure 3-4. 1100-6 Operable Subunit Soil Sampling Locations

## 3.6 EPHEMERAL POOL

The Ephemeral Pool is a long, narrow, manmade depression located along the western edge of the asphalt paved 1171 Building parking area (figure 1-2). The depression acts as a drainage collection point for precipitation runoff flowing from the parking area surface. It is bounded on the east by the parking facility and on the west by ballast of the Hanford Rail Line. On the north and south, the Ephemeral Pool boundaries are not as distinct. The bottom of the depression gradually rises toward both the north and south to near the elevation of surrounding land. Overall dimensions are approximately 6.1 m (20 ft) wide (east-west direction) by 183 to 213 m (600 to 700 ft) in length (north-south direction).

The Ephemeral Pool was designed to collect runoff from the parking area and direct it to a central culvert located approximately at the lengthwise mid-point of the depression. Settlement and/or poor grading of the depression floor results in the formation of a series of linked pools after rainfall events that temporarily hold a portion of the collected moisture within the drainage way until it evaporates or infiltrates into the ground. A pervious gravel lining encourages infiltration of the collected runoff into the vadose zone beneath this site.

9 3 1 2 7 4 0 1 5 6

### 3.6.1 Vadose Zone Sampling

**3.6.1.1 Phase I Soil Sampling.** The Phase I RI report describes the sampling and analytical results for two surface samples taken within the Ephemeral Pool. Results of the analyses indicated the presence of PCB's in low to moderate concentrations (300 to 4700 $\mu$g/kg). Contaminants identified in surface soil samples collected during the Phase I investigation included:

<u>Inorganic Contaminants</u>

| | |
|---|---|
| Lead | Zinc |

<u>Organic Contaminants</u>

| | | |
|---|---|---|
| Aroclor-1260 | Alpha-Chlordane | Gamma-Chlordane |
| Endosulfan II | Endrin | Heptachlor |

**3.6.1.2 Phase II Soil Sampling.** Six surface samples and one duplicate were obtained for the Phase II RI in order to delineate the lateral extent of organic contamination at the Ephemeral Pool (figure 3-5). The soil samples collected during the Phase II RI were submitted for PCB and pesticide analyses. Laboratory results confirm the presence of alpha and gamma chlordane in concentrations of 210 to 1100 $\mu$g/kg and 330 to 1700 $\mu$g/kg, respectively. Positive results for PCB's (Aroclor 1260) were obtained from two of the seven samples with concentrations of 11,000 and 42,000 $\mu$g/kg. Contaminants identified in surface soil samples collected during the Phase II investigation included:

<u>Inorganic Contaminants</u>
(Not analyzed)

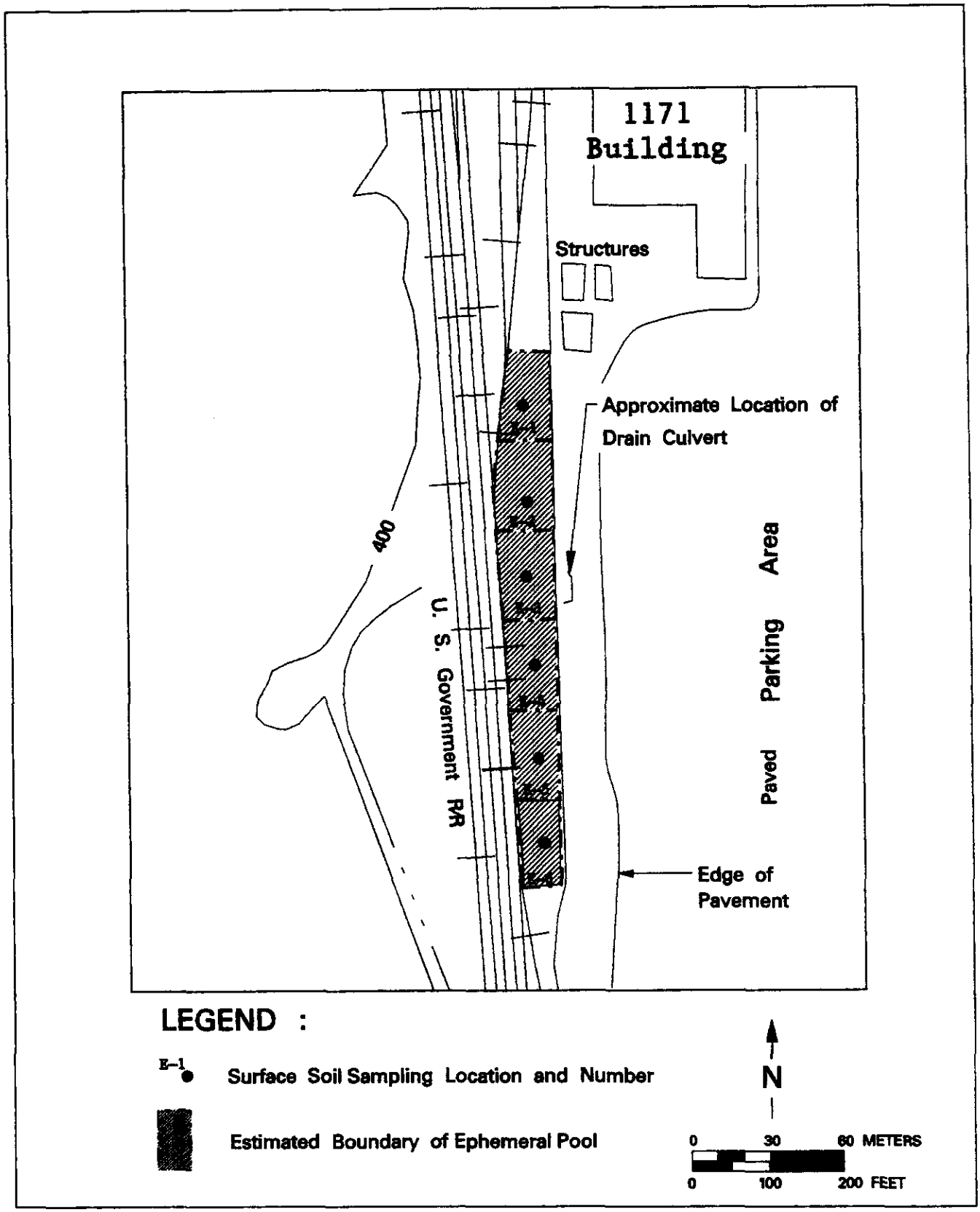



Figure 3-5. Ephemeral Pool Subunit Phase II Soil Sampling Locations

Organic Contaminants

Chlordane[1]
Endosulfan II
Endrin
PCB's[2]

[1] alpha and gamma isomers combined for evaluation as total chlordane.
[2] all polychlorinated biphenyls combined for evaluation as total PCB's.

Analytical results are presented in appendix D.

### 3.6.2 Summary of Investigations

Organic and pesticide contamination of soils within the Ephemeral Pool subunit were detected at concentrations above UTL's.

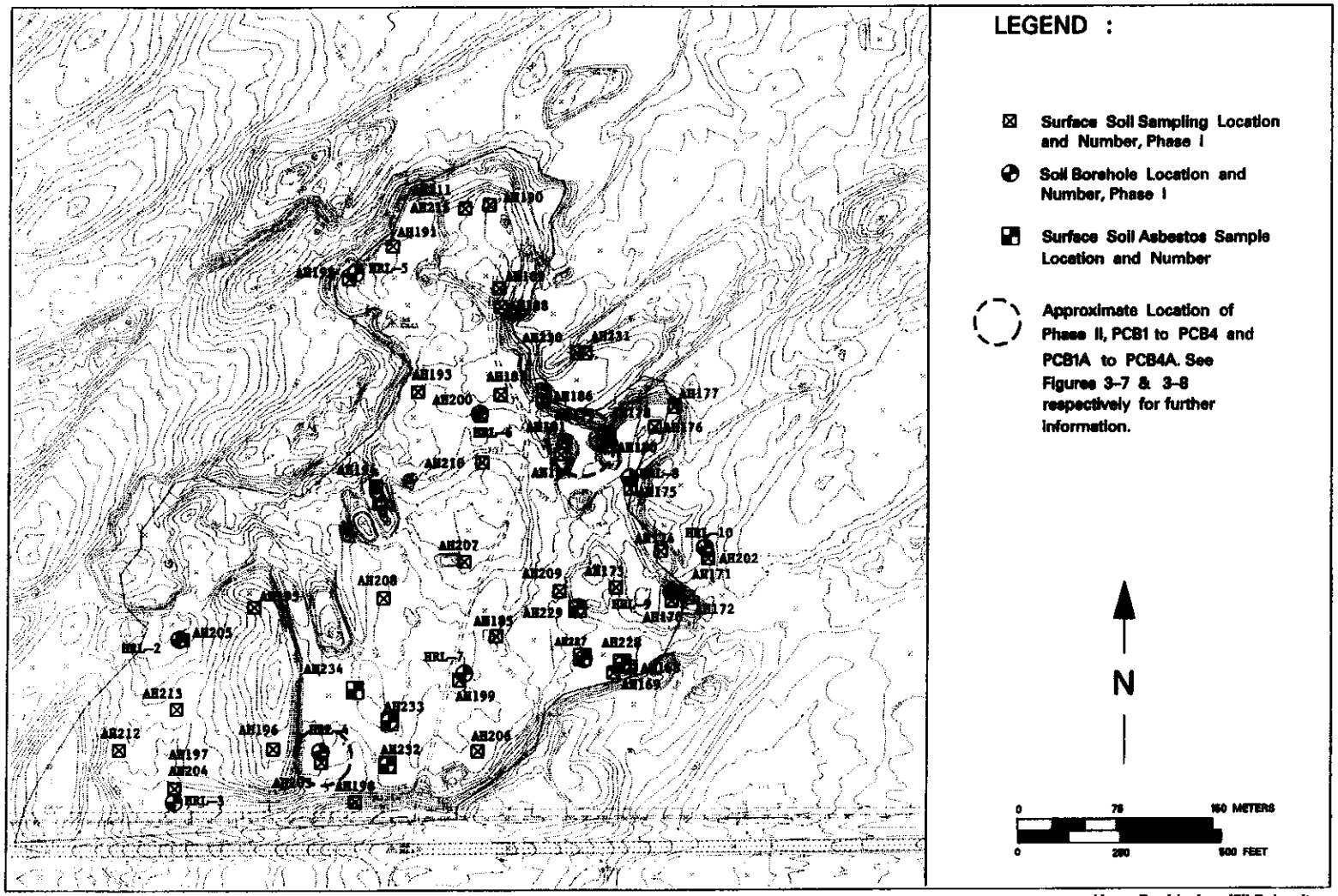
## 3.7 HRL

The HRL, which is located northeast of the SPC facility and north of Horn Rapids Road, extends over approximately 20 hectares (50 acres) of the 600 Area (figure 1-2). It was operated from the late 1940's into the 1970's as an uncontrolled landfill for Hanford Site contractors, and was repeatedly used for unauthorized dumping by non-Hanford staff and area residents throughout its lifetime. Records indicate the predominant debris types deposited in disposal trenches excavated on the site were office construction refuse and demolition-derived materials, *e.g.*, broken concrete, waste metals and wood, metal piping, and insulation. HRL was not a hazardous waste landfill. The vast majority of materials deposited were solid waste.

The landfill is sited in generally flat terrain. Five partially to completely filled disposal trenches have been identified at the site through a study of historic aerial photographs, onsite investigations, and geophysical surveys. Surface debris consisting of auto and truck tires, wood, metal shavings, soft drink cans and bottles, and other small pieces of refuse are scattered across the site. A single trench, the western-most of the identified waste disposal trenches, was posted with signs warning that the feature contained asbestos.

### 3.7.1 Vadose Zone Sampling

**3.7.1.1 Phase I Soil Sampling.** Soil sampling at HRL was performed as described in the Phase I RI report (DOE/RL-90-18). Fourteen boreholes were advanced during the Phase I RI at HRL. These boreholes yielded 63 discrete soil samples; 8 samples were obtained from the surface strata and 55 were obtained from the subsurface. Forty-two additional surface samples were taken from the landfill (figure 3-6). It should be noted that during the




Horn Rapids Landfill Subunit
Soil Sampling Locations

Fig. 3-6

Phase I RI, boreholes were intentionally sited to avoid drilling through known and suspected waste deposits. The locations were determined during scoping meetings, and following implementation of the landfill geophysical and soil-gas surveys. These decisions were made jointly by DOE and regulatory agencies for reasons of safety and health concerns and places substantial limitations on the representativeness of the soil quality results of the Phase I data.

Numerous inorganic, organic, pesticide, and PCB contaminants were encountered in the surface and subsurface soils of the HRL during the Phase I investigation. Contaminants identified in surface soil samples collected during the Phase I investigation included:

Inorganic Contaminants

| | | | |
|---|---|---|---|
| Aluminum | Arsenic | Barium | Beryllium |
| Cadmium | Calcium | Chromium | Cobalt |
| Copper | Cyanide | Iron | Lead |
| Magnesium | Mercury | Nickel | Potassium |
| Silver | Sodium | Thallium | Zinc |

Organic Contaminants

| | | | |
|---|---|---|---|
| Aroclor-1248 | Aroclor-1254 | Alpha-Chlordane | 4,4'-DDD |
| 4,4'-DDE | 4,4'-DDT | Heptachlor | 2-methylnaphthalene |
| Naphthalene | Tetrachloroethene | | |

Contaminants identified in subsurface soil samples collected during the Phase I investigation at the HRL subunit included:

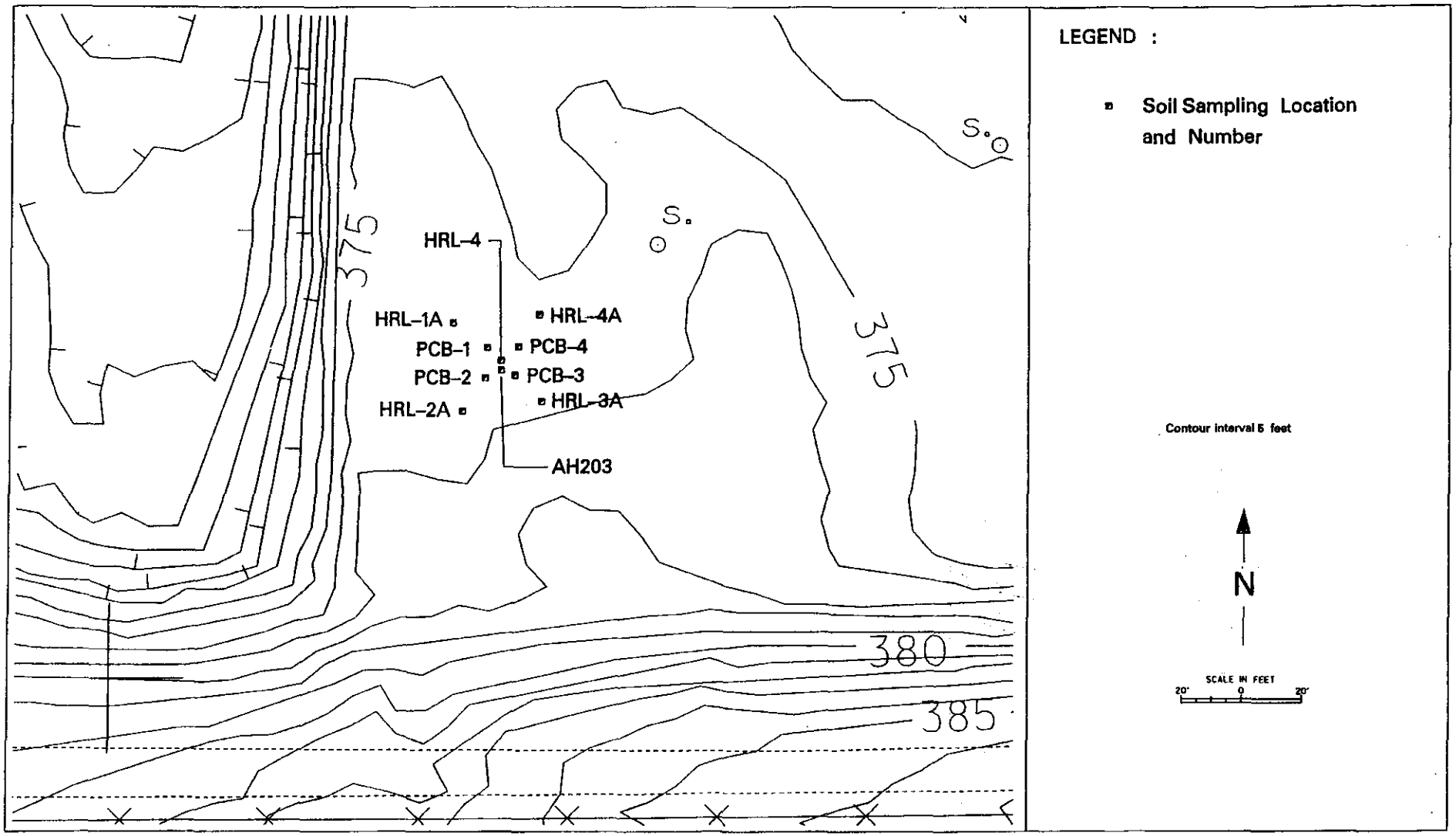
Inorganic Contaminants

| | | | |
|---|---|---|---|
| Aluminum | Antimony | Arsenic | Barium |
| Beryllium | Cadmium | Calcium | Chromium |
| Cobalt | Copper | Cyanide | Iron |
| Lead | Magnesium | Mercury | Nickel |
| Potassium | Silver | Sodium | Thallium |
| Zinc | | | |

Organic Contaminants

Aroclor-1248

**3.7.1.2 Phase II Soil Sampling.** Phase II sampling was performed in an attempt to further delineate pesticide and PCB contamination at HRL. Eight surface samples were taken from the vicinity of borehole HRL-4; PCB-1 to PCB-4 and PCB-1A to PCB-4A (figure 3-7). Fifteen samples were taken from the surface between depths of 0 and 0.7 m (0 and 2 ft) at pits 4 and 5; B4-1, B5-1, B5-2 and B5-3 (figure 3-8). Thirteen subsurface samples were taken during disposal trench characterization activities (see paragraph 3.7.4). Contaminants identified during Phase II soil analyses that were not detected above UTL's during the Phase I investigation include:




Horn Rapids Landfill Phase II
Soil Sample Locations

Figure 3-7.

9 3 1 2 7 4 0 1 5 2

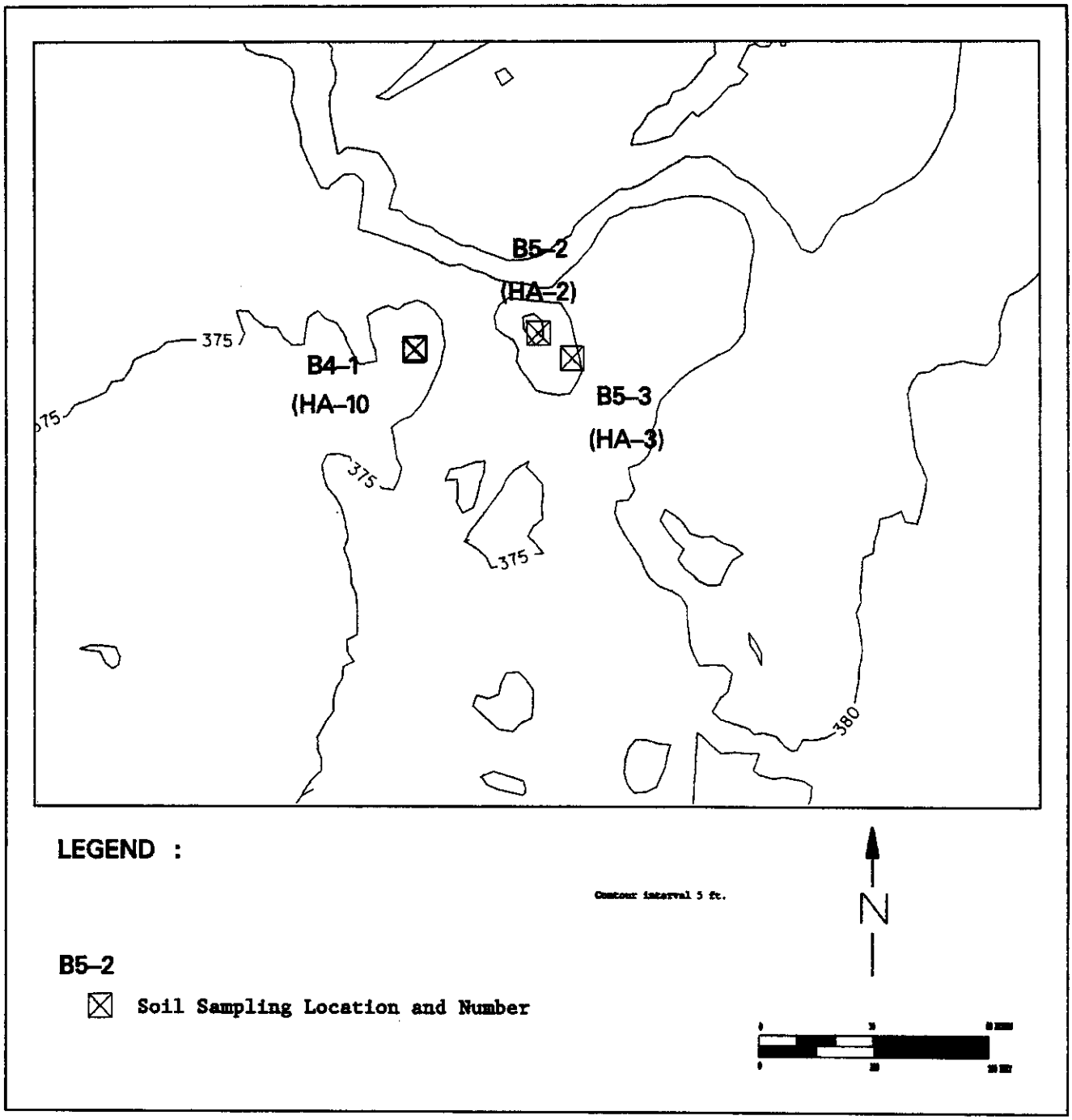



Figure 3-8. Horn Rapids Landfill Phase II Soil Sampling Locations.

| Surface | Subsurface |
|---|---|
| Inorganic Contaminants | Inorganic Contaminants |
| None encountered | Manganese |
| Organic Contaminants | Organic Contaminants |
| Endosulfan II | Dieldrin |
| Endrin | Total PCB's |

### 3.7.2 Geophysical Investigations

Two separate geophysical surveys were performed at HRL as part of the Phase I and II RI. Phase I RI surveys employed EMI, MAG, MD, and GPR methods. The geophysical investigation for the Phase II RI employed EMI, MAG, and GPR surveys.

**3.7.2.1 Phase I RI.** The Phase I geophysical investigation covered an area of approximately 24.7 hectares (61 acres) during the months of January through April 1989. The purpose was to obtain information regarding waste materials buried at the site, to locate waste disposal structures (pits and trenches), to identify any underground utilities crossing the site, and to identify any other waste disposal-related features existing within the landfill. Survey lines were laid out with a 30.5 m (100 ft) spacing.

Due to the wide spacing of survey lines, little in the way of detailed data concerning the disposal trench contents was obtained. Based on GPR results, disposal trenches were interpreted as containing abundant waste metals to at least depths approaching 5.5 m (18 ft). Waste deposits were found to be concentrated in a roughly 6.9 hectare (17 acre) area in the south-central portion of the landfill. Outside of the five identified waste disposal trenches, no other major waste accumulations were detected, although the entire surface of the subunit is littered with miscellaneous debris. The landfill had apparently been a large sand and gravel pit prior to its use as a disposal facility. This conclusion was reached due to the absence of eolian dune sand throughout the surveyed area and the exposure of normally buried natural deposits of sand and gravels at the ground surface (Sandness, *et. al.*, 1989).

**3.7.2.2 Phase II RI.** The Phase II RI geophysical investigation at HRL was performed to further delineate disposal trench boundaries identified during the first geophysical surveys of the site and to search for an accumulation of drums containing organic solvents said to have been buried at this facility. During May 1991, EMI and MAG surveys were performed to delineate the trenches fully and to perform the initial search for drums. GPR was used to define the spacial extent, both vertically and laterally, of anomalies identified by the initial two geophysical methods.

A total of 4.7 hectares (11.7 acres) were surveyed. The EMI survey grid was performed along lines spaced 3.1 m (10 ft) east-west and 6.1 m (20 ft) north-south. The grid for MAG measurements was laid out on lines spaced 3.1 by 3.1 m (10 x 10 ft). The GPR survey was run over east-west lines spaced at 3.1 m (10 ft) intervals; each line ranging from 24.4 m (80 ft) to 121.9 m (400 ft) in length. Details of these discussions are presented in

the minutes of the Unit Manager's Meetings in the summer and early fall of 1991. The minutes are available as part of the Administrative Record for the 1100-EM-1 Operable Unit.

Anomalies identified by the EMI survey were located in the immediate vicinity of disposal trenches, adjacent to the burn cage located at the northern edge of the landfill and, finally, the burn cage itself was identified as an anomaly. MAG anomalies were generally coincident with those identified by EMI. Results obtained near the disposal trenches were interpreted as being caused by an abundance of shallow deposits of metallic debris buried within the features. The quantity of metallic debris was such that each disposal trench effectively registered as a single buried metal object. GPR survey results were less specific. Signal penetration outside the disposal trenches reached to depths of 4.9 to 6.1 m (16 to 20 ft). Fairly continuous stratigraphic boundaries were found to exist in these areas. In contrast, signal returns from directly over the disposal trenches were generally chaotic. Penetration into the subsurface was severely limited and irregular. A total of 253 targets were identified during the GPR survey, most at depths of between 1.5 and 3.1 m (5 to 10 ft).

The overall interpretation of the Phase II RI geophysical investigation at HRL identifies extensive shallow deposits of metallic debris buried within the recognized disposal trenches. There were no geophysical signatures obtained from any area investigated consistent with an interpretation indicating the presence of 10 or more drums in the subsurface at the HRL. The 10-drum guideline was established by the regulators as the minimum number which would constitute a significant concentration of drums requiring even further investigations. Of the five trenches of concern, the asbestos trench, (the western-most and longest disposal trench which was posted with signs identifying the presence of asbestos-containing materials), was the least likely candidate to contain buried drums based on geophysical survey results (Golder, 1991).

### 3.7.3 Soil-Gas Investigations

Soil-gas studies were performed at HRL and in surrounding areas during both the Phase I and Phase II RI utilizing permanent and temporary soil-gas extraction points. All permanent soil-gas probes were installed during the Phase I investigation. Monitoring of permanent probes continued through the Phase II investigations at HRL. Purposes of the soil-gas monitoring included the preliminary delineation of the groundwater contaminant plume located beneath the Horn Rapids area to assist in siting permanent groundwater monitoring wells; a survey of the vadose zone for a possible contaminant source contributing to groundwater quality degradation; and, evaluation of the sensitivity of soil-gas monitoring and its usefulness to define accurately the extent and rate of growth of a groundwater contaminant plume. A summary of the results of each is presented in the following paragraphs. Detailed results of soil-gas sampling activities performed at HRL can be found in Evans, 1989 and Golder Associates, 1992.

**3.7.3.1 Delineation of Groundwater Contaminant Plume.** The first stage of preliminary soil-gas sampling performed at HRL was for the purpose of scoping work for future RI sampling activities. Two hundred and eleven temporary soil-gas extraction points were installed in the landfill area to depths between 1.1 and 1.2 m (3.5 and 4.0 ft) during the

period of March through May, 1989. Evidence of contamination by several chlorinated species including trichloroethene (TCE); 1,1,1 trichloroethane (TCA); and PCE was found within the HRL. TCE was widespread on the east side of the landfill and was found in a narrow plume extending from the southern boundary northwards toward the center of the landfill. A small area with positive TCA readings is coincident with the TCE plume which extends from the landfill's southern boundary. A region of positive PCE readings is located approximately 152 m (500 ft) east of the TCE maximum (Evans, 1989). Results of this preliminary scoping study were used to determine the siting of subsequent groundwater monitoring wells installed near HRL during the Phase I RI.

During the second stage of RI sampling, a total of 53 additional sampling probes were installed, sampled, and analyzed to delineate the TCE plume previously identified in the vicinity of HRL. The probes were temporary and were removed immediately after sampling had been completed. They extended from an area near the SPC pretreatment ponds to approximately 610 m (2,000 ft) northeast of the landfill center. TCE was detected at concentrations from 2 to 255 parts per billion by volume (ppbv) in 36 of the 53 probes. The highest TCE concentrations were obtained just outside the disturbed portions at the eastern limits of HRL. Results obtained from this stage of soil-gas monitoring were used in the siting of groundwater monitoring wells MW-19, MW-20, MW-21, and MW-22 installed during the Phase II investigation.

**3.7.3.2 Vadose Zone Contaminant Source Investigation.** A total of 36 permanent soil-gas extraction points were installed within the limits of HRL during the period between December, 1990 and February, 1991. In addition, forty temporary extraction points were placed within the South Pit, immediately south of the landfill across Horn Rapids Road, between November and December, 1990. South Pit was a satellite facility associated with HRL (figure 1-2). Disposal trenches within the South Pit area have been observed on aerial photographs taken throughout the operating history of the Hanford Site. Like HRL, waste disposal at South Pit was unregulated and undocumented. Waste material, (as evidenced by surface observations, the study of aerial photographs, and geophysical surveys), is assumed to be similar to that found at the Horn Rapids facility. Since the groundwater contaminant plume skirts South Pit, it was included in the investigation as containing a possible vadose zone source for the groundwater contaminants. The purpose of these soil gas probe installations was to investigate the possibility of a vadose zone contaminant source that is contributing to the degradation of the underlying groundwater.

TCE was detected in 38 of the 40 temporary soil-gas extraction points sampled in South Pit. Concentrations ranged from 5 to 394 ppbv. Of the 36 permanent soil-gas probes installed within HRL, TCE was detected at 17 locations with concentrations ranging from 3 to 233 ppbv. These results strongly suggest that a vadose zone source for TCE or any other volatile organic compound is not present within HRL or South Pit. The concentration measured was far below that expected if a free source of the contaminant existed within the vadose zone. An approximate concentration for TCE in the vadose zone soil-gas, if present as a free source, can be estimated from its vapor pressure (EPA, 1987). The concentration immediately above the source would be expected to be 7 percent, or 70,000,000 ppbv.

This is determined by taking the vapor pressure of TCE divided by the sum of the vapor pressure and atmospheric pressure:

$$7 \text{ percent TCE per liter of air} = (60/(60+760))*100$$

where 60 is the TCE vapor pressure (in mm Hg at 25°C) and 760 is atmospheric pressure (in mm Hg at sea level and 25°C). Sample results at HRL indicate TCE levels from nondetect to 394 ppbv as compared to an estimated maximum of 70,000,000 ppbv if a liquid TCE source were present near any of the sampling locations (Golder, 1992).

### 3.7.4 Disposal Trench Characterization

Anecdotal information gathered during the Phase I RI, suggested a quantity of up to 200 drums of carbon tetrachloride ($CCl_4$) may have been buried in one of the disposal trenches located within HRL. Golder Associates, Inc., performed a suite of geophysical surveys at the landfill including EMI, GPR, and MAG during May, 1991. Survey results discounted the anecdotal reports and did not present evidence for the presence of a large (greater than 10) accumulation of drums buried within the landfill facility. However, EPA and Ecology directed that the largest of the geophysical anomalies, representing the possible accumulation of 10 or more drums, be investigated and the known disposal trenches at the landfill be characterized (Unit Manager's Meeting minutes, January 14, 1991, S.W. Clark, WHC to R.K. Stewart, DOE). Eight exploration trenches were excavated within the landfill debris trenches during September and October 1991 to complete these tasks (figure 3-9). Exploration trenches were sited based on the location of the largest anomalies discovered during the geophysical survey and trench depths were planned to intercept the particular anomaly in question. Geologic logs of the test pits are provided in appendix A.

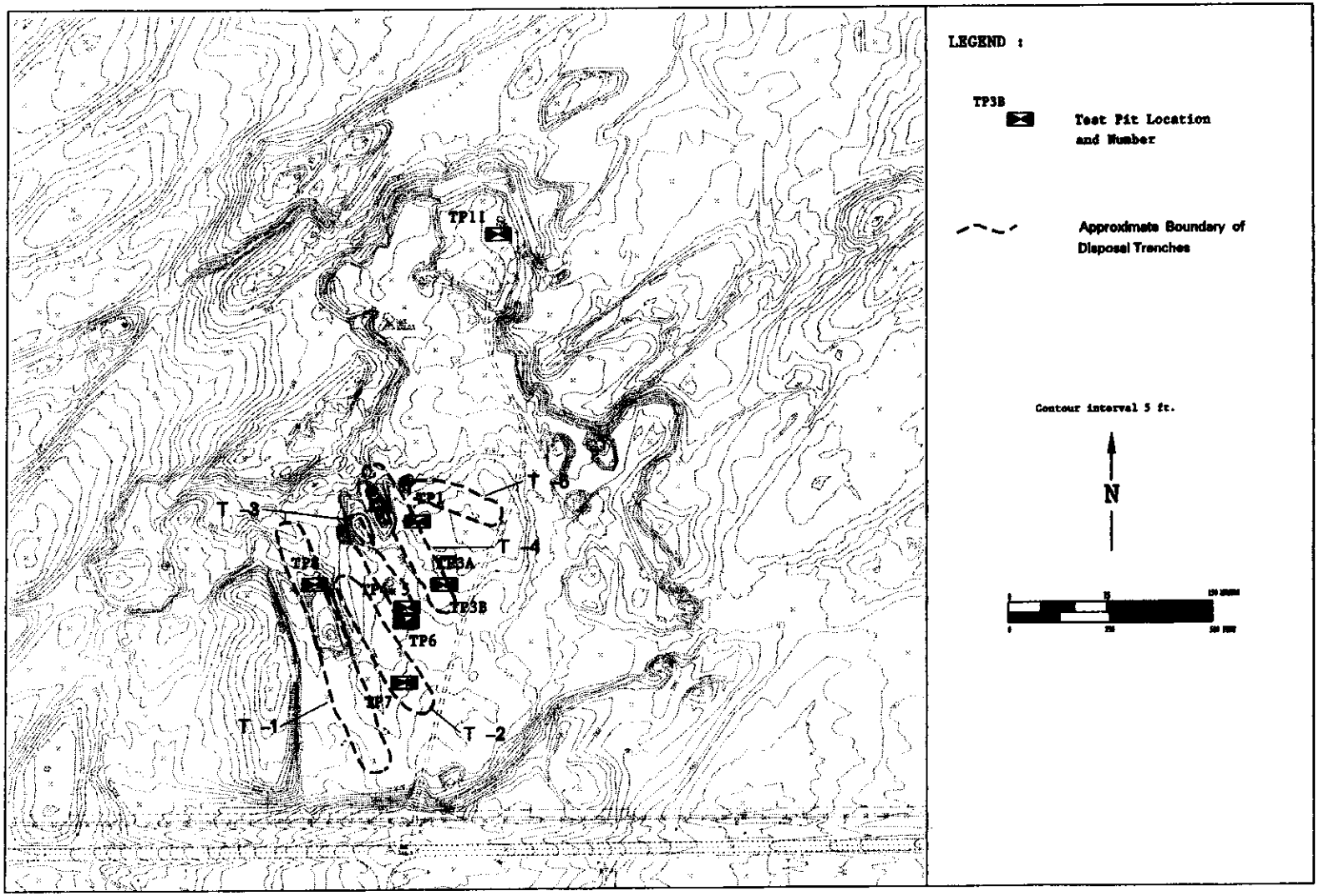
**3.7.4.1 Soils.** The soil matrix within all trench excavations consisted of sandy gravel having a fairly uniform composition averaging 53 percent gravel, 44 percent sand, and less than 4 percent silt. Soil structure was lacking in the gravel deposits as they likely have been repeatedly reworked by heavy equipment during debris burial operations throughout the life of the landfill facility. A deposit of 100 percent fine to medium sand was encountered below a depth of 13 feet within Trench No. 3A. The material appeared to be in an undisturbed state. Structural details of the sand deposit were unrecognizable due to the depth of the trench. The excessive sloughing of the excavation sidewalls prohibited safe trench entry for site personnel to inspect details of the deposit. All soil material encountered is interpreted as belonging to the Hanford formation. Trench depths, soil gradations and classification, and the percentage of soil versus debris encountered in each trench is presented in table 3-3.

**3.7.4.2 Debris.** Debris encountered during trench excavation can be roughly grouped into six categories; automotive, shop, construction, miscellaneous, medical, and unknown.

3.7.4.2.1 Automotive Debris--Automotive debris consisting of car and truck tires, mufflers, lengths of tail pipe, and inner tubes was found in all areas of the landfill. However, the highest concentration of automotive debris relative to other debris types seemed to be in the central portion of the landfill area. Most of the automotive debris appeared to have been



9 3 1 2 7 4 7 1 5 6




HRL Disposal Trench Characterization Exploration Trench Locations

Figure 3-9.

**TABLE 3-3: DEBRIS TRENCH COMPOSITION HORN RAPIDS LANDFILL CHARACTERIZATION 1100-EM-1 OPERABLE UNIT**

| | DEPTH (FT) | SAND (%) | GRAVEL (%) | SILT (%) | SOIL (%) | DEBRIS (%) | SOIL CLASSIFICATION (after Folk, 1954) |
|---|---|---|---|---|---|---|---|
| Trench #1 | 0-11 | 43 | 52 | 5 | 90 | 10 | Sandy Gravel |
| Trench #3A | 1-13 | 40 | 55 | <5 | 97 | 3 | Sandy Gravel |
| | 13-21 | 100 | 0 | 0 | 100 | 0 | Sand |
| Trench #3B | 0-8 | 52 | 44 | 4 | 97 | 3 | Sandy Gravel |
| Trench #4/5 | 0-0.5 | 35 | 60 | 5 | 100 | 0 | Silty Sandy Gravel |
| | 0.5-12 | 45 | 55 | <3 | 99.5 | 0.5 | Sandy Gravel |
| Trench #6 | 0-6.5 | 35 | 65 | <2 | 95 | 5 | Sandy Gravel |
| Trench #7 | 0-6 | 52 | 43 | 0 | 85 | 15 | Sandy Gravel |
| Trench #8 | 0-5 | 30 | 65 | <5 | 98 | 2 | Sandy Gravel |
| Trench #11 | 0-5 | 54 | 40 | 6 | N/R | N/R | Sandy Gravel |

Notes: 1. N/R – Results not reported in boring logs.

9 3 1 2 7 4 0 1 5 8

randomly dumped into the debris trenches. Tires may have occasionally been laced prior to burial, *i.e.*, carefully stacked to conserve space when large quantities were involved.

3.7.4.2.2 Shop Debris--Shop debris is characterized by accumulations of stainless steel lathe shavings, again concentrated in the central area of the landfill property. Large quantities of the material seem to have been haphazardly dumped into the debris trenches while smaller quantities appear to have been spread into distinct layers. The metal has a fresh appearance, with little or no deterioration apparent.

3.7.4.2.3 Construction Debris--Construction debris consisted of a variety of material including: metal flashing strips of various lengths, pieces of gypsum wallboard, roofing material, metal culverts, concrete, reinforcing steel (rebar), piping, steel cable, electrical wiring, asbestos and fiberglass insulation, and timbers. This material was uncovered in varying amounts in all eight of the characterization trenches. There was no apparent preferential disposal of this material although construction debris seemed to occur in associations. Metal flashing, gypsum wallboard, and fiberglass insulation were usually in close proximity to each other as were piping, cable, and asbestos insulation. Metal culvert lengths were found with concrete slabs and asphalt debris. Asphalt debris was usually present with roofing paper. All the materials were apparently collected during demolition activities and brought directly to the landfill for disposal.

3.7.4.2.4 Miscellaneous Debris--Miscellaneous debris includes all other types of material: soda bottles, paint containers, trash cans, coffee cans, cigarette butts, cloth, ash, and other items. The greatest abundance of this material was observed in the northern portion of the landfill, adjacent to the burn cage. Paint containers seemed to be concentrated in the central portion of the landfill area.

3.7.4.2.5 Medical Debris--One unique association of debris was encountered during the excavation of Trench No. 6. Medical waste consisting of between 30 and 40 multi-injection vials containing a milky white substance, a single plastic intravenous-dispenser bag, an "eye-dropper" bottle containing a clear liquid, one multi-injection vial containing a clear liquid, and one 1.8 to 2.0 cm long by 1.0 cm diameter (7- to 8-inch long by 4-inch diameter) cylindrical bottle containing a clear liquid were uncovered at a depth of approximately 2.0 m (6.5 feet). No intact labels were present on any of the bottles or vials.

The majority of the material went undiscovered until backfilling operations had commenced and site workers were specifically alerted to watch for the presence of medical waste in the spoils pile. The medical waste was initially discovered when multi-injection vials were observed to fall from the backhoe bucket while it was being swung to the spoils pile. Trench excavation was immediately stopped when the medical waste was noticed due to the unknown hazards associated with the material. Based on visual inspection by Pacific Northwest Laboratories personnel, the milky white liquid material was very tentatively identified as some form of penicillin; likely surplus stock from a hospital or other medical facility. No identification was made for the clear liquids.

None of the medical waste was submitted for laboratory identification because no onsite laboratory could be located that was willing or capable of accepting medical waste for

analysis. Offsite laboratories were inaccessible for analysis of the medical waste because the contents of the containers could not be certified by the health physics staff as being radiation-free and thus could not be released for offsite shipment. As excavation was stopped immediately after the discovery of the waste, the total extent of other medical products which may be present was not determined. Regulators were notified of the discovery and ultimately directed that all medical waste, chemical soil samples, and soil screening samples collected from this excavation be placed in the bottom of the trench and reburied [Unit Manager's Meeting minutes, October 31, 1991, from J. Stewart, (USACE) 0 to R. Stewart, (DOE)]. Only a very small volume of medical debris was discovered.

3.7.4.2.6 Unknown Debris--Two unknown waste substances were uncovered during the excavation of Trench #3A; a white crystalline powder, and an isolated pocket of bright purple, stained soil.

3.7.4.2.6.1 White Crystalline Powder--The white crystalline powder appeared to have been originally contained in plastic-lined paper bags, resembling concrete bags in size and shape. Labelling on the bags was illegible. The material was placed in the debris trench in layers. Field screening of the substance proved negative for radiation and volatile organics. A suggestion was made by site workers that the material had the appearance of commercial fertilizer.

Chemical analysis performed during field screening of the sample using a HAZCAT® kit tentatively identified the substance as sodium bisulfate. The identification was based on the following:

- The substance is water soluble.
- Water pH after dissolution of the substance is <2.0.
- When a wire coated with the substance is introduced into a flame, the flame color turns yellow.
- When the heated, the substance liberates sulfur dioxide.

A sample was subsequently analyzed at the Corps of Engineers North Pacific Division Laboratory in Troutdale, Oregon. Laboratory analysis confirmed the field screening results (see appendix D). Laboratory results must be qualified, however, due to the fact that the sample chain-of-custody was broken. No additional sampling is anticipated as available results provide sufficient assurance that no significant health and environmental threat is posed by this substance.

3.7.4.2.6.2 Stained Soil--Soil excavated from a depth of approximately 3.1 m (10 ft) in Trench No. 3A was stained bright purple. The stained soil was first noted in materials removed from the excavation by the backhoe bucket. Approximately 0.06 to 0.08 $m^3$ (2 to 3 $ft^3$) of stained soil was observed. Subsequent scoops failed to remove additional similar material and no staining was observed within the exploration trench. Field screening of the stained soil was negative for radiation and volatile organics. No source for the staining was observed. The site safety officer on duty during the discovery suggested the staining may have occurred due to the disposal of a permanganate compound.



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Chemical analysis performed during field screening using a HAZCAT® kit provided a preliminary identification of the substance as potassium permanganate. The identification was based on the following:

- The substance is water soluble.
- The substance dissolves in alcohol.
- The sample provides a positive char test for the presence of manganese.
- The flame test for the presence of potassium was inconclusive due to difficulties in discerning changes in the flame color.
- The purple color is a characteristic of permanganate.

The sample was subsequently analyzed at the U.S. Army Corps of Engineers North Pacific Division Laboratory in Troutdale, Oregon (see appendix D). Laboratory analysis confirmed the field screening results. Again, laboratory results must be qualified due to the fact that the sample chain-of-custody was compromised. As with the white powder, available results provide sufficient assurance that no significant health or environmental threat is posed by the stained soil.

**3.7.4.3 Field Screening.** Field screening was performed continuously during the excavation of exploration trenches within the HRL. Soils were screened for organic vapors and for the presence of asbestos-containing materials (ACM). Air was monitored for the presence of asbestos fibers. Splits of soil samples collected for laboratory analysis were screened for the presence of heavy metals with a portable X-ray fluorescence (XRF) analyzer.

3.7.4.3.1 Organic Vapors--Soil and debris were continuously monitored with an oxygen/explosive level indicator and an organic vapor monitor (OVM) throughout the excavation process. A single positive OVM reading occurred in Trench No. 1 associated with a paint can and paint residue. The can and residue were collected, drummed, moved offsite, and disposed. At all other times, readings were negative.

3.7.4.3.2 Air Monitoring--Air monitoring for asbestos was implemented due to known past disposal of ACM at HRL and the discovery of asbestos waste during excavation of exploration Trench No. 1. Site-wide monitoring equipment was located at the edge of each control zone, downwind from the excavation. Personal air monitors were worn by personnel required to enter the control zones. Both types of monitors were checked daily. Asbestos detected by the monitors was below action levels in all cases.

3.7.4.3.3 Asbestos Debris Monitoring--Field personnel were constantly monitoring excavations and spoil piles for the presence of ACM. Suspect material was collected by the site geologist and/or the site safety officer and forwarded to the Hanford Environmental Health Foundation (HEHF) laboratories for analysis. All suspect material collected and analyzed proved to contain asbestos although only a single debris trench was signed as containing asbestos. There seemed to be no pattern to the location of ACM within the landfill. Virtually all of the material appeared to have been piping insulation. Much of the asbestos material collected and analyzed was in a friable state.

3.7.4.3.4 XRF Monitoring--As noted above, soil samples collected for laboratory analysis were also subjected to screening by an XRF device. An X-Met 880© portable XRF analyzer was used to evaluate the samples for the presence of heavy metal contamination. Anomalous concentrations of iron were identified in many of the samples submitted for analysis. However, it was not determined whether the anomalies were the result of anthropogenic contamination or the result of natural variations in the iron content of HRL soils. Two samples revealed anomalous concentrations of copper and zinc. Laboratory analyses confirmed the field screening results, but concentrations were at levels below regulatory cleanup levels. XRF screening was performed as part of a Hanford Site-wide study to determine the utility of XRF screening techniques to environmental projects. Data collected by XRF screening were not utilized in the 1100-EM-1 Operable Unit analyses for the identification of potential site contamination.

**3.7.4.4 Conclusions.** Excavations at HRL confirmed the geophysical survey interpretation that a large accumulation of drums are not buried within the facility. Geophysical magnetic anomalies were found to represent accumulations of metallic objects including automotive debris, sheet metal, and metallic lathe shavings. Ground penetrating radar reflections could be explained by large, flat-lying pieces of sheet metal and automotive debris such as large truck mufflers. Asbestos-containing pipe insulation was the single hazardous material identified at the site. $CCl_4$ was not detected in any of the soil samples obtained from HRL during the Phase II investigation.

Medical waste discovered in Trench No. 6 will remain buried. Identification of two unknown substances, a white crystalline powder and soil stained a bright purple color, were confirmed by laboratory testing to contain sodium bisulfate and potassium permanganate, respectively. The medical waste, sodium bisulfate, and the potassium permanganate are not believed to represent an imminent threat to human health or the environment.

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### 3.7.5 Summary of Subunit Soil Investigations

Inorganic, organic, and pesticide contamination was detected in soils at HRL subunit. Geophysical surveys conducted at HRL detected numerous anomalous readings in the vicinity of waste disposal trenches. None of the anomalies, however, were consistent with the presence of buried drums. Soil-gas readings detected TCE, TCA, and PCE vapors. Concentrations were far below those to be expected if a free source of the contaminants existed within the vadose zone. Waste disposal trench explorations failed to locate drums containing organic liquids. Debris within the waste disposal trenches fit into six broad categories including automotive debris, shop debris, construction debris, miscellaneous debris, medical waste, and unidentified waste. Asbestos was the single hazardous substance positively identified during waste disposal trench characterization.

## 3.8 SUMMARY OF 1100-EM-1 SOIL INVESTIGATIONS

Phase I surface and soil investigations included radiological surveys, geophysical surveys, several soil-gas surveys, soil sampling, and laboratory analysis of soil samples.

Several subunits were identified with such a limited extent of contamination that little-to-no-further work was conducted (*e.g.*, subunits 1100-1, 1100-2, 1100-3, and 1100-4). The bulk of the Phase I analytical data was presented in the appendices of DOE/RL-90-18. Additional technical data is located in several referenced WHC publications (*e.g.*, soil gas reports).

Phase II surface and soil investigations focussed on additional characterization of the Ephemeral Pool and HRL. Additional soil samples were analyzed with data presented in appendix D. At the Ephemeral Pool and HRL, PCB's were measured in several samples.

Maximum values of all analytes at each subunit were presented for soils in tables 3-1 and 3-2. These values were compared with site-wide UTL's or background to identify contaminants. These tabulated lists were further screened to remove essential micronutrients. At the concentrations measured, aluminum, calcium, iron, magnesium, potassium, and sodium are nontoxic and do not pose a human health or an environmental threat (EPA, 1989A).

The remaining soil contaminants are used for risk-based screening in subsequent sections. In addition, where available, above background values were compared with published cleanup criteria. These soil contaminants are presented in table 3-4.

## 3.9 GROUNDWATER INVESTIGATIONS

Eleven full rounds of groundwater sampling have been completed at the 1100-EM-1 Operable Unit between January 1990 and the present. All analytical data available for groundwater sampling rounds 1 through 4 are presented in DOE/RL-90-18 and WHC 1990. Groundwater contaminants detected in concentrations exceeding background values were identified in DOE/RL-90-18 in WHC 1990. Analyses for groundwater samples collected during the first two sampling rounds included those analytes identified in the TAL, TCL, WAC 173-304, RCRA, and primary and relevant secondary drinking water parameters.

More detailed characterization of groundwater in the 1100-EM-1 Operable Unit was performed during Phase II investigations. The scope of the additional characterization was negotiated between DOE, Ecology, and EPA, and was finalized on July 24, 1991. DOE and the regulatory agencies agreed: that further hydrogeological investigations would include SPC property; that pump testing proposed by the U.S. Army Corps of Engineers, Walla Walla District to determine parameters for the unconfined aquifer in the vicinity of HRL for entry into the groundwater flow and transport model would not be performed; that monitoring wells MW-8 and MW-9, located along the western HRL boundary, would be used to establish background water quality for HRL; and, that no new monitoring wells would be constructed within the Operable Unit for the purposes of this final RI/FS-(EA) report.

Documentation provided to EPA and Ecology during the 1992 Revisions to Milestones Dispute outlined concerns that implementation of the aforementioned agreements would depreciate the quality and quantity of data available for input in the groundwater flow and transport modeling effort. The EPA and Ecology acknowledged these concerns but believed

**Table 3-4. Summary of 1100-EM-1 Operable Unit Soil Contaminants of Potential Concern and Maximum Contaminant Concentrations. (sheet 1 of 1)**

| Contaminant | 1100-1 (mg/kg) | 1100-2 (mg/kg) | 1100-3 (mg/kg) | 1100-4 (mg/kg) | Biscolored Soil Site (BN-1100-6) (mg/kg) | Horn Rapids Landfill (mg/kg) | Ephemeral Pool (mg/kg) |
|---|---|---|---|---|---|---|---|
| Antimony | – | – | – | – | – | 15.8 | – |
| Arsenic | 3.2 | – | – | 5.8 | – | 6.6 | – |
| Barium | – | – | – | – | – | 1,320 | – |
| Beryllium | – | – | – | 0.93 | – | 1.3 | – |
| Cadmium | – | – | – | – | – | 2.4 | – |
| Chromium | – | 18.8 | 14 | – | – | 1,250 | – |
| Cobalt | – | – | 17.8 | – | – | 42.5 | – |
| Copper | 37.9 | 24.4 | 31.7 | 18.8 | – | 1,280 | – |
| Cyanide | – | – | – | – | – | 0.56 | – |
| Lead | 286 | 94.6 | 26.4 | 5.7 | 22.1 | 854 | 54.2 |
| Manganese | – | 386 | 436 | – | – | 501 | – |
| Mercury | 0.39 | – | – | – | – | 1.3 | – |
| Nickel | 20.9 | – | – | – | – | 557 | – |
| Selenium | – | – | – | – | – | 0.97 | – |
| Silver | – | – | – | 2 | – | 7.7 | – |
| Thallium | – | 0.48 | 0.4 | 0.48 | – | 3.1 | – |
| Vanadium | 118 | – | – | – | – | 101 | – |
| Zinc | 100 | 56.6 | 60 | 63.8 | 111 | 3,160 | 67.5 |
| BEHP | – | – | – | – | 25,000 | – | – |
| Beta-HCH | – | – | – | – | – | 0.094 | – |
| Chlordane | – | – | – | – | 1.86 | – | 2.8 |
| Chlorobenzene | – | 0.006 | – | – | – | – | – |
| DDT | – | 0.16 | – | – | 0.17 | 1.98 | – |
| Endosulfan II | – | – | – | – | – | 0.11 | 0.16 |
| Endrin | – | – | – | – | – | 0.42 | 0.039 |
| Heptachlor | – | – | – | – | 0.065 | 0.02 | 0.029 |
| 2-Hexanone | – | – | – | – | 0.053 | – | – |
| Naphthalene | – | – | – | – | – | 8.2 | – |
| PCB's | – | – | – | – | – | 100 | 42 |
| Tetrachloroethene | – | 0.035 | – | – | – | 0.006 | – |
| Trichloroethene | – | 0.006 | – | – | – | – | – |
| 1,1,1-Trichloroethane | – | – | – | – | 0.035 | – | – |

– Indicates not a contaminant at this subunit
Note: This table includes data from the Phase I RI and Phase II RI.



9 3 1 2 7 4 0 1 7 4

that a "bias-for-action" needed to be emphasized for the Phase II groundwater investigations at the 1100-EM-1 Operable Unit.

### 3.9.1 SPC Facility and DOE 300 Area Site Investigations

Various data derived from adjacent areas were considered in the 1100-EM-1 RI analyses. Groundwater level measurements taken in the 1100 Area were coordinated with measurements being taken for ongoing investigations at the SPC facility and within the Hanford 300 Area. During the last several rounds, groundwater level measurements were taken at the three areas on the same dates to make possible an accurate comparison of the data. SPC and 300 Area water level data were included in the 1100 Area analysis of groundwater flow direction beneath the Operable Unit; specifically, data were used in refining groundwater flow paths in the area encompassed by the groundwater model (see paragraph 6.2). Table 3-5 lists groundwater level measurements obtained from investigations performed in the 300 Area by WHC. Table 3-6 presents groundwater elevations measured at the SPC facility by Geraghty and Miller, Inc. Groundwater elevation for the 1100 Area wells were presented in table 2-6.

Analytical data from groundwater samples obtained from SPC wells were included in the development and analysis of the 1100 Area groundwater modeling effort. Groundwater sampled from monitoring wells on SPC property intercepting the plume contains dissolved ammonia, sulphate, fluoride, elevated beta activity, TCE, and nitrate. Chemical data obtained from samples collected at the SPC facility is presented in appendix F.

Aquifer pump testing was performed at both the SPC facility and within the 300 Area. Results of these efforts were used to confirm the validity of aquifer properties used in the 1100 Area groundwater model. Pump tests implemented in both the 300 Area and at the SPC facility are further described in paragraph 2.4.3.2.6, and in appendixes G and H.

### 3.9.2 1100-EM-1 Groundwater Investigations

As noted above, all analytical data for the Phase I RI have been published in DOE/RL-90-18 and WHC 1990. Phase II analytical data is presented in appendix E of this report. All the groundwater data were compared with site-wide groundwater UTL's. Maximum values of all analytes exceeding these "background" values are presented in table 3-7.

This tabulated list of contaminants was further screened to remove : micronutrients (aluminum, barium, calcium, iron, magnesium, potassium, sodium, and zinc); contaminants having an obvious anomalous concentration during a single round of sampling while all other rounds either did not detect the contaminant or detected the contaminant at the analyte's Sample Quantitation Limit (methylene chloride, acetone, chloroform, toluene, $C_{12}$ hydrocarbon, and diethylphthalate); or contaminants detected below current MCL's (chromium, copper, lead, silver, 111, trichloroethane, tetrachloroethene, radium, gross alpha, chloride, and sulfate.)

## Table 3– 5.1100–EM–1 Operable Unit
## 300 Area Monitoring Well Groundwater Levels

| Well ID | 2/90 | 6/90 | 9/90 | 3/91 | 4/91 | 5/91 | 6/91 | 7/91 | 8/91 | 9/91 | 10/91 | 11/91 | 12/91 | 1/92 | 2/92 | 3/92 | 4/92 | 5/92 | 6/92 | 7/92 | 8/92 | 9/92 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DATES | | | | | | | | | | | | | | | | | | | | | |
| | Groundwater Elevations (m) | | | | | | | | | | | | | | | | | | | | | |
| 399–1–3 | 104.63 | 105.67 | 103.99 | 104.91 | 105.45 | 105.73 | 105.53 | 104.78 | 104.61 | 104.00 | 104.28 | 104.29 | 104.58 | 104.25 | 104.01 | 104.16 | 104.44 | | | | | |
| 399–1–4 | 105.08 | 106.08 | 104.54 | 105.45 | 105.74 | 106.02 | 105.91 | 105.20 | 104.98 | 104.45 | 104.58 | 104.70 | 104.87 | 104.63 | 104.39 | 104.48 | 104.72 | | | | | |
| 399–1–5 | 104.77 | 105.79 | 104.13 | 105.14 | 105.50 | 105.79 | 105.58 | 104.86 | 104.72 | 104.22 | 104.37 | 104.42 | 104.67 | 104.35 | 104.10 | 104.19 | 104.50 | | | | | |
| 399–1–7 | 104.61 | 105.67 | 103.99 | 104.97 | 105.44 | 105.71 | 105.52 | 104.77 | 104.60 | 104.12 | 104.28 | 104.28 | 104.56 | 104.24 | 104.00 | 104.17 | 104.43 | | | | | |
| 399–1–8 | NA | NA | NA | 104.99 | 105.44 | 105.71 | 105.53 | 104.78 | 104.61 | 104.12 | 104.28 | 104.30 | 104.58 | 104.26 | 104.26 | 104.02 | 104.16 | | | | | |
| 399–1–10 | 104.77 | 105.80 | 104.15 | 105.20 | 105.73 | 106.03 | 105.79 | 104.92 | 104.90 | NA | 104.45 | 104.38 | 104.83 | 104.46 | 104.07 | 104.28 | 104.58 | | | | | |
| 399–1–11 | 104.92 | 105.92 | 104.40 | 105.32 | 105.61 | 105.89 | 105.70 | 105.01 | 104.79 | 104.30 | 104.42 | 104.50 | 104.74 | 104.46 | 104.21 | 104.30 | 104.59 | | | | | |
| 399–1–12 | 104.77 | 105.79 | 104.11 | 105.12 | 105.48 | 105.76 | 105.63 | 104.87 | 104.73 | 104.22 | 104.35 | 104.44 | 104.65 | 104.35 | 104.12 | 104.21 | 104.48 | | | | | |
| 399–1–13 | 104.79 | 105.80 | 104.14 | 105.13 | 105.47 | 105.75 | 105.66 | 104.90 | 104.76 | 104.24 | 104.37 | 104.48 | 104.64 | 104.38 | 104.16 | 104.24 | 104.48 | | | | | |
| 399–1–14 | 104.92 | 105.91 | 104.36 | 105.27 | 105.55 | 105.82 | 105.76 | 105.06 | 104.87 | NA | 104.46 | 104.58 | 104.74 | 104.50 | 104.28 | 104.33 | 104.57 | | | | | |
| 399–1–15 | 104.96 | 105.96 | 104.42 | 105.33 | 105.62 | 105.86 | 105.80 | 105.10 | 104.98 | 104.41 | 104.49 | 104.60 | 104.78 | 104.54 | 104.32 | 104.34 | 104.63 | | | | | |
| 399–1–16A | 104.61 | 105.67 | 103.99 | 104.97 | 105.45 | 105.71 | 105.52 | 104.76 | 104.60 | 104.10 | 104.26 | 104.23 | 104.55 | 104.23 | 103.98 | 104.16 | 104.46 | | | | | |
| 399–1–17A | 104.69 | 105.73 | 104.05 | 105.03 | 105.43 | 105.71 | 105.56 | 104.78 | 104.67 | 104.19 | 104.31 | 104.39 | 104.61 | 104.31 | 104.07 | 104.20 | 104.46 | | | | | |
| 399–1–19 | 104.73 | 105.78 | 104.09 | 105.09 | 105.47 | 105.75 | 105.55 | NA | NA | NA | 105.03 | 105.08 | 105.29 | 104.98 | 104.74 | 104.82 | 105.27 | | | | | |
| 399–2–1 | 104.58 | 105.59 | 103.93 | 104.77 | 105.45 | 105.74 | 105.50 | 104.57 | 104.61 | 104.04 | 104.21 | 104.16 | 104.52 | 104.23 | 103.94 | 104.12 | 104.44 | | | | | |
| 399–2–2 | 104.60 | 105.65 | 103.98 | 104.91 | 105.45 | 105.72 | 105.52 | 104.75 | 104.62 | 104.09 | 104.25 | 104.19 | 104.55 | 104.22 | 103.99 | 104.13 | 104.46 | | | | | |
| 399–2–3 | 104.59 | 105.65 | 103.97 | 104.89 | 105.45 | 105.71 | 105.50 | 104.73 | 104.58 | 104.08 | 104.25 | 104.17 | 104.51 | 104.20 | 104.05 | 104.12 | 104.44 | | | | | |
| 399–3–1 | 104.54 | 105.56 | 103.91 | 104.76 | 105.42 | 105.70 | 105.45 | 104.56 | 104.59 | 104.01 | 104.19 | 104.28 | 104.57 | 104.20 | 103.93 | 104.09 | NA | | | | | |
| 399–3–6 | 104.64 | 105.68 | 103.98 | 104.98 | 105.39 | 105.64 | 105.53 | 104.72 | 104.61 | 104.11 | 104.25 | 104.31 | 104.58 | 104.28 | 104.06 | 104.14 | 104.39 | | | | | |
| 399–3–7 | 104.62 | 105.66 | 103.97 | 105.26 | 105.40 | 105.66 | 105.50 | 104.71 | 104.59 | 104.10 | 104.24 | 104.29 | 104.59 | 104.25 | 104.04 | 104.13 | 104.42 | | | | | |
| 399–3–9 | 104.53 | 105.58 | 103.89 | 104.81 | 105.42 | 105.68 | 105.44 | 104.65 | 104.53 | 103.99 | 104.16 | 104.27 | 104.49 | 103.96 | 103.72 | 103.85 | 103.25 | | | | | |
| 399–3–10 | 104.51 | 105.54 | 103.86 | 104.77 | 105.40 | 105.67 | 105.40 | 104.62 | 104.51 | 103.96 | 104.13 | 104.27 | 104.57 | 104.19 | 103.95 | 104.08 | 104.38 | | | | | |
| 399–3–12 | 104.56 | 105.61 | 103.93 | 104.88 | 105.40 | 105.66 | 105.46 | 104.67 | 104.53 | 104.03 | 104.19 | 104.17 | 104.53 | 104.23 | 103.45 | 103.57 | 103.79 | | | | | |
| 399–4–1 | 104.49 | 105.53 | 103.87 | 104.79 | 105.37 | 105.63 | 105.37 | 104.59 | 104.46 | 103.98 | 104.30 | 104.14 | 104.50 | 104.16 | 103.73 | 103.85 | 104.19 | | | | | |
| 399–4–9 | 104.51 | 105.53 | 103.85 | 104.72 | 105.41 | 105.67 | 105.41 | 104.61 | 104.52 | 103.96 | 104.13 | 104.28 | 104.48 | 103.95 | 103.71 | 103.85 | 104.15 | | | | | |
| 399–4–10 | 104.50 | 105.51 | 103.83 | 104.67 | 105.40 | 105.66 | 105.38 | 104.58 | 104.51 | 103.89 | 104.09 | 104.27 | 104.43 | 104.18 | 103.91 | 104.07 | 104.38 | | | | | |
| 399–4–11 | 104.56 | 105.59 | 103.93 | 104.88 | 105.38 | 105.63 | 105.45 | 104.65 | 104.53 | 104.04 | 104.19 | 104.25 | 104.54 | 104.21 | 103.98 | 104.09 | 104.40 | | | | | |
| 399–5–1 | 104.68 | 105.66 | 104.03 | 104.97 | 105.36 | 105.60 | 105.51 | 104.74 | 104.67 | 104.15 | 104.28 | 104.40 | 104.53 | 104.62 | 104.11 | 104.15 | 104.39 | | | | | |
| 399–6–1 | 104.76 | 105.77 | 104.13 | 105.28 | 105.38 | 105.61 | 105.63 | 104.87 | 104.78 | 104.26 | 104.37 | 104.49 | NA | 103.84 | 103.66 | 103.66 | 103.82 | | | | | |
| 399–8–1 | 104.79 | 105.81 | 104.14 | 105.12 | 105.44 | 105.67 | 105.66 | 104.90 | 104.78 | 104.26 | 104.39 | 104.50 | 104.58 | 104.42 | 104.20 | 103.84 | 104.05 | | | | | |
| 399–8–2 | 104.96 | 105.93 | 104.43 | 105.22 | 105.42 | 105.64 | 105.78 | 105.14 | 104.99 | 104.56 | 104.55 | 104.64 | 104.59 | 104.65 | 104.46 | 104.46 | 103.89 | | | | | |
| 399–8–3 | 104.89 | 105.89 | 104.28 | 105.22 | 105.49 | 105.72 | 105.75 | 105.00 | 104.89 | 104.38 | 104.48 | 104.59 | 104.63 | 104.51 | 104.30 | 103.82 | 103.99 | | | | | |

BLANK – Measurements have been obtained but not yet entered into HEIS
NA – Measurements are not recorded in HEIS database

## Table 3-6. 1100-EM-1 Operable Unit
## Seimens Power Co. Monitoring Well Groundwater Levels

DATES

| Well ID | 2/90 | 6/90 | 9/90 | 3/91 | 4/91 | 5/91 | 6/91 | 7/91 | 8/91 | 9/91 | 10/91 | 11/91 | 12/91 | 1/92 | 2/92 | 3/92 | 4/92 | 5/92 | 6/92 | 7/92 | 8/92 | 9/92 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Groundwater Elevations (m) | | | | | | | | | | | | | |
| GM-1 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.35 | 108.31 | 108.27 | 108.20 | 108.15 | 108.10 | 108.12 | 108.18 | 108.189 | 108.204 | |
| GM-2 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.34 | 108.31 | 108.28 | 108.23 | 108.18 | 108.13 | 108.13 | 108.18 | 108.216 | 108.219 | |
| GM-3 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.30 | 108.26 | 108.23 | 108.19 | 108.14 | 108.09 | 108.08 | 108.128 | 107.866 | 108.171 | |
| GM-4 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.22 | 108.20 | 108.17 | 108.12 | 108.08 | 108.03 | 108.02 | 108.067 | 108.116 | 108.116 | |
| GM-5 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.16 | 108.17 | 108.14 | 108.10 | 108.05 | 108.00 | 107.99 | 108.052 | 108.094 | 108.091 | |
| GM-6 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.18 | 108.18 | 108.15 | 108.10 | 108.06 | 108.01 | 107.99 | 108.043 | 108.079 | 108.082 | |
| GM-7 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.12 | 108.14 | 108.11 | 108.07 | 108.03 | 107.97 | 107.96 | 108.006 | 108.04 | 108.049 | |
| GM-8 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.10 | 108.12 | 108.09 | 108.05 | 108.02 | 107.97 | 107.95 | 107.991 | 108.03 | 108.037 | |
| GM-9 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.10 | 108.09 | 108.06 | 108.03 | 107.99 | 107.94 | 107.92 | 107.954 | 107.994 | 108.003 | |
| GM-10 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 108.09 | 108.07 | 108.05 | 108.01 | 107.98 | 107.92 | 107.90 | 107.665 | 107.707 | 107.713 | |
| GM-11 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 107.98 | 108.00 | 107.98 | 107.94 | 107.91 | 107.85 | 107.83 | 107.869 | 107.607 | 107.918 | |
| GM-12 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 107.89 | 107.90 | 107.88 | 107.83 | 107.80 | 107.75 | 107.72 | 107.765 | 107.805 | 107.805 | |
| TW-1 | NA | NA | 107.92 | NA | NA | NA | NA | 107.96 | 108.04 | NA | NA | 108.20 | 108.21 | 108.19 | 108.14 | 108.10 | 108.05 | 108.04 | 108.085 | 108.113 | 108.128 | |
| TW-2 | NA | NA | 107.91 | NA | NA | NA | NA | 107.96 | 108.04 | NA | NA | 108.20 | 108.21 | 108.18 | 108.13 | 108.09 | 108.04 | 108.03 | 108.079 | 108.11 | 108.122 | |
| TW-3 | NA | NA | 107.94 | NA | NA | NA | NA | 107.99 | 108.11 | NA | NA | 108.27 | 108.24 | 108.21 | 108.16 | 108.11 | 108.06 | 108.03 | 108.11 | 108.131 | 108.146 | |
| TW-4 | NA | NA | 107.96 | NA | NA | NA | NA | 108.00 | 108.09 | NA | NA | 108.24 | 108.25 | 108.22 | 108.16 | 108.12 | 108.07 | 108.06 | 108.116 | 108.146 | 108.155 | |
| TW-5 | NA | NA | 107.96 | NA | NA | NA | NA | 108.01 | 108.10 | NA | NA | 108.25 | 108.26 | 108.23 | 108.17 | 108.12 | 108.07 | 108.07 | 108.128 | 108.152 | 108.162 | |
| TW-6 | NA | NA | 107.97 | NA | NA | NA | NA | 108.03 | 108.12 | NA | NA | 108.27 | 108.27 | 108.24 | 108.18 | 108.13 | 108.08 | 108.08 | 108.14 | 108.158 | 108.174 | |
| TW-7 | NA | NA | 107.98 | NA | NA | NA | NA | 108.04 | 108.17 | NA | NA | 108.33 | 108.29 | 108.25 | 108.20 | 108.14 | 108.09 | 108.09 | 108.152 | 108.177 | 108.189 | |
| TW-9 | NA | NA | 107.91 | NA | NA | NA | NA | 107.95 | 108.11 | NA | NA | 108.18 | 108.20 | 108.17 | 108.12 | 108.08 | 108.04 | 107.99 | 108.049 | 108.091 | 108.116 | |
| TW-11 | NA | NA | 107.99 | NA | NA | NA | NA | 108.03 | 108.03 | NA | NA | 108.28 | 108.28 | 108.25 | 108.19 | 108.14 | 108.09 | 108.09 | 108.149 | 108.174 | 108.183 | |
| TW-12 | NA | NA | 108.00 | NA | NA | NA | NA | 108.04 | NA | NA | NA | 108.29 | 108.29 | 108.25 | 108.20 | 108.15 | 108.09 | 108.09 | 108.152 | 108.183 | 108.189 | |
| TW-13 | NA | NA | 108.00 | NA | NA | NA | NA | 108.07 | 108.17 | NA | NA | 108.29 | 108.31 | 108.27 | 108.21 | 108.15 | 108.10 | 108.12 | 108.158 | 108.192 | 108.204 | |
| TW-14 | NA | NA | 107.84 | NA | NA | NA | NA | 107.83 | 108.13 | NA | NA | 108.10 | 108.08 | 108.06 | 108.02 | 107.98 | 107.93 | 107.91 | 107.948 | 107.997 | 108.003 | |
| TW-15 | NA | NA | 108.10 | NA | NA | NA | NA | 107.82 | 108.16 | NA | NA | 108.06 | 108.08 | 108.05 | 108.02 | 107.98 | 107.93 | 107.91 | 107.945 | 107.973 | 107.994 | |
| TW-16 | NA | NA | 108.16 | NA | NA | NA | NA | 107.88 | 107.98 | NA | NA | 108.12 | 108.13 | 108.12 | 108.08 | 107.83 | 107.99 | 107.97 | 107.942 | 107.68 | 108.052 | |
| TW-19 | NA | NA | 107.93 | NA | NA | NA | NA | 107.97 | 108.00 | NA | NA | 108.21 | 108.22 | 108.19 | 108.15 | 108.10 | 108.05 | 108.04 | 108.091 | 108.122 | 108.128 | |
| TW-20 | NA | NA | 107.94 | NA | NA | NA | NA | 108.00 | 107.98 | NA | NA | 108.23 | 108.24 | 108.21 | 108.16 | 108.12 | 108.06 | 108.05 | 108.104 | 108.14 | 108.149 | |
| TW-21 | NA | NA | 107.96 | NA | NA | NA | NA | 108.01 | NA | NA | NA | 108.27 | 108.27 | 108.24 | 108.18 | 108.12 | 108.09 | 108.08 | 108.134 | 108.165 | 108.171 | |
| TW-22 | NA | NA | 107.99 | NA | NA | NA | NA | 108.04 | NA | NA | NA | 108.28 | 108.28 | 108.23 | 108.18 | 108.12 | 108.07 | 108.09 | 108.146 | 108.158 | 108.113 | |
| TW-23 | NA | NA | 108.02 | NA | NA | NA | NA | 108.07 | 108.06 | NA | NA | 108.35 | 108.33 | 108.29 | 108.24 | 108.20 | 108.14 | 108.11 | 108.189 | 108.119 | 108.259 | |
| TW-24 | NA | NA | 108.00 | NA | NA | NA | NA | 108.05 | 108.08 | NA | NA | 108.31 | 108.30 | 108.27 | 108.22 | 108.17 | 108.13 | 108.08 | 108.158 | NA | NA | |
| TW-25 | NA | NA | 108.01 | NA | NA | NA | NA | 108.08 | 108.12 | NA | NA | 108.30 | 108.32 | 108.29 | 108.25 | 108.21 | 108.17 | 108.12 | 108.177 | 108.219 | 108.268 | |
| TW-26 | NA | NA | 107.91 | NA | NA | NA | NA | 107.96 | 108.13 | NA | NA | 108.19 | 108.20 | 108.18 | 108.13 | 108.09 | 108.04 | 107.99 | 108.034 | 108.061 | 108.116 | |

BLANK – Measurements have been obtained but not yet entered into HEIS
NA – Measurements are not recorded in HEIS database

**Table 3-7. Maximum Concentration of Groundwater Analytes Observed Exceeding Background or MCL's for Metals, Wet Chemistry, Volatile Organics, Semivolatile Organics, Pesticides, and Radionuclides for Sampling Rounds 1-9.**

| Analytes | MCL Level | UTL's | Maximum Concentration Observed |
|---|---|---|---|
| **Metals (ppb)** | | | |
| Aluminum | 50-200 [a] | 152 | 1350 |
| Barium | 1000 | 60.5 | 132 B [f] |
| Calcium | NA [i] | 74600 | 197000 |
| Chromium | 100 [b] | 7.8 | 57.5 |
| Copper | 1300 | 5.22 [h] | 71.9 |
| Iron | 300 [a] | 820 | 2050 |
| Lead | 50 [c] | 13.7 | 25.3 |
| Magnesium | NA | 20200 | 42100 |
| Manganese | NA | 390 | 352 |
| Nickel | 100 [d] | 15 | 140 [j] |
| Silver | 50 | 4 | 11.7 |
| Potassium | NA | 7140 | 13900 |
| Sodium | NA | 29500 | 56900 |
| Zinc | NA | 8.3 | 223 |
| **Wet Chemistry (ppm)** | | | |
| Ammonia | NA | 0.15 | .087 |
| Fluoride (F) | 4 [b] | 0.5 | 3.7 |
| Chloride (Cl) | 250 [a] | 22.1 | 110 |
| Phosphate ($PO_4$-P) | NA | 1 | 1.9 |
| Sulfate ($SO_4$) | 255 [a] | 42.5 | 89.6 |
| Nitrate (as N) | 10 | 54.4 | 217 |

9 3 1 2 7 4 0 1 7 8

**Table 3-7. Maximum Concentration of Groundwater Analytes Observed Exceeding Background or MCL's for Metals, Wet Chemistry, Volatile Organics, Semivolatile Organics, Pesticides, and Radionuclides for Sampling Rounds 1-9.**

| Analytes | MCL Level | UTL's | Maximum Concentration Observed |
|---|---|---|---|
| **Votatile Organics, Semivolatile Organics, and Pesticides (ppb)** | | | |
| Methylene Choride | 5 [d] | 1 | 13 |
| Acetone | NA | 10 | 31 |
| Chloroform | 100 | 1 | 5 |
| 1,1,1-Trichloroethane | 200 [b] | 1.2 | 3 |
| Trichloroethene | 5 [b] | 1 | 104 D [g] |
| Tetrachloroethene | 5 [b] | 1 | 4 J |
| Toluene | 2000 [d] | 1 | 2 J |
| $C_{12}$ Hydrocarbon | NA | NA | 100 J [e] |
| Diethylphalate | NA | 10 | 34 |
| **Radionuclides (pCi/L)** | | | |
| Gross Alpha | 15 [b] | 8.4 | 11 + 5 |
| Gross Beta | 50 [a] | 18 | 87 7 |
| Radium | 20 | 1.7 [h] | 2.36 |

[a] National Secondary Drinking Water Regulations - Secondary Maximum Contaminant Levels.
[b] National Revised Primary Drinking Water Regulations - Maximum Contaminant Levels (MCL's).
[c] Primary Drinking Water Regulations - Maximum Contaminant Levels (effective through 7 Dec 92).
[d] Proposed National Primary Drinking Water Regulations - Maximum Contaminant Levels.
[e] J= estimated value.
f B means analyte was also found in the blank, the concentration reported is uncertain.
[g] D means the concentration was determined at a secondary dilution.
[h] Parameter was never detected in the respective background samples; therefore, the highest reported respective background SQL is substituted as a surrogate UTL.
[i] NA = not available or not applicable.
[j] Issues not yet revolved for suspicious values: additional data is being obtained for further evaluation.



9 3 1 2 7 5 4 0 1 7 9

Ammonia was not considered further because of the low concentrations at which it was detected, and because it degrades to nitrate. Nitrate does have an MCL and was considered in subsequent analyses for 1100-EM-1 contaminants through the risk assessment phase of the investigation.

Nickel was identified just exceeding a "proposed" MCL at two wells during the RI. These elevated values are questionable on several grounds, including comparison of "filtered" versus "unfiltered" aliquots and potential well construction/groundwater sampling complications. In addition, elevated nickel concentrations were not identified in soil samples taken from either of these two wells. This element was not carried through the risk assessment screening for groundwater.

An MCL for specific beta activity has not been developed. However, compliance with individual MCL's for beta emitters may be assumed, without further analysis, if the average maximum contaminant levels are intended to produce an annual dose equivalent to the total body or any internal organ less than 4 millirem/year. Specifically, if the average annual concentration of gross beta activity is less than 50 pCi/L. Since the gross beta activity exceeded this concentration, specific analyses of the potential beta-contributing radionuclides were conducted (40 CFR, parts 141, 142, and 143).

Technetium-99 (Tc-99) appears to account for most, if not all, of the elevated beta activity. No other significant contributors to the total beta activity have been detected (Prentice *et. al.*, 1992). Other analyses were made to search for the presence of tritium and strontium-90 in the groundwater using liquid scintillation and gamma spectrometry analysis techniques. Neither analyte was detected.

Tc-99 is a fission product derived mainly from the recycling of nuclear fuels. It is very persistent in the environment, having a half-life of 2.1E+05 years; however, it poses a relatively small internal health hazard. This minimal health hazard is evidenced by the high proposed MCL for Tc-99 (3.8E+03 pCi/L) and its relatively small ingestion slope factor (1.3E-12/pCi). The average Tc-99 concentration measured in HRL/SPC groundwater samples was 120 pCi/L. Since this concentration is well below proposed MCL's, the gross beta activity was eliminated from further evaluation in the risk assessment process.

After the above screening process, analytes remaining, *i.e.*, TCE and nitrate, are evaluated as contaminants of potential concern for 1100-EM-1 Operable Unit groundwater. These two contaminants are consistent with the list of contaminants of potential concern to be considered as directed by EPA (see section 5.0).

## 3.10 SUMMARY OF SITE INVESTIGATIONS

Site investigations of the 1100-EM-1 Operable Unit included radiological surveys, geophysical surveys, soil-gas surveys, intrusive trenching activities to explore subsurface conditions, surface and subsurface soil sampling and laboratory analyses, groundwater level monitoring, and groundwater sampling and laboratory analyses. Maximum values for all analytes at each subunit are summarized for surface and subsurface soils in tables 3-1 and



9 3 1 2 7 4 1 3 0

3-2. These maximum values are compared with site-wide UTL's or background. The tables were further screened to remove essential micronutrients. For soils collected at each subunit, the maximum values of analytes detected at levels exceeding background are presented in table 3-4. These remaining soil contaminants are used for risk-based pre-screening to develop contaminants of potential concern (COPC) in section 4.

Analytical results of Phase II groundwater investigations are presented in appendix E. Additional chemical data from earlier phases of the RI are presented in DOE/RL-90-18 and WHC 1990. Table 3-7 lists groundwater contaminants measured at concentrations above MCL's or site background. Groundwater contaminants were further screened to remove micronutrients and those analytes occurring at concentrations below published regulatory criteria. Anomalous measurements, including those confirmed by subsequent measurements to be below regulatory criteria, were also screened at this stage. TCE and nitrate remain as the contaminants of potential concern for the groundwater at and near the HRL subunit. Groundwater contamination is not an issue at the remaining six subunits of the 1100-EM-1 Operable Unit.

The distribution of the contaminants of potential concern for both soil and groundwater will be discussed in additional detail in section 4.0.

# 4.0 NATURE AND EXTENT OF CONTAMINATION

Section 4.0 presents the nature and extent of contamination detected within the 1100-EM-1 Operable Unit. The focus is on the significant contaminants and their distribution throughout the Operable Unit. All analytes detected in concentrations exceeding background levels were identified in section 3.0. This extensive list was further screened to include only those contaminants exceeding published criteria, or where substantiated anomalies were measured (tables 3-6 and 3-7). In this section, the screened lists are reviewed and risk-based screening criteria are applied. Contaminants remaining after the risk-based evaluation will constitute the contaminants of concern for the Operable Unit. Further development and discussion of the risk-based screening and risk assessment process are presented in section 5.0 and appendix K.

Groundwater contaminants are limited to trichloroethene and nitrate contaminated plumes detected beneath SPC property and beneath the HRL subunit. All other contaminants detected during the Phase I and Phase II groundwater sampling rounds were eliminated from further consideration as described in the previous section. Groundwater contamination will not be discussed for subunits other than HRL.

Analytical results from surface soil samples recovered within the Operable Unit confirm the presence of surface soil contamination in concentrations above UTL's. Some areas are characterized by a single soil sample and others by more than one soil sample. The distribution of surface soil contamination present in concentrations above UTL's are illustrated in figures 4-1 through 4-24. All maps were developed by locating soil sampling sites having elevated analyte values, estimating the horizontal extent of contamination based on surface topographic features, and by postulating the most plausible explanation for the existence of the concentration at each sampling site. For example, if only a single soil sample was collected from the floor of a surface depression, then the sample was assumed to be representative of the total area of the depression floor. A single positive soil analysis from the base of a depression where more than a single soil sample was obtained was interpreted as being representative of the depression base immediately adjacent to the sampling location, possibly indicating the presence of a localized low within the depression. The mode of contaminant accumulation was interpreted as runoff flowing into the depression and depositing contaminated soil, by spills or dumping incidents or, alternatively, wind deposition of contaminated sediments. Contaminant concentrations located on flat terrain were illustrated as having a lateral extent large enough to be obvious; the mode of contaminant accumulation, in flat areas, not being as easily theorized as elevated concentrations present within surface depressions. Surface soil contamination maps are not to be construed as absolutes, but only as indications of the general distribution of the contaminants within the boundaries of each subunit.

## 4.1 BATTERY ACID PIT - 1100-1

Elevated concentrations of contaminants detected within the surface and subsurface soils at the 1100-1, Battery Acid Pit subunit are listed in paragraph 3.1.1. Results of preliminary risk-based screening for the remaining soil contaminants present at this subunit

are summarized in table 4-1. The only COPC at the 1100-1, Battery Acid Pit subunit are vanadium and arsenic. Both were observed in a single soil sample, A1004S, obtained from the depth interval of 1.6 to 1.9 m (5.3 to 6.1 ft) below the ground surface at borehole BAP-1 (see figure 3-1). Neither contaminant was detected in surface soil samples. The remaining contaminants (such as copper, mercury, nickel, and zinc) pose no known human health or environmental risks at the measured concentrations. Lead concentration is below published cleanup criteria.

## 4.2 PAINT AND SOLVENT PIT - 1100-2

Contaminants detected in soil samples at the 1100-2, Paint and Solvent Pit subunit are listed in paragraph 3.2.1. As insufficient data are available to ascertain speciation, chromium is conservatively assumed to be in the hexavalent (most toxic) state for the purposes of this report. Results of preliminary risk-based screening for soil contaminants at the 1100-2, Paint and Solvent Pit subunit are summarized in table 4-2. The only resultant COPC for the 1100-2 subunit is chromium. Elevated chromium is found within only a single surface soil sample obtained immediately prior to the drilling of borehole DP-9 (figure 4-1). The remaining contaminants (copper, manganese, thallium, zinc, chlorobenzene, DDT, PCE, and TCE) pose no known human health or environmental risks at the measured concentrations. Lead levels are below the published cleanup criteria.

## 4.3 ANTIFREEZE AND DEGREASER PIT - 1100-3

Soil contaminants detected at concentrations above background levels at the 1100-3, Antifreeze and Degreaser Pit subunit are listed in paragraph 3.3.1. Table 4-3 summarizes the results of the preliminary risk-based screening for the subunit. Chromium exceeds the screening criteria and is thus regarded as the only COPC at the 1100-3 subunit.

Chromium was encountered in concentrations exceeding background levels at only one surface location in the extreme northeast portion of the Antifreeze and Degreaser Pit (figure 4-2). This substance was not encountered at elevated levels in the subsurface stratum of the 1100-3 subunit soils. Other contaminants (cobalt, copper, manganese, and zinc) occur at levels that pose no known substantive threat to the environment or public health. Lead occurs at levels well below published cleanup criteria.

## 4.4 ANTIFREEZE TANK SITE - 1100-4

Elevated contaminant parameters detected in the subsurface soils at and near the 1100-4, Antifreeze Tank Site subunit are listed in paragraph 3.4.1. Aluminum and potassium, the only two contaminants associated with the actual location of the former antifreeze disposal tank, were eliminated from further consideration for reasons previously stated in section 4.0. No organic compounds were detected at elevated levels within this subunit. The remaining parameters were detected at elevated concentrations only at the

**Table 4-1. Preliminary Risk-Based Screening for Soil Contaminants at the Battery Acid Pit (1100-1) Subunit.**

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Arsenic | 3.2 | 3.0E-04[a] | 2.4 | -- | -- | 1.7E+00[e] | 0.038 | 5.0E+01[a,b] | 4.3 | -- |
| Copper | 37.9 | 4.0E-02[f] | 320 | -- | -- | -- | -- | -- | -- | -- |
| Lead | 266 | ND | -- | ND | -- | ND | -- | ND | -- | 500-1,000[d] |
| Mercury | 0.39 | 3.0E-04[b] | 2.4 | 8.5E-05[b] | 1,100 | -- | -- | -- | -- | -- |
| Nickel | 20.9 | 2.0E-02[a] | 160 | -- | -- | -- | -- | 8.4E-01[a] | 78 | -- |
| Vanadium | 111 | 7.0E-03[b] | 56 | -- | -- | -- | -- | -- | -- | -- |
| Zinc | 100 | 2.0E-01[b] | 1,600 | -- | -- | -- | -- | -- | -- | -- |

[a]Integrated Risk Information System (IRIS, EPA 1992a)
[b]Health Effects Assessment Summary Tables (HEAST, EPA 1992b)
[c]Based on 30% absorption of inhaled arsenic (EPA 1992b)
[d]EPA 1989b
[e]Surrogate based on proposed arsenic unit risk of 5E-05 $\mu g/L$ (EPA 1991).
[f]EPA Region-10 (see Appendix A)
-- Indicates not available
ND Not Determined
Note: Shaded areas indicate screening criterion exceeded

**Table 4-2. Preliminary Risk-Based Screening for Soil Contaminants at the Paint and Solvent Pit (1100-2) Subunit.**

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Chromium | 16.8 | 5.0E-03[a] | 40 | -- | -- | -- | -- | 4.1E+01[a] | 1.6 | -- |
| Copper | 24.4 | 4.0E-02 | 320 | -- | -- | -- | -- | -- | -- | -- |
| Lead | 94.6 | ND | -- | ND | -- | ND | -- | ND | -- | 500-1000[c] |
| Manganese | 366 | 1.0E-01[a] | 800 | 1.1E-04[a] | 1,400 | -- | -- | -- | -- | -- |
| Thallium | 0.48 | 7.0E-05[b] | 0.56 | -- | -- | -- | -- | -- | -- | -- |
| Zinc | 56.6 | 2.0E-01[b] | 1,600 | -- | -- | -- | -- | -- | -- | -- |
| Chlorobenzene | 0.006 | 2.0E-02[a] | 160 | 5E-03[b] | 65,000 | -- | -- | -- | -- | -- |
| DDT | 0.16 | 5.0E-04[a] | 4.0 | -- | -- | 3.4E-01[a] | 0.19 | 3.4E-01[a] | 190 | -- |
| Tetrachloroethene | 0.035 | 1.0E-02[a] | 80 | -- | -- | 5.2E-02[d] | 1.2 | 2E-03[d] | 33,000 | -- |
| Trichloroethene | 0.006 | -- | -- | -- | -- | 1.1E-02 | 5.8 | 6.0E-03 | 11,000 | -- |

[a]Integrated Risk Information System (IRIS, EPA 1992a)
[b]Health Effects Assessment Summary Tables (HEAST, EPA 1992b)
[c]EPA 1989b
[d]EPA-Region 10 (see Appendix A)
--- Indicates not available
ND Not Determined
Note: Shaded areas indicate screening criterion exceeded

9 3 1 2 7 4 0 1 3 6

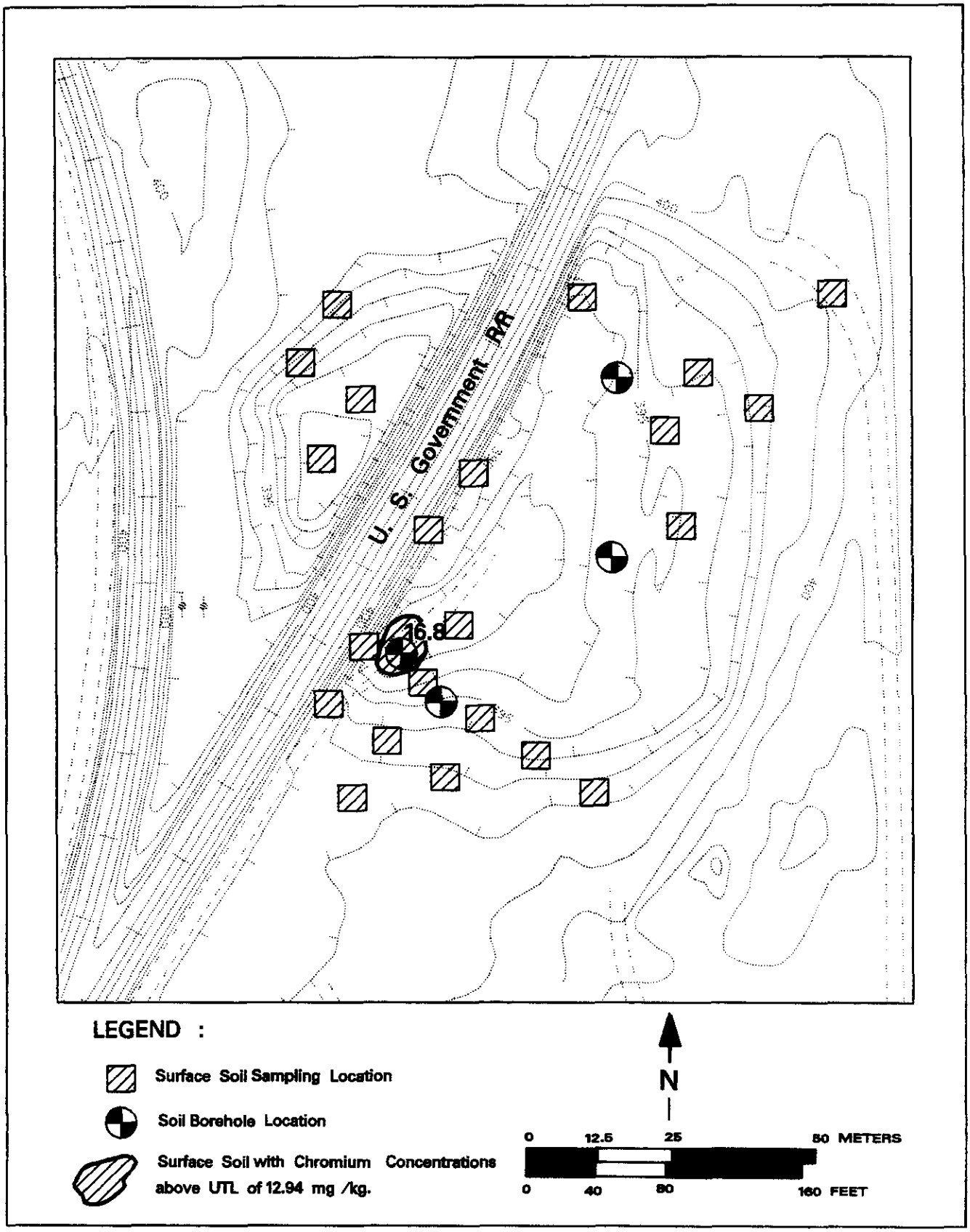


Figure 4-1. 1100-2, Paint and Solvent Pit – Chromium Distribution in Surface Soils

Table 4-3. Preliminary Risk-Based Screening for Soil Contaminants at the Antifreeze and Degreaser Pit (1100-3) Subunit.

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Chromium | 14 | 5.0E-03[a] | 40 | -- | -- | -- | -- | 4.1E+01[a] | 1.6 | -- |
| Cobalt | 17.8 | 6.0E-02[c] | 480 | -- | -- | -- | -- | -- | -- | -- |
| Copper | 31.7 | 4.0E-02[f] | 320 | -- | -- | -- | -- | -- | -- | -- |
| Lead | 26.4 | ND | -- | ND | -- | ND | -- | ND | -- | 500-1,000[d] |
| Manganese | 436 | 1.0E-01[a] | 800 | 1.1E-04[a] | 1,400 | -- | -- | -- | -- | -- |
| Zinc | 60 | 2.0E-01[b] | 1,600 | -- | -- | -- | -- | -- | -- | -- |

[a]Integrated Risk Information System (IRIS, EPA 1992a)
[b]Health Effects Assessment Summary Tables (HEAST, EPA 1992b)
[c]Based on 30% absorption of inhaled arsenic (EPA 1992b)
[d]EPA 1989b
[e]Surrogate based on proposed arsenic unit risk of 5E-05 $\mu g/L$ (EPA 1991)
[f]EPA Region-10 (see Appendix A)
-- Indicates not available
ND Not Determined
Note: Shaded areas indicate screening criterion exceeded

9 3 1 2 7 4 0 1 3 8

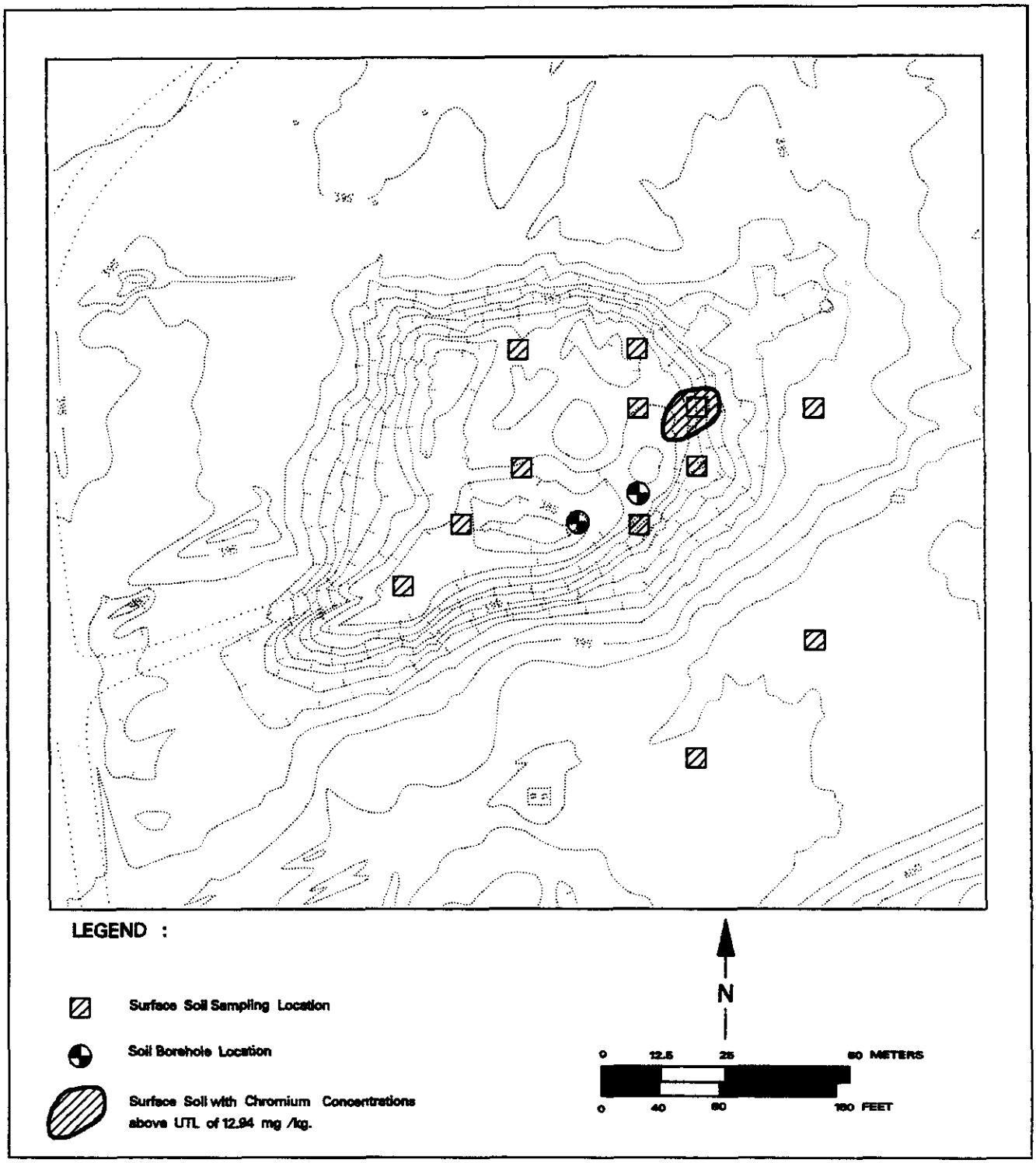


Figure 4-2. 1100-3, Antifreeze and Degreaser Pit – Chromium Distribution in Surface Soils.

location of a nearby groundwater monitoring well, MW-3, to be discussed in the following paragraph.

Preliminary risk-based screening of contaminants detected near the Antifreeze Tank Site in soil samples obtained during the installation of monitoring well MW-3 (see figure 3-1) indicates that arsenic and beryllium are the only parameters that exceed screening criteria (table 4-4). Arsenic was encountered at an elevated concentration in only a single sample obtained from below the water table, approximately 15 m (50 ft) below the ground surface. Beryllium was detected at elevated concentrations throughout the soil column penetrated during the installation of well MW-3. Concentrations detected varied from a low of 0.51 milligrams (mg)/kg to a high of 0.93 mg/kg. The maximum concentration was detected at a depth of approximately 7.9 m (26 ft) below the ground surface. There was no apparent pattern to the distribution of beryllium within the soil column.

Other contaminants (copper, silver, thallium, and zinc) are present at levels posing no known substantive risk to public health or the environment. Lead is measured at levels below cleanup criteria.

## 4.5 DISCOLORED SOIL SITE - UN-1100-6

Inorganic and organic contaminants present in the surface soils of the UN-1100-6, Discolored Soil Site subunit are listed in paragraph 3.5.1. Table 4-5 summarizes the preliminary risk-based screening for the UN-1100-6 subunit.

Because there are insufficient data to develop an RfD for di-n-octyl phthalate, and the substance is not a known carcinogen, this compound is combined and evaluated with the carcinogen, BEHP. Insignificant concentrations of di-n-octyl phthalate, as compared with BEHP, provide further justification for combining these two substances for the purposes of further evaluation.

The COPC for the UN-1100-6, Discolored Soil Site subunit - BEHP, chlordane, and heptachlor - were each encountered in several samples. Figure 4-3 shows the areal distribution of BEHP at the subunit. Figures 4-4 and 4-5 illustrate the distribution of alpha- and gamma-chlordane within the UN-1100-6 subunit. Figure 4-6 presents the areal extent of heptachlor contamination at the Discolored Soil Site. All surface contamination is limited to the eastern end of the depression, coincident with the actual area of stained soil. Subsurface sampling was not performed at this subunit, but based on field observations, the soil staining appears to be limited to the top 20.3 to 25.4 cm (8 to 10 in) of soil.

Other contaminants (zinc; DDT; 2-hexanone; and 1,1,1-trichloroethane) occur at levels that pose no known substantive risks to public health or the environment. Lead is present at levels below regulatory cleanup criteria.

**Table 4-4. Preliminary Risk-Based Screening for Soil Contaminants at the Antifreeze Tank Site (1100-4) Subunit.**

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Arsenic | 5.9 | 3.0E-04[a] | 2.4 | -- | -- | 1.7E+00[c] | 0.038 | 5.0E+01[a] | 4.3[e] | -- |
| Beryllium | 0.93 | 5.0E-03[a] | 40 | -- | -- | 4.3E+00[a] | 0.015 | 8.4E+00[a] | 7.8 | -- |
| Copper | 19.8 | 4.0E-02[f] | 320 | -- | -- | -- | -- | -- | -- | -- |
| Lead | 5.7 | ND | -- | ND | -- | ND | -- | ND | -- | 500-1000[d] |
| Silver | 2 | 5.0E-03[a] | 40 | -- | -- | -- | -- | -- | -- | -- |
| Thallium | 0.48 | 7.0E-05[b] | 0.56 | -- | -- | -- | -- | -- | -- | -- |
| Zinc | 63.8 | 2.0E-01[b] | 1,600 | -- | -- | -- | -- | -- | -- | -- |

[a]Integrated Risk Information System (IRIS, EPA 1992a)
[b]Health Effects Assessment Summary Tables (HEAST, EPA 1992b)
[c]Based on 30% absorption of inhaled arsenic (EPA 1992b)
[d]EPA 1989b
[e]Surrogate based on proposed arsenic unit of risk of 5E-05 $\mu m/L$ (EPA 1991)
[f]EPA Region-10 (see Appendix A)
-- Indicates not available
ND Not Determined
Note: Shaded area indicate screening criterion exceeded

**Table 4-5. Preliminary Risk-Based Screening for Soil Contaminants at the Discolored Soil Site (UN-1100-6) Subunit.**

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Lead | 22.1 | ND | -- | ND | -- | ND | -- | ND | -- | 500-1,000[c] |
| Zinc | 111 | 2.0E-01[b] | 1,600 | -- | -- | -- | -- | -- | -- | -- |
| BEHP | 25,000 | 2.0E-02[a] | 160 | -- | -- | 1.4E-02[a] | 4.5 | 1.4E-02[d] | 4,600 | -- |
| Chlordane | 1.86 | 6.0E-05[a] | 0.48 | -- | -- | 1.3E+00[a] | 0.049 | 1.3E+00[a] | 51 | -- |
| DDT | 0.17 | 5.0E-04[a] | 4.0 | -- | -- | 3.4E-01[a] | 0.19 | 3.4E-01[a] | 190 | -- |
| Heptachlor | 0.065 | 5.0E-04[a] | 4.0 | -- | -- | 4.5E+00[a] | 0.014 | 4.5E+00[a] | 14 | -- |
| 2-hexanone | 0.053 | 5.0E-02[f] | 400 | 9.0E-02[f] | 1,000,000 | - | -- | -- | -- | -- |
| 1,1,1-trichloroethane | 0.035 | 9.0E-02 | 720 | 3E-01 | 4,000,000 | - | -- | -- | -- | -- |

[a] Integrated Risk Information System (IRIS, EPA 1992a)
[b] Health Effects Assessment Summary Tables (HEAST, EPA 1992b)
[c] EPA 1989b
[d] Surrogate inhalation SF assumed to equal BEHP oral SF
[e] Surrogate based on proposed arsenic unit risk of 5E-05 μg/L (EPA 1991)
[f] Surrogate based on 2-butanone (HEAST, EPA 1992b)
-- Indicates not available
ND Not Determined
Note: Shaded areas indicate screening criterion exceeded

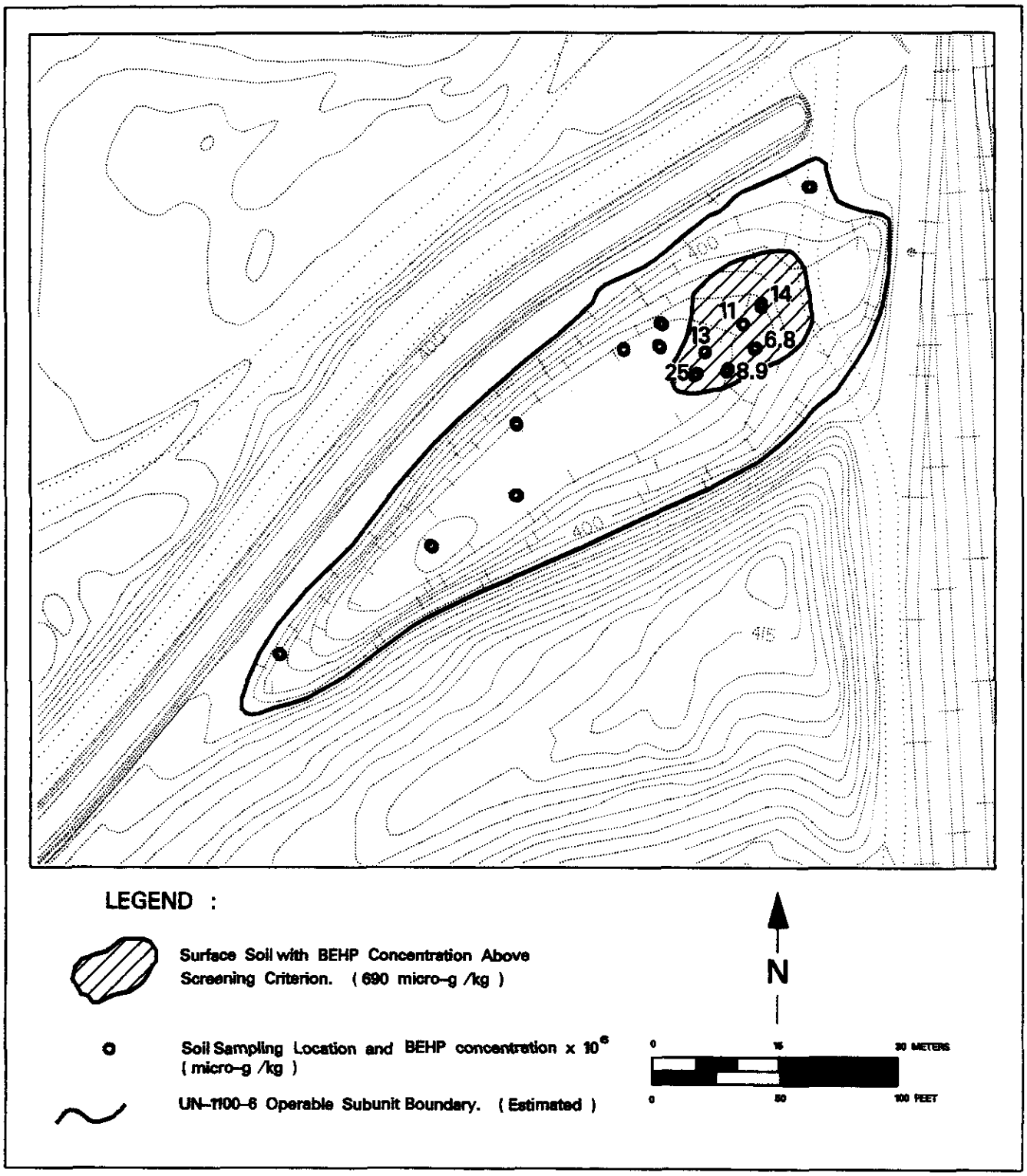


Figure 4-3. UN-1100-6, Discolored Soil Site - BEHP Distribution in Surface Soils at Concentrations above a UTL of 690 micro-g /kg.

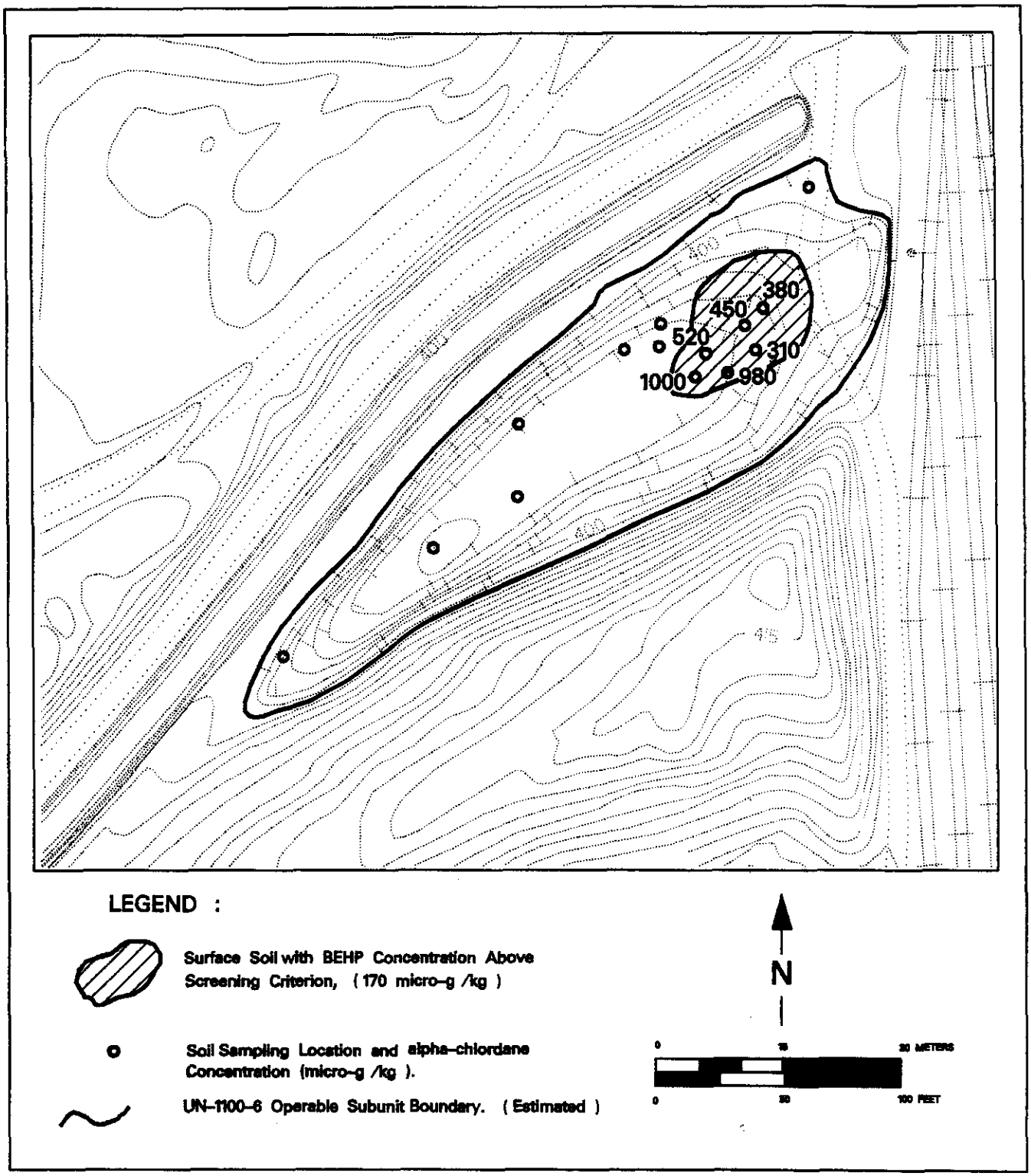


Figure 4-4. UN-1100-6, Discolored Soil Site – alpha – Chlordane Distribution in Surface Soils at Concentrations above a UTL 170 micro-g /kg.

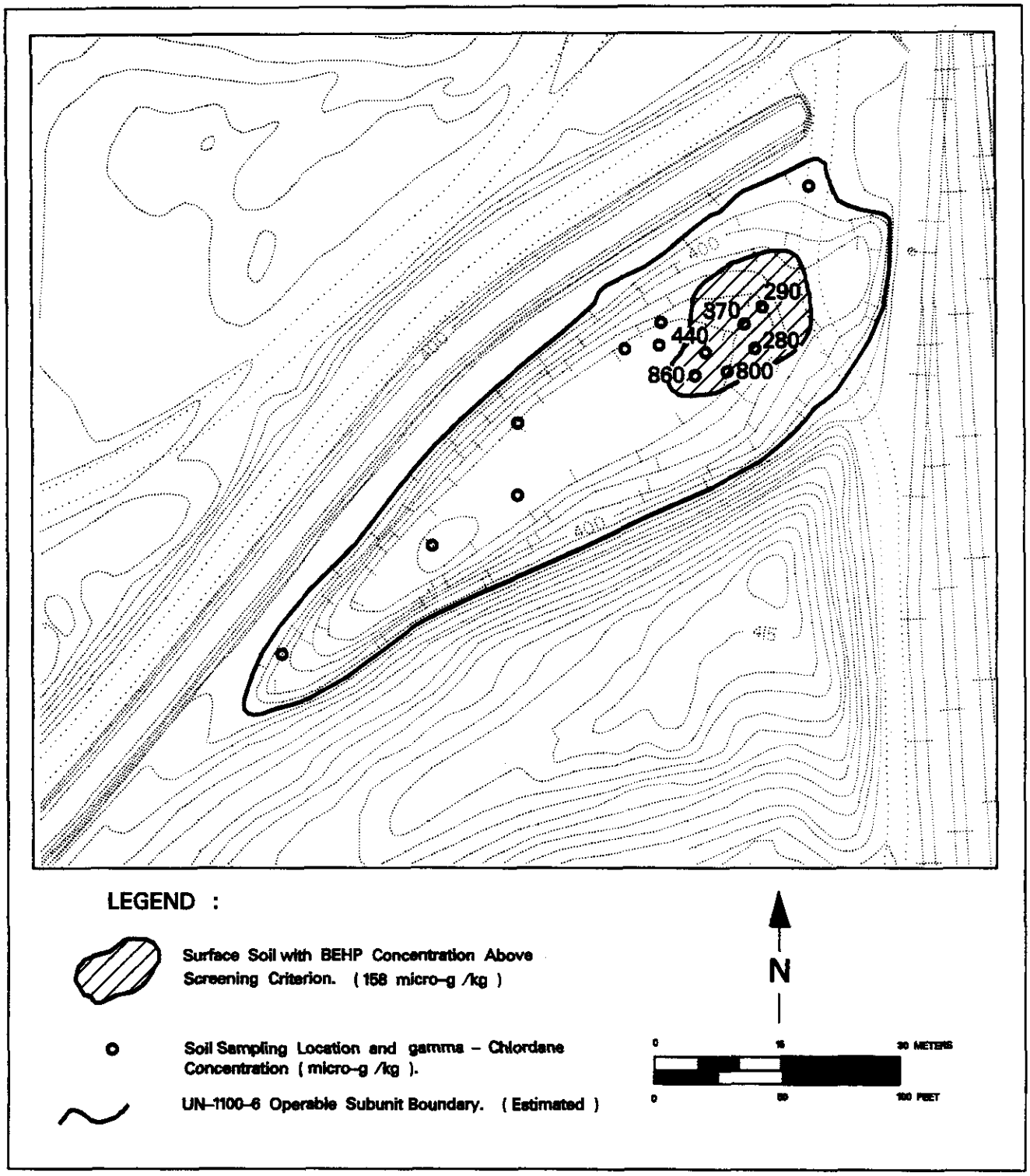


Figure 4-5. UN-1100-6, Discolored Soil Site - gamma - Chlordane Distribution in Surface Soils at Concentrations above a UTL of 158 micro-g /kg.

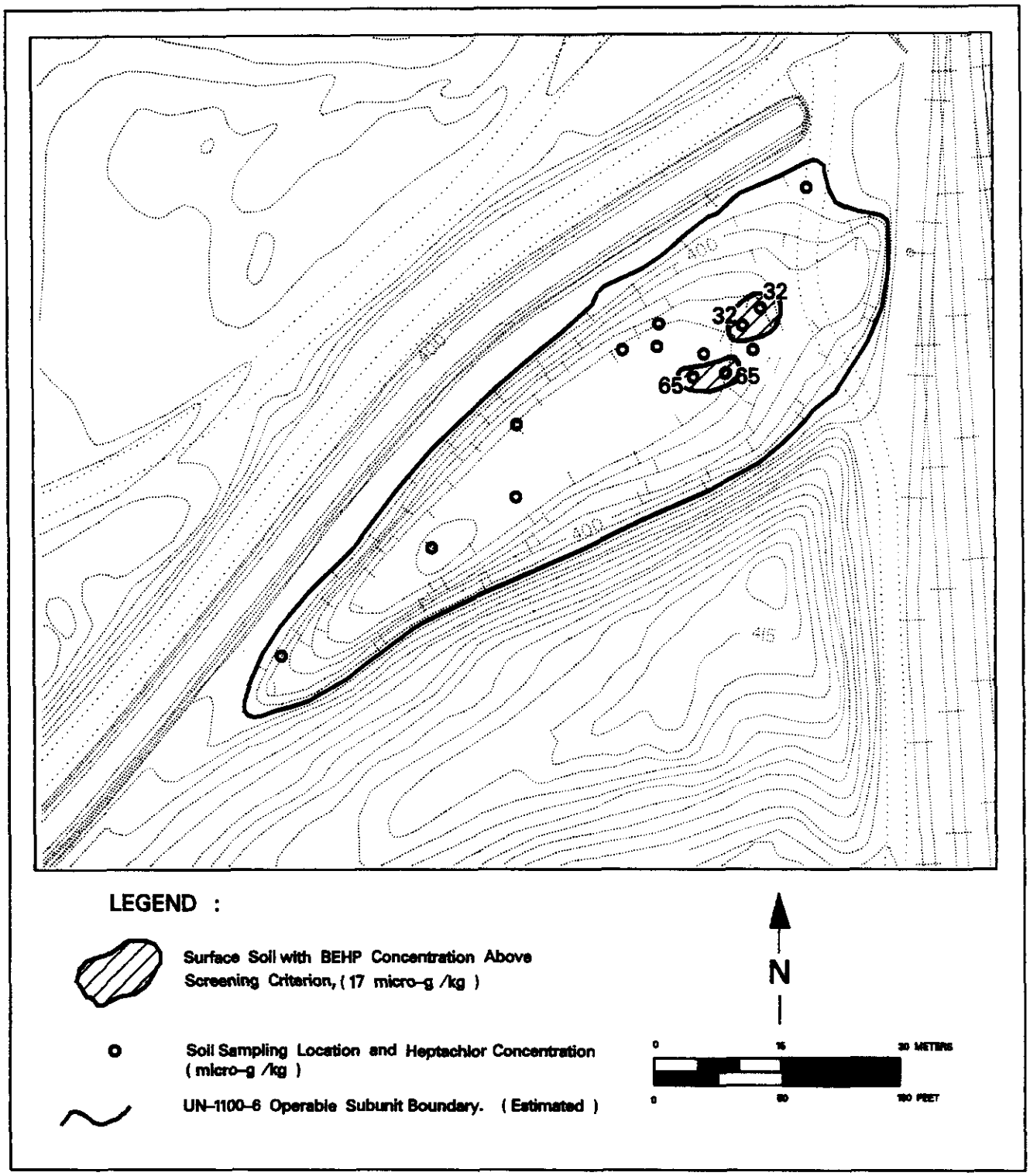


Figure 4-6. UN-1100-6, Discolored Soil Site – Heptachlor Distribution in Surface Soils at Concentrations above a UTL of 17 micro-g /kg.

## 4.6 EPHEMERAL POOL

The contaminants detected at the Ephemeral Pool subunit are listed in paragraph 3.6.1. The preliminary risk-based screening for the identified contaminants is presented in table 4-6. Chlordane, heptachlor, and PCB's are the contaminants of potential concern at this subunit. Heptachlor was detected in one of two soil samples collected within the subunit during the Phase I investigation. The exact position of the sample site within the subunit is uncertain due to the lack of a sample location survey at the time the sample was collected. During Phase II soil sampling, heptachlor was not detected. Chlordane was identified at all sampling locations during the Phase II investigation with relatively high concentrations detected at either end of the Ephemeral Pool feature; sample sites E-1, E-5, and E-6. Elevated PCB concentrations were identified at sample locations E-2 and E-3 (figure 4-7). Sampling of subsurface soils was not performed during either the Phase I or Phase II investigations. It is assumed that both the PCB and chlordane contaminants are restricted to near-surface soils due to their relative immobility in soil/water systems.

Other contaminants (zinc, Endosulfan II, and Endrin) are measured at levels that pose no known substantive risk to the environment or public health. Lead is measured at levels below cleanup criteria.

## 4.7 HORN RAPIDS LANDFILL

As listed in paragraph 3.7.1, numerous inorganic contaminants were encountered in the surface and subsurface soils of HRL. The only subsurface organic contaminants detected were PCB's in borehole HRL-4 and in exploration trench test pit (TP)-1.

Table 4-7 summarizes the results of the preliminary risk-based screening for soil contaminants at HRL. The COPC for the HRL subunit are:

- Antimony
- Arsenic
- Barium
- Beryllium
- Cadmium
- Chromium
- Cobalt
- Copper
- Nickel
- Thallium
- Vanadium
- Zinc
- Cyanide
- Lead
- Mercury
- Selenium
- Silver
- Beta-HCH
- DDT
- Heptachlor
- PCB's
- Chlordane
- Endrin
- Endosulfan II
- Napthalene
- Tetrachloroethene

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9 3 1 2 7 3 4 0 1 9 7

**Table 4-6. Preliminary Risk-Based Screening for Soil Contaminants at the Ephemeral Pool.**

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Lead | 54.2 | ND | -- | ND | -- | ND | -- | ND | -- | 500-1,000[e] |
| Zinc | 67.5 | 2.0E-01[b] | 1,600 | -- | -- | -- | -- | -- | -- | -- |
| Chlordane | 2.8 | 6.0E-05[a] | 0.48 | -- | -- | 1.3E+00[a] | 0.049 | 1.3E+00[a] | 50 | -- |
| Endosulfan II | 0.16 | 5E-05[a] | 0.4 | -- | -- | -- | -- | -- | -- | -- |
| Endrin | 0.039 | 3E-04[a] | 2.4 | -- | -- | -- | -- | -- | -- | -- |
| Heptachlor | 0.029 | 5.0E-04[a] | 4.0 | -- | -- | 4.5E+00[a] | 0.014 | 4.5E+00[a] | 14 | -- |
| PCBs | 42 | -- | -- | -- | -- | 7.7E+00[a] | 0.005 | 7.7E+00[c] | 8.5 | 1-25[d] |

[a]Integrated Risk Information System (IRIS, EPA 1992a)
[b]Health Effects Assessment Summary Tables (HEAST, EPA 1991)
[c]Surrogate inhalation SF assumed to be equal to PCB oral SF
[d]40 CFR 761
[e]EPA 1989b

-- Indicates not available

ND = Not determined

Note: Shaded areas indicate screening criterion exceeded

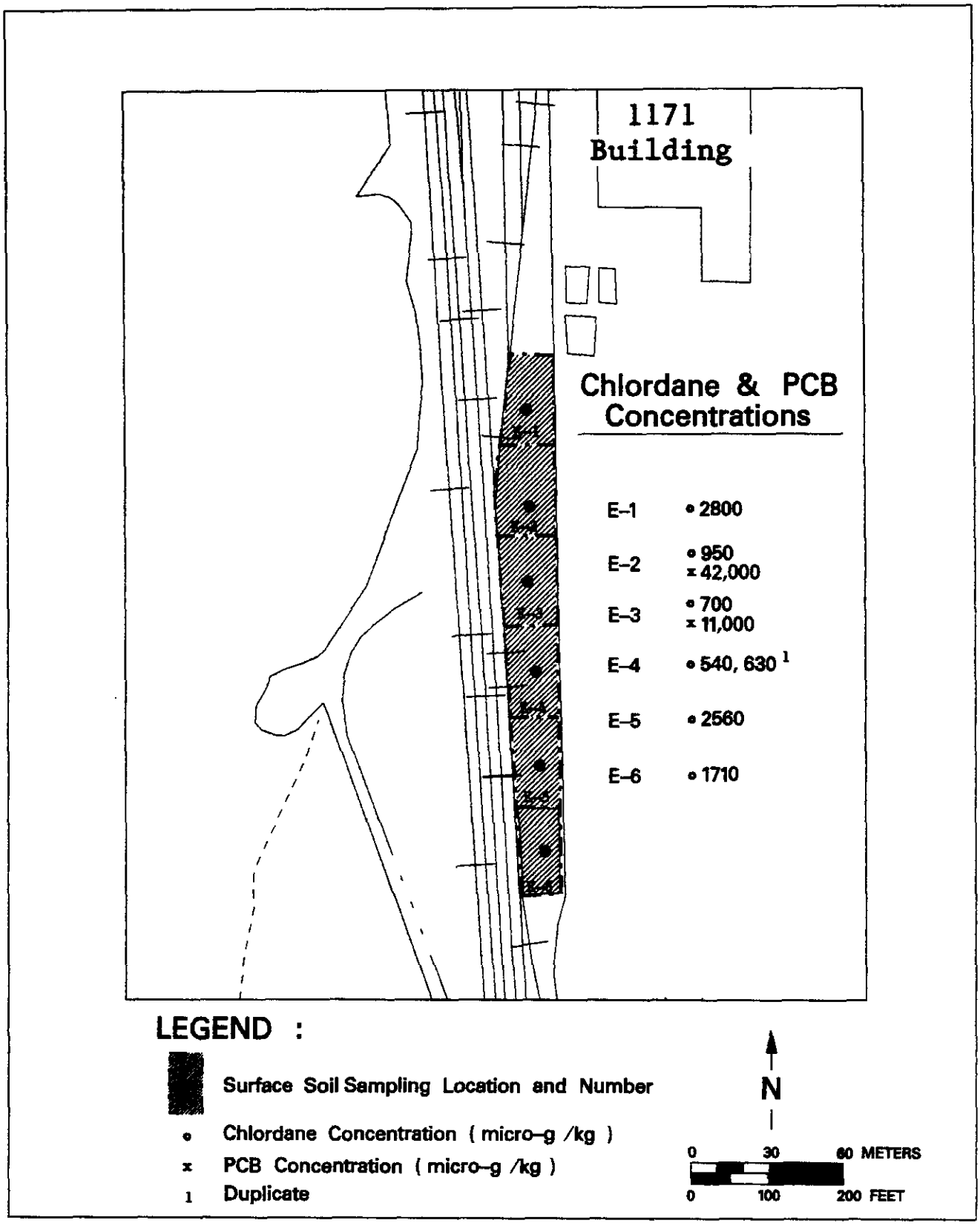



Figure 4-7. Ephemeral Pool – Chlordane and PCB Distribution in Surface Soils

**Table 4-7. Preliminary Risk-Based Screening for Soil Contaminants at the Horn Rapids Landfill. (sheet 1 of 2)**

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Antimony | 15.6 | 4.0E-04[a] | 3.2 | -- | -- | -- | -- | -- | -- | -- |
| Arsenic | 6.6 | 3.0E-04[a] | 2.4 | -- | -- | 1.7E+00[+] | 0.038 | 5.0E+01[a] | 4.3[a] | -- |
| Barium | 1320 | 7.0E-02[a] | 560 | 1.0E-04[b] | 1,300 | -- | -- | -- | -- | -- |
| Beryllium | 1.3 | 5.0E-03 | 41 | -- | -- | 4.3E+00[a] | 0.015 | 8.4E+00[a] | 7.8 | -- |
| Cadmium | 2.4 | 1.0E-03[a] | 8.0 | -- | -- | -- | -- | 6.1E+00[a] | 10 | -- |
| Chromium | 1250 | 5.0E-03[a] | 40 | -- | -- | -- | -- | 4.1E+01[a] | 1.6 | -- |
| Cobalt | 42.5 | 6.0E-02[f] | 480 | -- | -- | -- | -- | -- | -- | -- |
| Copper | 1280 | 4.0E-02[f] | 320 | -- | -- | -- | -- | -- | -- | -- |
| Cyanide | 0.56 | 2.0E-02[a] | 160 | -- | -- | -- | -- | -- | -- | -- |
| Lead | 854 | ND | -- | ND | -- | ND | -- | ND | -- | 500-1,000[d] |
| Manganese | 501 | 1.0E-01[a] | 800 | 1.1E-04[a] | 1400 | -- | -- | -- | -- | -- |
| Mercury | 1.3 | 3.0E-04[b] | 2.4 | 8.6E-05[b] | 1,100 | -- | -- | -- | -- | -- |
| Nickel | 557 | 2.0E-02[a] | 160 | -- | -- | -- | -- | 8.4E-01[b] | 78 | -- |
| Selenium | 0.97 | 5.0E-03[b] | 44 | -- | -- | -- | -- | -- | -- | -- |
| Silver | 7.7 | 5.0E-03[a] | 40 | -- | -- | -- | -- | -- | -- | -- |
| Thallium | 3.1 | 7.0E-05[a] | 0.56 | -- | -- | -- | -- | -- | -- | -- |
| Vanadium | 101 | 7.0E-03[b] | 56 | -- | -- | -- | -- | -- | -- | -- |
| Zinc | 3160 | 2.0E-01[b] | 1,600 | -- | -- | -- | -- | -- | -- | -- |
| Beta-HCH | 0.094 | -- | -- | -- | -- | 1.8E+00[a] | 0.036 | 1.8E+00[a] | 36 | -- |
| DDT | 1.98 | 5.0E-04[a] | 4.0 | -- | -- | 3.4E-01[a] | 0.19 | 3.4E-01[a] | 190 | -- |
| Endosulfan II | 0.11 | 5.0E-05[a] | 0.4 | -- | -- | -- | -- | -- | -- | -- |

Table 4-7. Preliminary Risk-Based Screening for Soil Contaminants at the Horn Rapids Landfill. (sheet 2 of 2)

| Parameter | Maximum Detected Soil Concentration (mg/kg) | Oral RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Inhalation RfD (mg/kg-d) | Soil Concentration at HQ=0.1 (mg/kg) | Oral SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Oral ICR = 1E-07 (mg/kg) | Inhalation SF $(mg/kg\text{-}d)^{-1}$ | Soil Concentration at Inhalation ICR = 1E-07 (mg/kg) | Regulatory Soil Cleanup Guidelines (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|---|
| Endrin | 0.42 | 3.0E-04[a] | 2.4 | -- | -- | -- | -- | -- | -- | -- |
| Heptachlor | 0.02 | 5.0E-04[a] | 4.0 | -- | -- | 4.5E+00[a] | 0.014 | 4.5E+00[a] | 14 | -- |
| Naphthalene | 8.2 | 4.0E-02[b] | 320 | -- | -- | -- | -- | -- | -- | -- |
| PCBs | 102 | -- | -- | -- | -- | 7.7E+00[a] | 0.008 | 7.7E+00[h] | 8.5 | 1-25[i] |
| Tetrachloroethane | 0.006 | 1.0E-02[a] | 80 | -- | -- | 5.2E-02[f] | 1.2 | 2.0E-03[f] | 33,000 | -- |

[a]Integrated Risk Information System (IRIS, EPA 1992a)
[b]Health Effects Assessment Summary Tables (HEAST, EPA 1991 or EPA 1992b)
[c]Based on 30% absorption of inhaled arsenic (EPA 1992b)
[d]EPA 1989b
[e]Surrogate inhalation SF assumed to equal BEHP oral SF
[f]EPA-Region 10 (see Appendix A)
[g]Surrogate oral and inhalation RfDs based on 2-butanone (HEAST, EPA 1992b)
[h]Surrogate inhalation SF assumed to be equal to PCB oral SF
[i]40 CFR 761
[+]Surrogate based on proposed arsenic unit risk of 5E-05 μg/L (EPA 1991)
-- Indicates not available
ND = Not Determined
Note: Shaded areas indicate screening criterion exceeded

### 4.7.1 Horn Rapids Landfill Soil Contaminants

The distribution of each contaminant within the HRL subunit are discussed in the following paragraphs. UTL's for surface and subsurface soil contaminants were presented in tables 3-1 and 3-2, respectively. Maps providing the locations and designations of all surface sampling and borehole locations within the HRL subunit were included in figures 3-6 and 3-9.

**4.7.1.1 Antimony.** Antimony was detected in surface soil samples at concentrations above the UTL levels at three locations in the east-central portion of the landfill. Figure 4-8 shows the distribution of this analyte in the surface soils. Antimony was detected in only a single subsurface sampling location; borehole HRL-2 within the depth interval of 1.6 to 2.2 m (5.1 to 7.1 ft).

**4.7.1.2 Arsenic.** Arsenic was not detected in surface soils at concentrations above the UTL for this substance. Subsurface distribution was sporadic. It was detected in exploration trenches 7, 8, and 11 at depths between 1.2 and 1.5 m (4 and 5 ft), in borehole HRL-3 at a depth of 7.3 m (24 ft), and in borehole HRL-7 at an approximate depth of 1.0 m (10 ft).

**4.7.1.3 Barium.** The distribution of barium in the surface soils at HRL in concentrations above a UTL of 120.1 mg/kg is presented in figure 4-9. Only one subsurface sample yielded an elevated barium concentration; B00Z59, obtained from a depth of 1.2 m (4.0 ft) in exploration trench TP-11 (see figures 3-6 and 3-9).

**4.7.1.4 Beryllium.** Figure 4-10 presents the beryllium distribution at concentrations above UTL levels in surface soils at the HRL subunit. Beryllium was widespread in subsurface samples obtained from borings HRL-2 through -10. Concentrations above the subsurface UTL were detected throughout the length of the soil column penetrated [*i.e.*, depths of 4.6 to 8.5 m (15 to 28 ft)]. As discussed in section 2.0, these boreholes were sited to intentionally avoid penetrating assumed locations where waste had been buried during landfill operation. These boreholes, therefore, are assumed to penetrate undisturbed soil deposits for much of their depth. Only a single soil sample collected from a known disturbed area contained an elevated concentration of beryllium. Sample B00ZV3, gathered from a depth of 1.5 m (5 ft) in exploration trench TP-8, contained beryllium at a level exceeding the UTL.

**4.7.1.5 Chromium.** Chromium distribution in surface soils is illustrated in figure 4-11. It appears to be generally isolated to the eastern edge of the landfill, appearing in samples obtained from shallow depressions in the ground surface. Subsurface chromium contamination is scattered throughout the subunit. Boreholes HRL-4, -5, -6, and -8 show concentrations above UTL values at depths of approximately 4.6 m (15 ft). One soil sample from HRL-6 at a depth of 7.6 m (25 ft) also showed elevated chromium. Samples obtained during Phase II characterization of the landfill's waste disposal trenches contained elevated concentrations of chromium in exploration trenches TP-3A, -4, -5, and -11 at depths of 5.8, 3.7, and 1.2 m (19, 12, and 4 ft), respectively.

**4.7.1.6 Copper.** The distribution of copper in the surface soils of HRL at concentrations above the UTL value is depicted in figure 4-12. Areas of high copper concentrations are

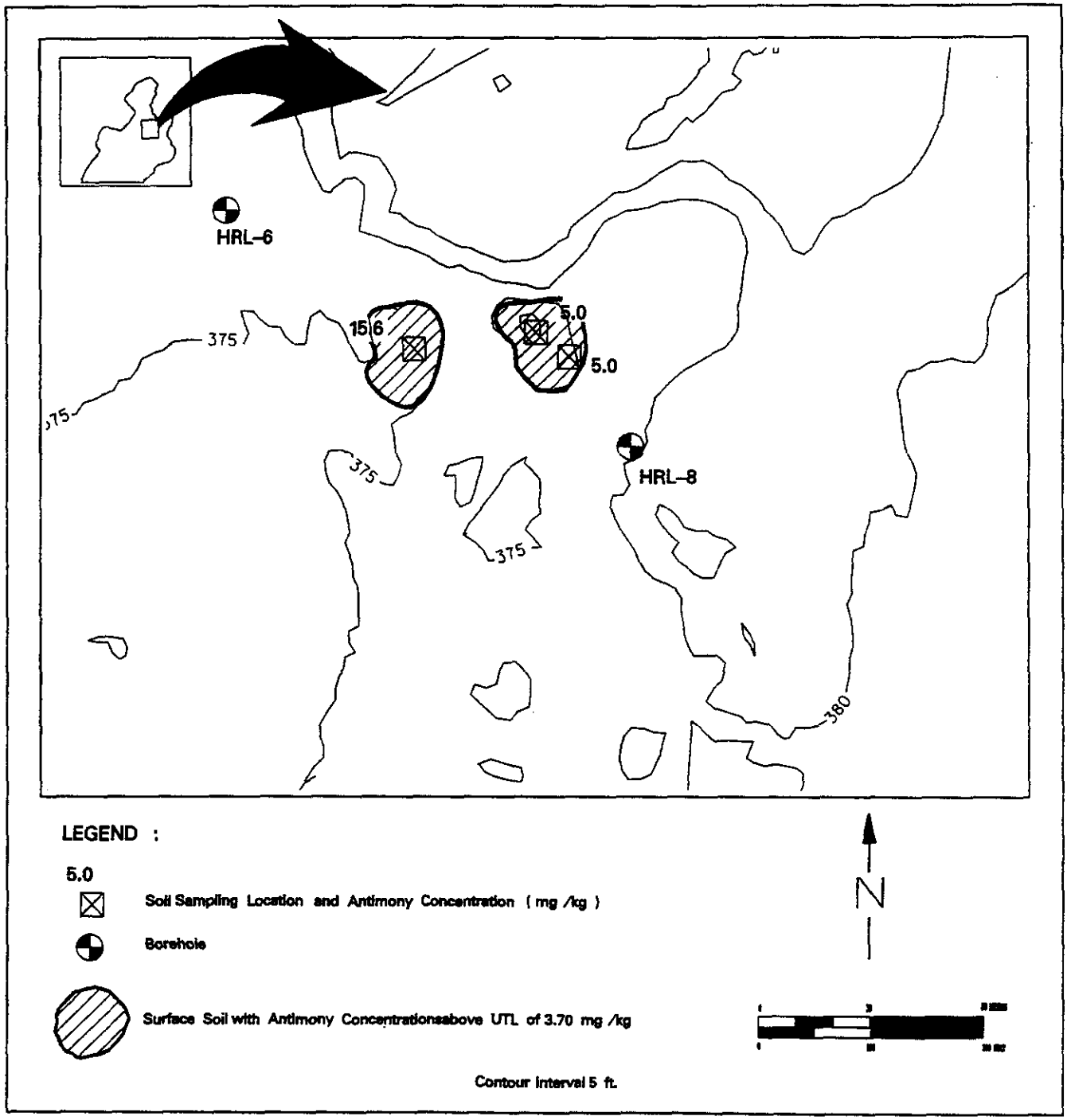
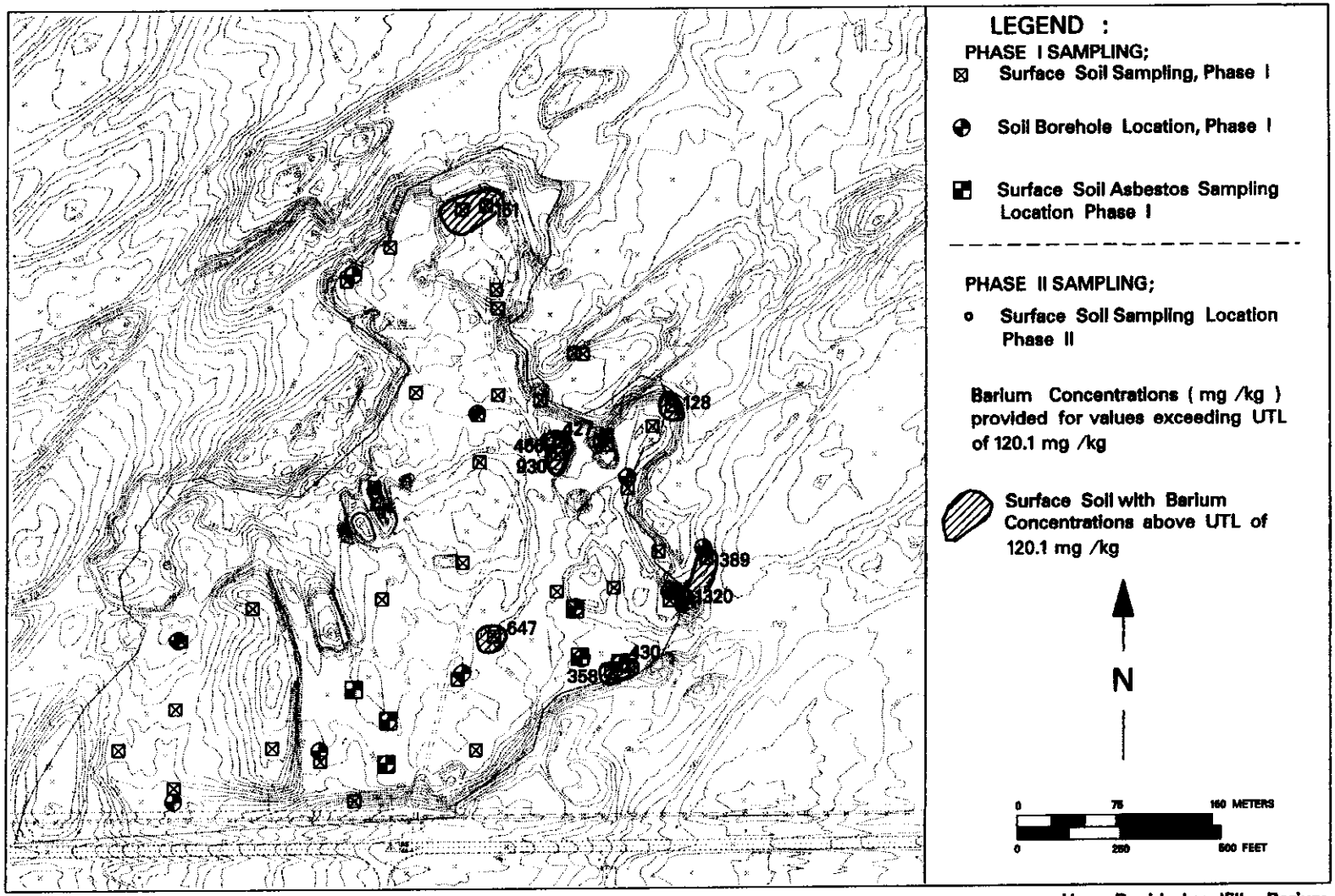
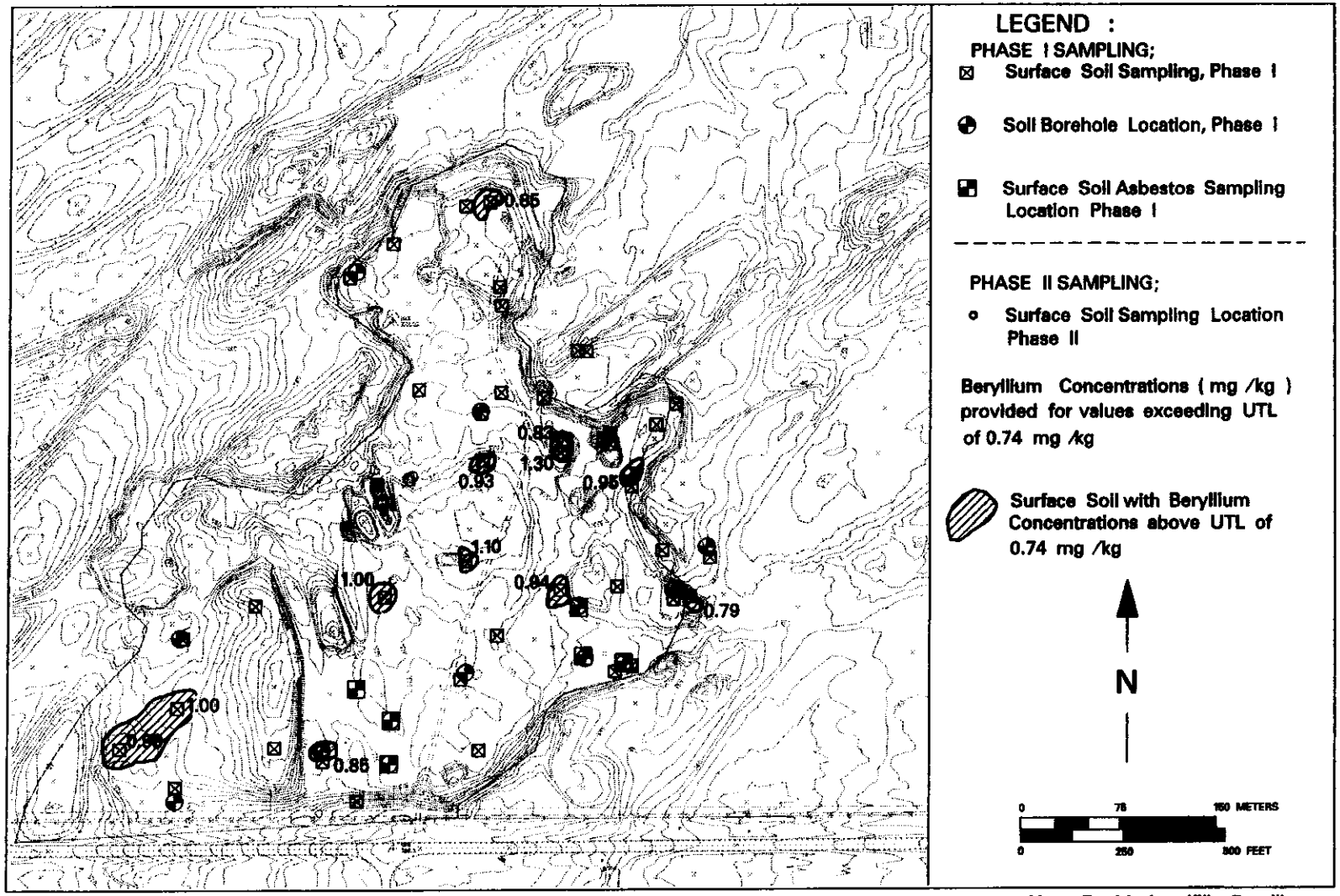



Figure 4-8. Horn Rapids Landfill – Antimony Distribution in Surface Soils



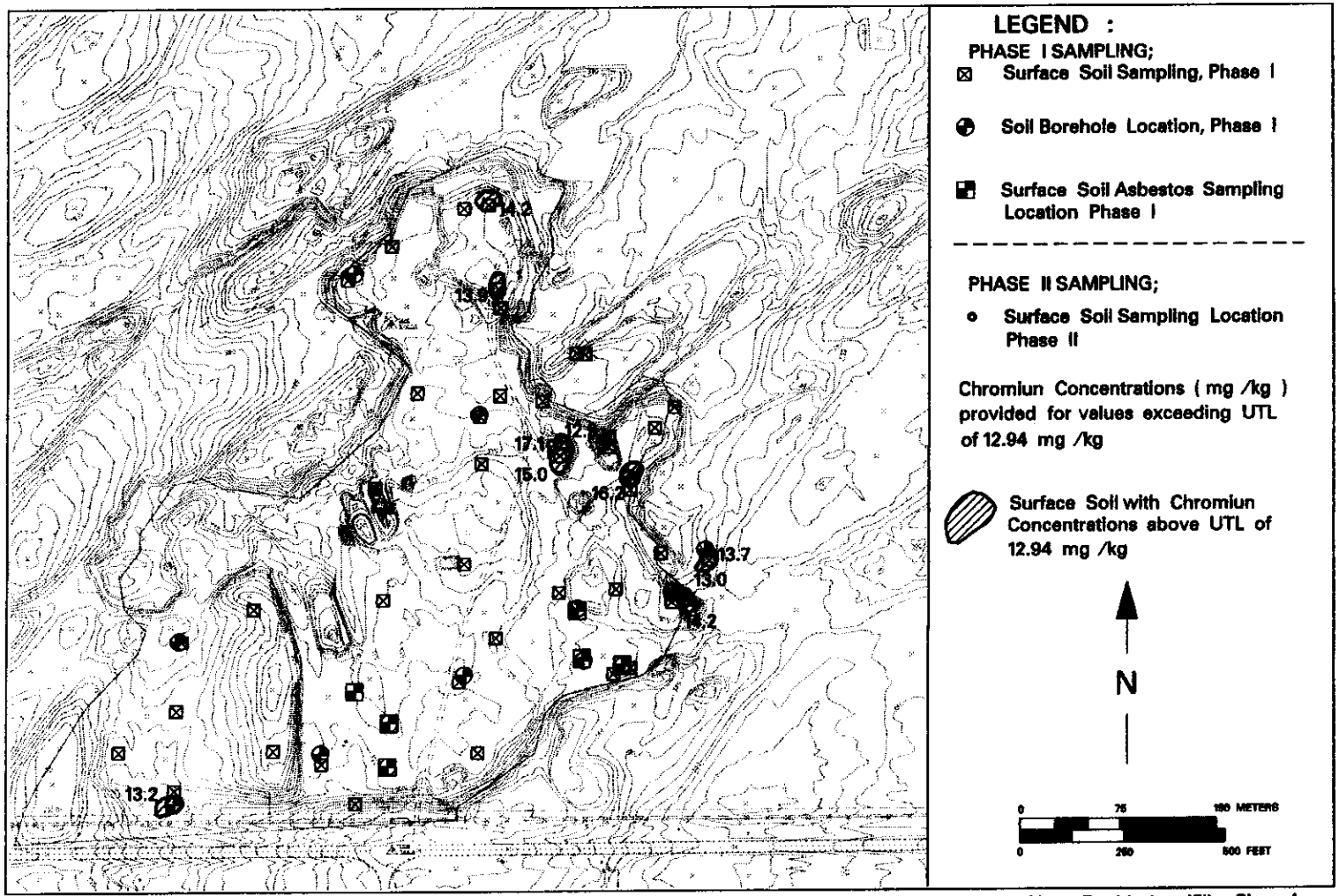

Horn Rapids Landfill – Barium Distribution in Surface Soils.

Fig. 4–9




Horn Rapids Landfill – Beryllium Distribution in Surface Soils

Fig. 4–10




Horn Rapids Landfill – Chromium Distribution In Surface Soils

Fig. 4–11

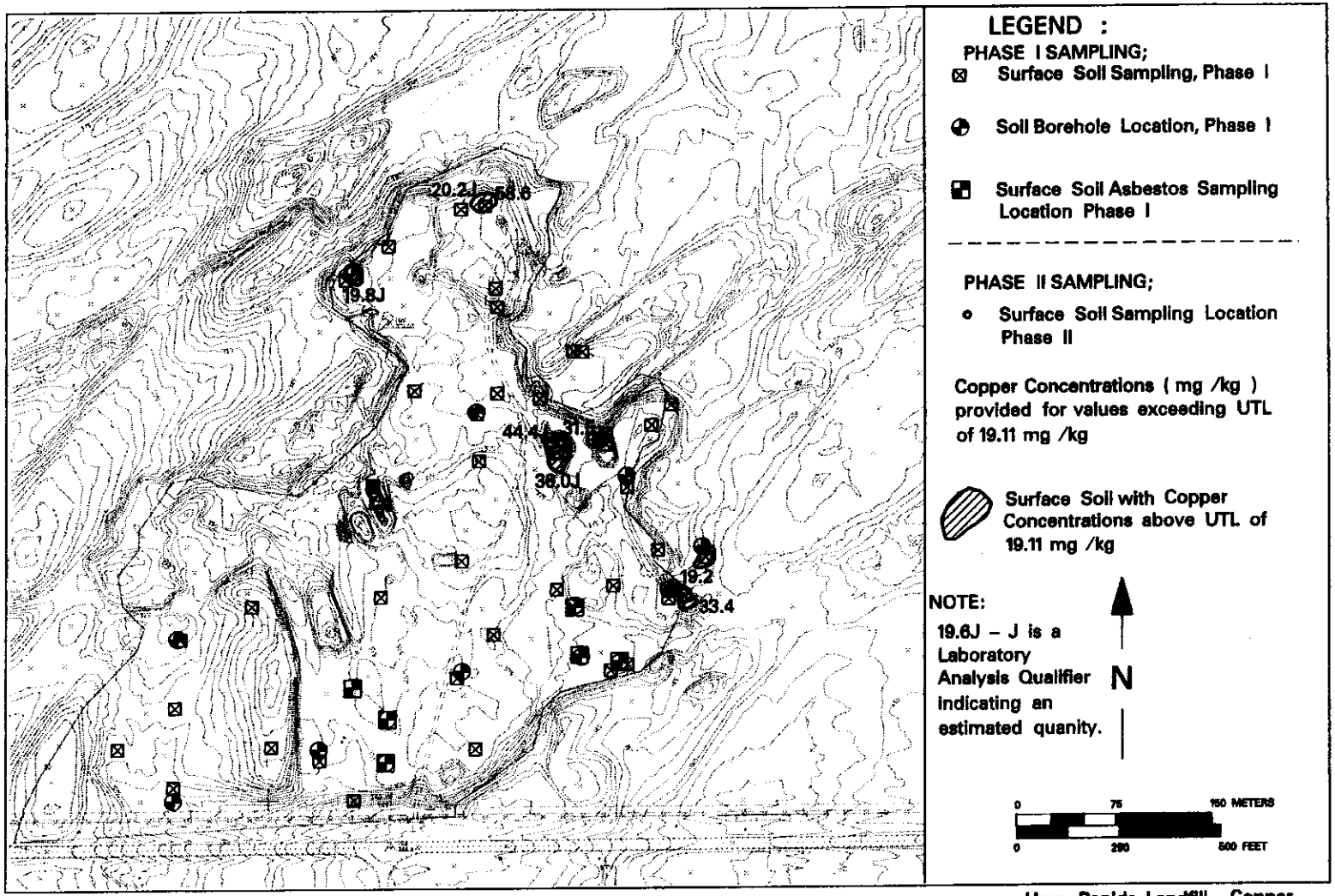
generally restricted to depressions in the ground surface or to the base of relatively steep soil slopes. Copper was also a common contaminant detected above UTL values in soil samples obtained from the subsurface. Elevated levels of copper were detected in boreholes HRL-4, -5, -6, -8, -9, and -10 and appeared to be randomly distributed throughout the depth of natural soil deposits sampled. Elevated levels of copper were also detected in soil samples obtained from exploration trenches TP-3A, -4, -5, -8, and -11. Again, copper appeared to be randomly distributed within these disturbed deposits.

**4.7.1.7 Lead.** Figure 4-13 illustrates the distribution of lead present at concentrations above UTL levels in the surface soil of HRL. With few exceptions, the locations of elevated lead levels are within surface depressions of the subunit. Elevated levels of lead in the subsurface were detected in soil samples obtained from boreholes HRL-6 and HRL-10. Both boreholes showed elevated lead concentrations at a depth of approximately 6.1 to 7.6 m (20 to 25 ft). In addition, HRL-10 had elevated values at a depth of approximately 1.2 m (4.0 ft). Exploration trenches TP-3A, -4, -5, -7, -8, and -11 encountered elevated lead concentrations at depths ranging from 1.2 to 5.8 m (4 to 19 ft). There was no pattern to the lead distribution in the subsurface at these locations.

**4.7.1.8 Nickel.** Nickel was detected at the HRL subunit at concentrations above UTL values in a single surface sample located in the extreme northern portion of the facility. Figure 4-14 presents the location of elevated nickel concentrations in the HRL surface soils. The distribution of nickel in the subsurface is scattered, as there appeared to be no consistency in the depths of elevated nickel concentrations from borehole-to-borehole. Boreholes HRL-4, -5, -6, -8, and -10 showed elevated nickel in soil samples collected from varying depths. As with the boring samples, nickel was found randomly distributed in exploration trenches at levels above UTL levels. Soil samples collected from trenches TP-3A, -4, -5, -7, and -11 had elevated nickel at depths of 5.8, 3.7, 1.5, and 1.2 m (19, 12, 5, and 4 ft), respectively.

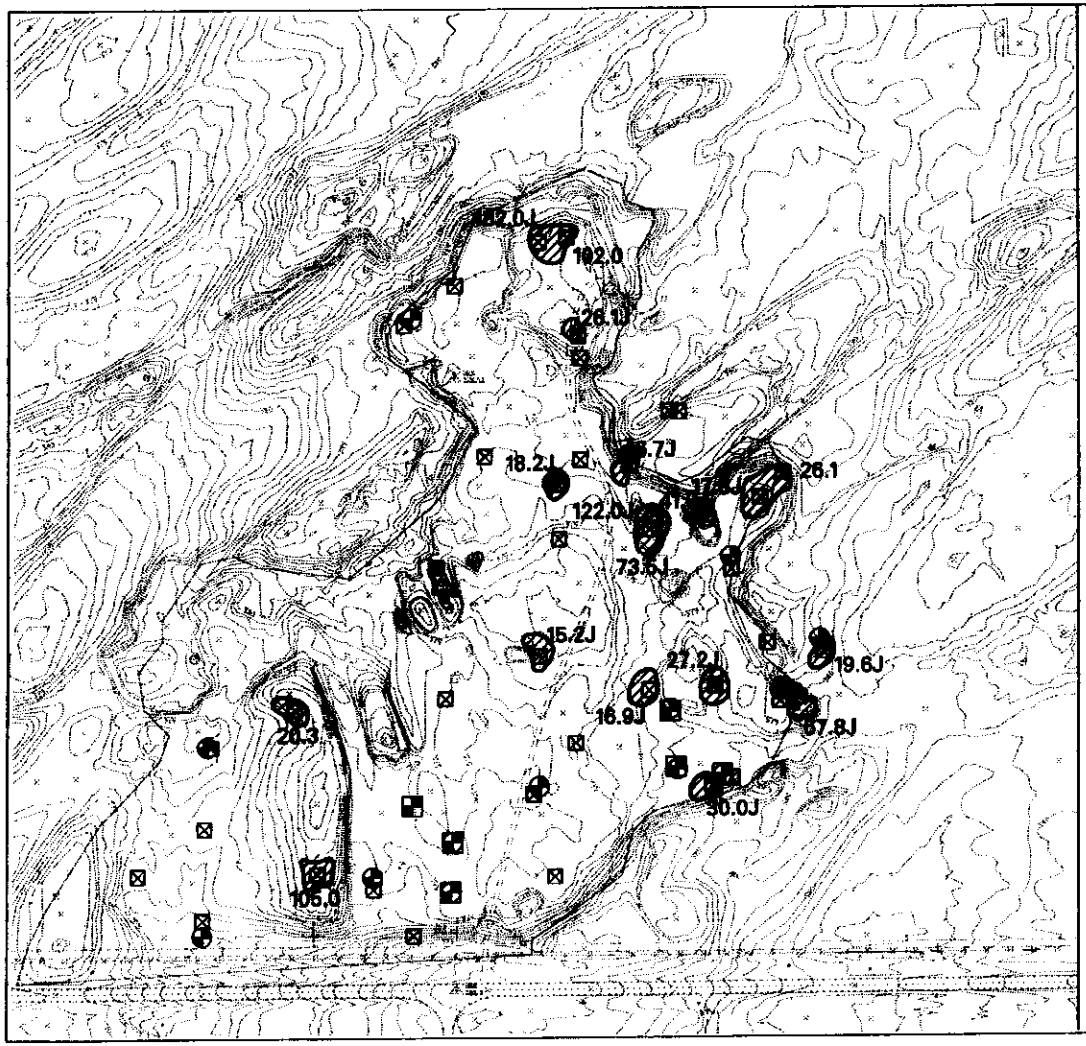
**4.7.1.9 Thallium.** A single surface soil sample in the extreme southeast corner of the subunit yielded thallium concentrations above UTL levels. Figure 4-15 shows the location of the elevated thallium within HRL. Borehole HRL-7 was the only location having elevated thallium in the subsurface. Soil samples obtained at the depth intervals of 3.9 to 4.6 m and 6.9 to 7.6 m (12.7 to 15.1 ft and 22.7 to 25.0 ft) during drilling of the borehole tested positive for thallium at concentrations exceeding UTL levels.

**4.7.1.10 Vanadium.** Vanadium was detected in two surface samples at concentrations exceeding UTL values; AH188 in the northern portion of the landfill, and AH203 in the southern portion. These sampling locations are presented in figure 4-16. Elevated concentrations of vanadium were not detected in subsurface soil samples collected from HRL.




Horn Rapids Landfill – Copper Distribution in Surface Soils

Fig. 4–12




**LEGEND :**

PHASE I SAMPLING;

- Surface Soil Sampling, Phase I
- Soil Borehole Location, Phase I
- Surface Soil Asbestos Sampling Location Phase I

PHASE II SAMPLING;

- Surface Soil Sampling Location Phase II

Lead Concentrations ( mg /kg ) provided for values exceeding UTL of 12.64 mg /kg

- Surface Soil with Lead Concentrations above UTL of 12.64 mg /kg

NOTE:

19.6J – J is a Laboratory Analysis Qualifier indicating an estimated quanity.

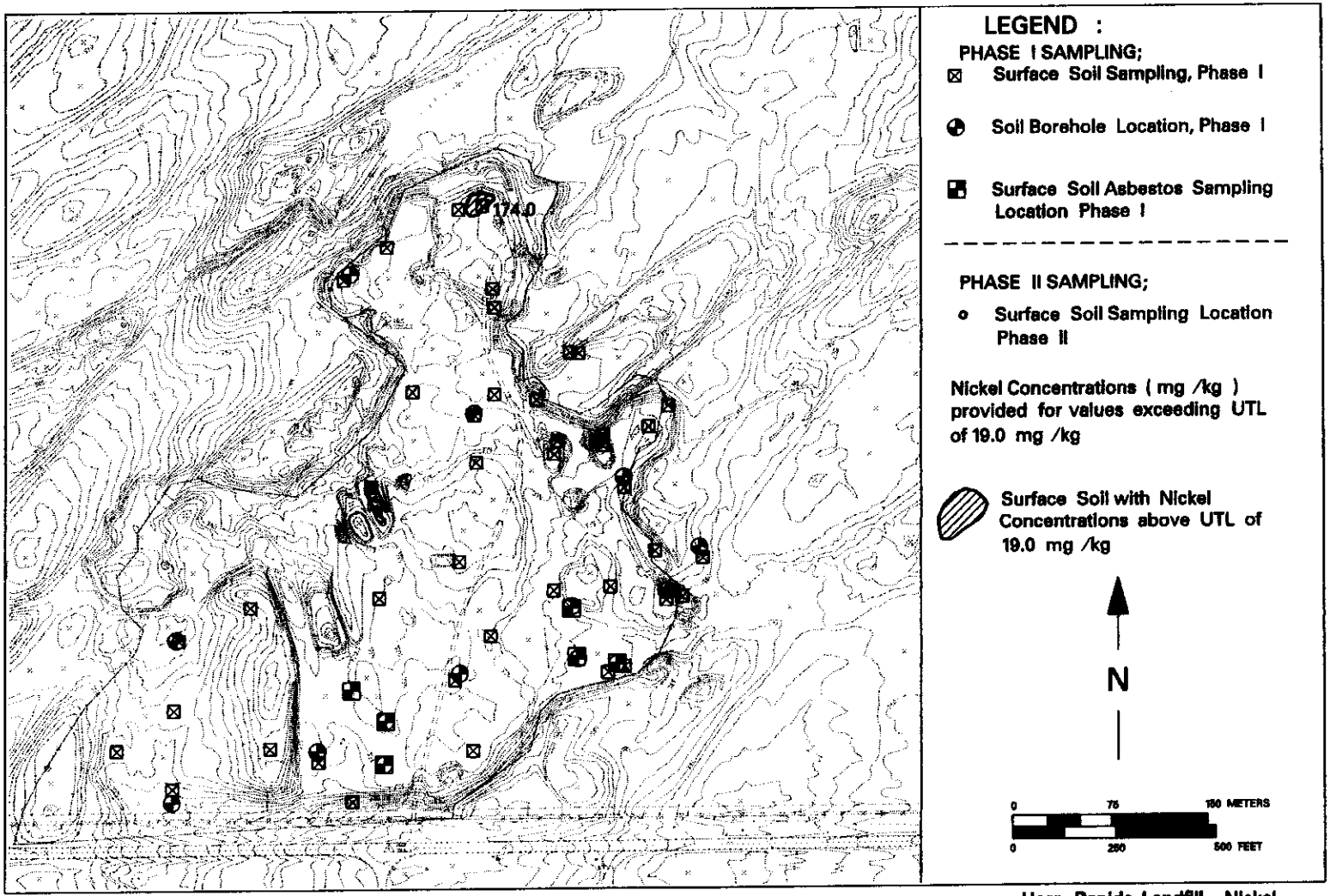
N

0 75 150 METERS

0 250 500 FEET

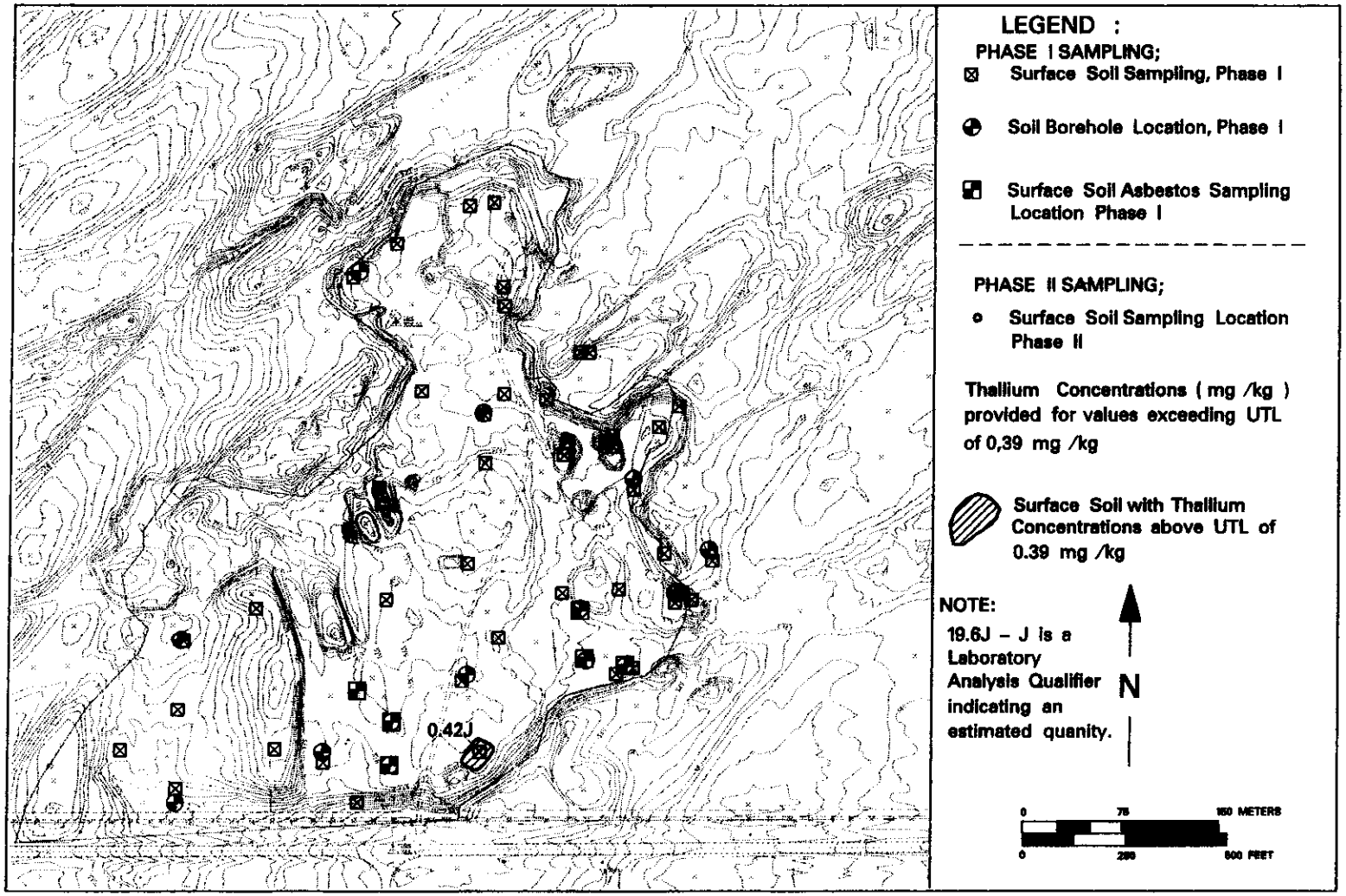
Horn Rapids Landfill – Lead Distribution in Surface Soils

Fig. 4–13



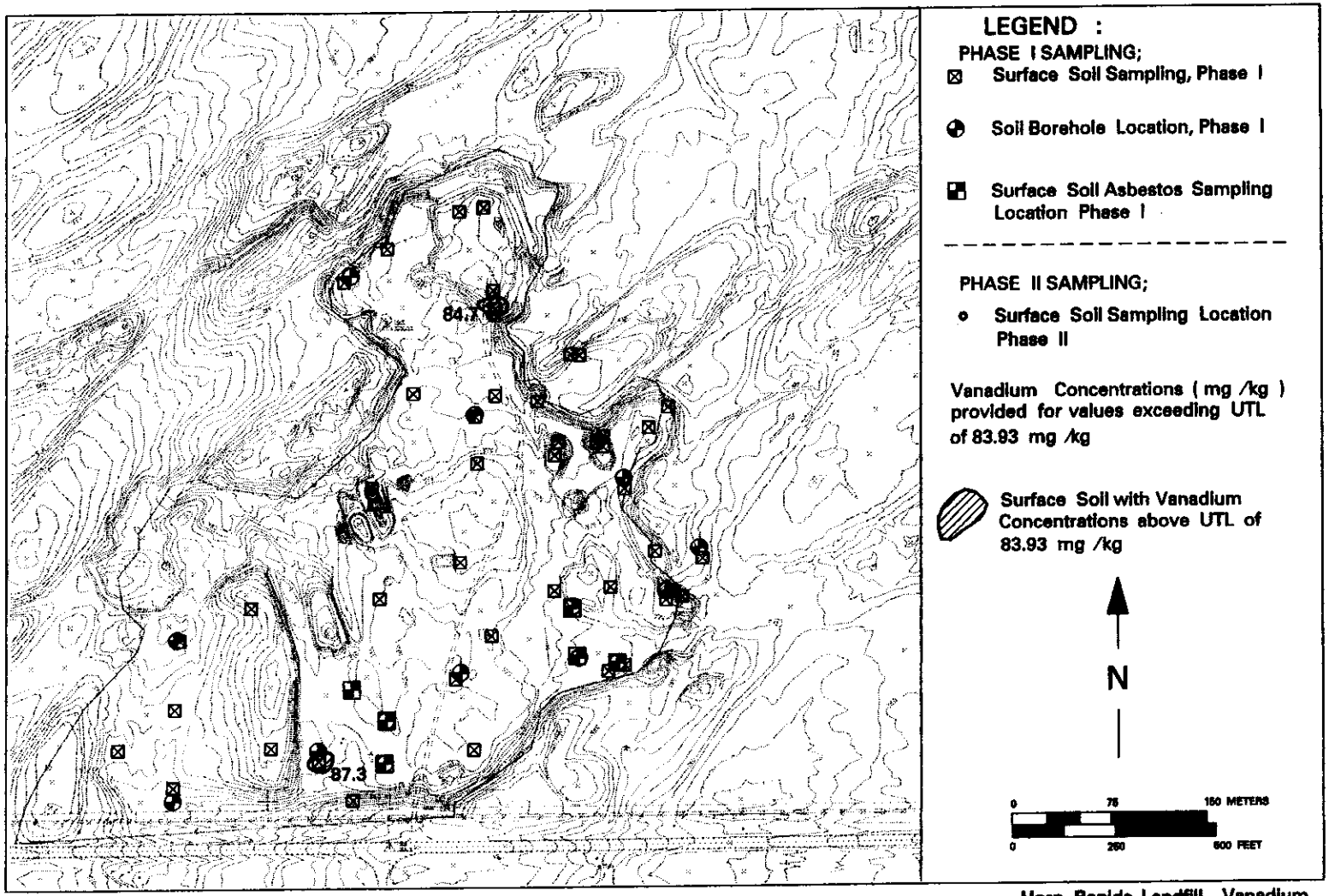

Horn Rapids Landfill – Nickel Distribution in Surface Soils

Fig. 4–14




Horn Rapids Landfill – Thallium Distribution in Surface Soils

Fig. 4–15




Horn Rapids Landfill – Vanadium Distribution in Surface Soils

Fig. 4–16

**4.7.1.11 Zinc.** Concentrations of zinc in the surface soil at HRL exceeding UTL values were limited to samples collected from the bottoms of depressions located adjacent to the landfill's eastern and northern boundary slopes. These areas are shown on figure 4-17. Elevated concentrations of zinc were detected in subsurface soils sampled during the drilling of boreholes HRL-5, -6, and -10 at depths of approximately 3.0, 3.7, and 5.8 m (10, 12, and 19 ft), respectively. Zinc was also detected in soils excavated from exploration trenches TP-3A, -4, -5, -8, and -11 at depths varying from 1.2 to 5.8 m (4 to 19 ft).

**4.7.1.12 beta-HCH (beta-hexachlorocyclohexane).** Concentrations of beta-HCH above UTL values were only detected in surface samples collected during the Phase II investigation. Three sample locations adjacent to borehole HRL-4 contained elevated beta-HCH; HRL-1A, -2A, and -4A. Sampling locations are presented in figure 4-18.

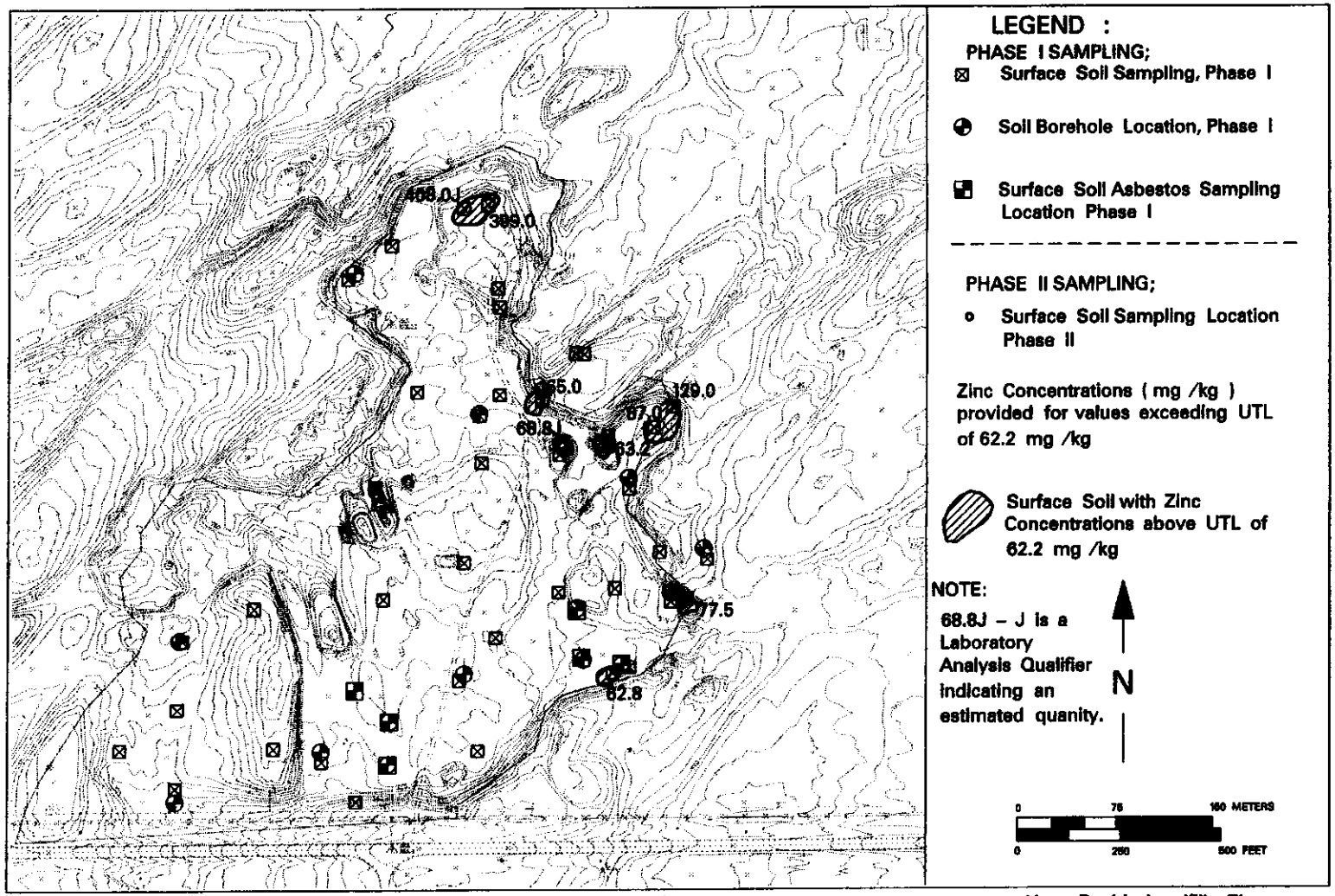
**4.7.1.13 DDT.** The insecticides 4,4'DDD, 4,4'DDE, and 4,4'DDT were found in surface soils at concentrations above UTL values in isolated locations within HRL (see figures 4-19, 4-20, and 4-21 and 4-22, respectively). No subsurface concentrations of insecticides or pesticides were detected within the HRL subunit.

**4.7.1.14 Heptachlor.** A single heptachlor analysis obtained from surface soil samples exceeded UTL values for the HRL subunit. The heptachlor in sample AH203, located along the south central boundary of the landfill (figure 4-23), only slightly exceeded the UTL. No elevated concentrations of heptachlor were detected in soil samples collected from subsurface strata.

**4.7.1.15 PCB's.** PCB contamination at concentrations exceeding UTL levels were detected in two surface samples collected during the Phase I investigation and in eight surface samples collected during the Phase II investigation. All 10 samples were collected in the same, very limited, area of the landfill (*i.e.*, adjacent to borehole HRL-4). Figure 4-24 shows the locations of Phase II samples having elevated PCB values. All PCB's detected in the surface soil were identified as aroclor-1248. One subsurface sample (sample A2205S from a depth interval of 1.6 to 2.4 m (5.4 to 8.0 ft) in borehole HRL-4) contained aroclor-1248 at a concentration exceeding the UTL limit. Aroclor-1254 was detected in one subsurface soil sample, collected from a depth of 2.7 m (9 ft) in exploration trench TP-1, at a concentration above the UTL.

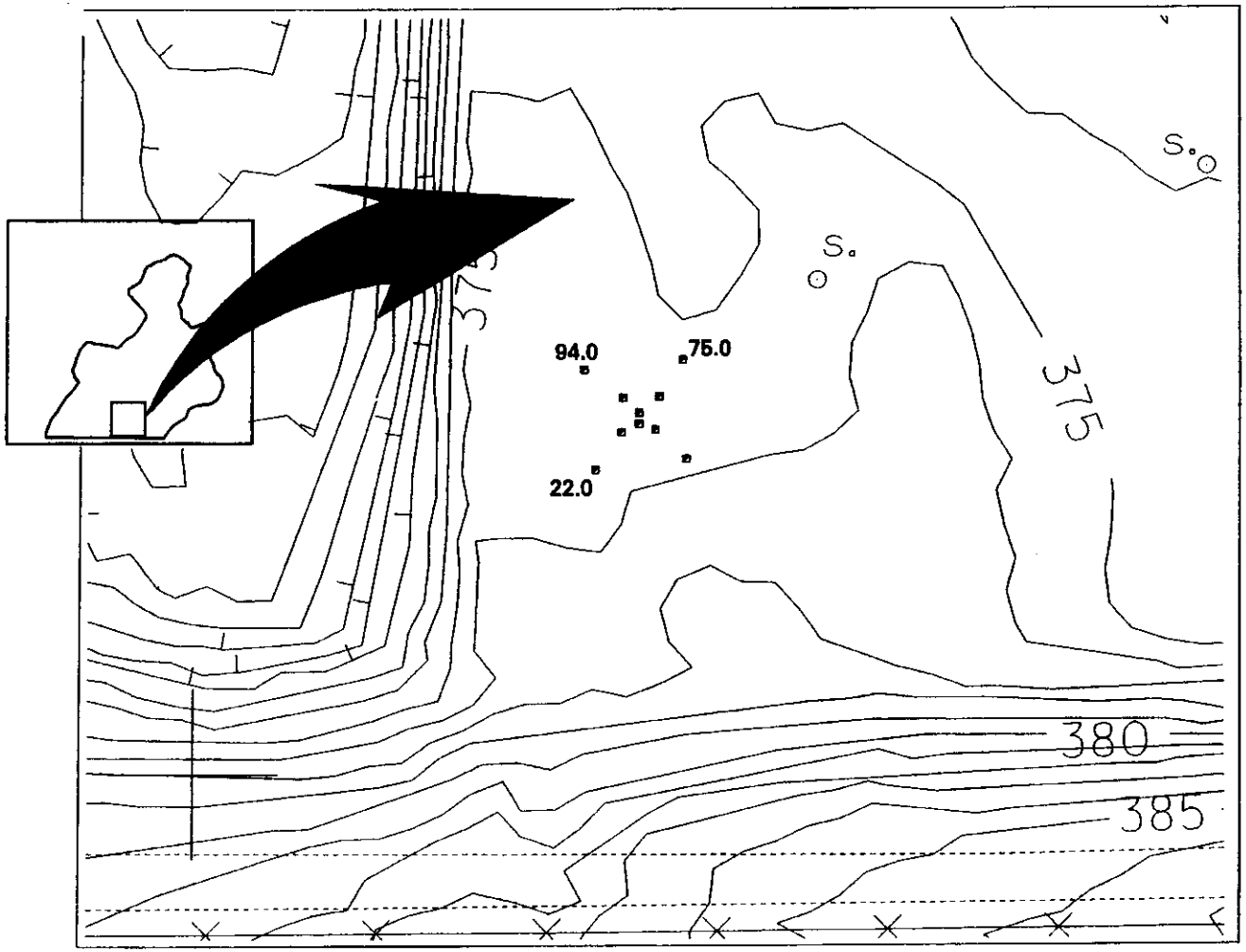
### 4.7.2 Groundwater

The extent of the TCE and nitrate plumes, identified in the Phase I RI, were further defined by new information concerning TCE and nitrate use at the SPC facilities and from additional data generated during the installation of new groundwater monitoring wells in the SPC/HRL area.




Horn Rapids Landfill – Zinc Distribution in Surface Soils

Fig. 4–17




**LEGEND :**

▪ Soil Sampling Location

beta – HCH concentrations ( micro–g /kg ) for values exceeding UTL of 17 micro–g /kg. Maximum value is recorded for the depth interval 0 – 1.5 ft.

Contour Interval 5 feet

N

0 5 10 METERS
0 10 20 30 FEET

Horn Rapids Landfill – beta–HCH Distribution in Surface Soil

Fig. 4–18

**LEGEND :**

PHASE I SAMPLING;

- ⊠ Surface Soil Sampling, Phase I
- Soil Borehole Location, Phase I
- Surface Soil Asbestos Sampling Location Phase I

PHASE II SAMPLING;

- o Surface Soil Sampling Location Phase II

4,4' DDD Concentrations ( micro-g /kg ) provided for values exceeding UTL 33 micro-g /kg

Surface Soil with 4,4' DDD Concentrations above UTL of 33 micro-g /kg

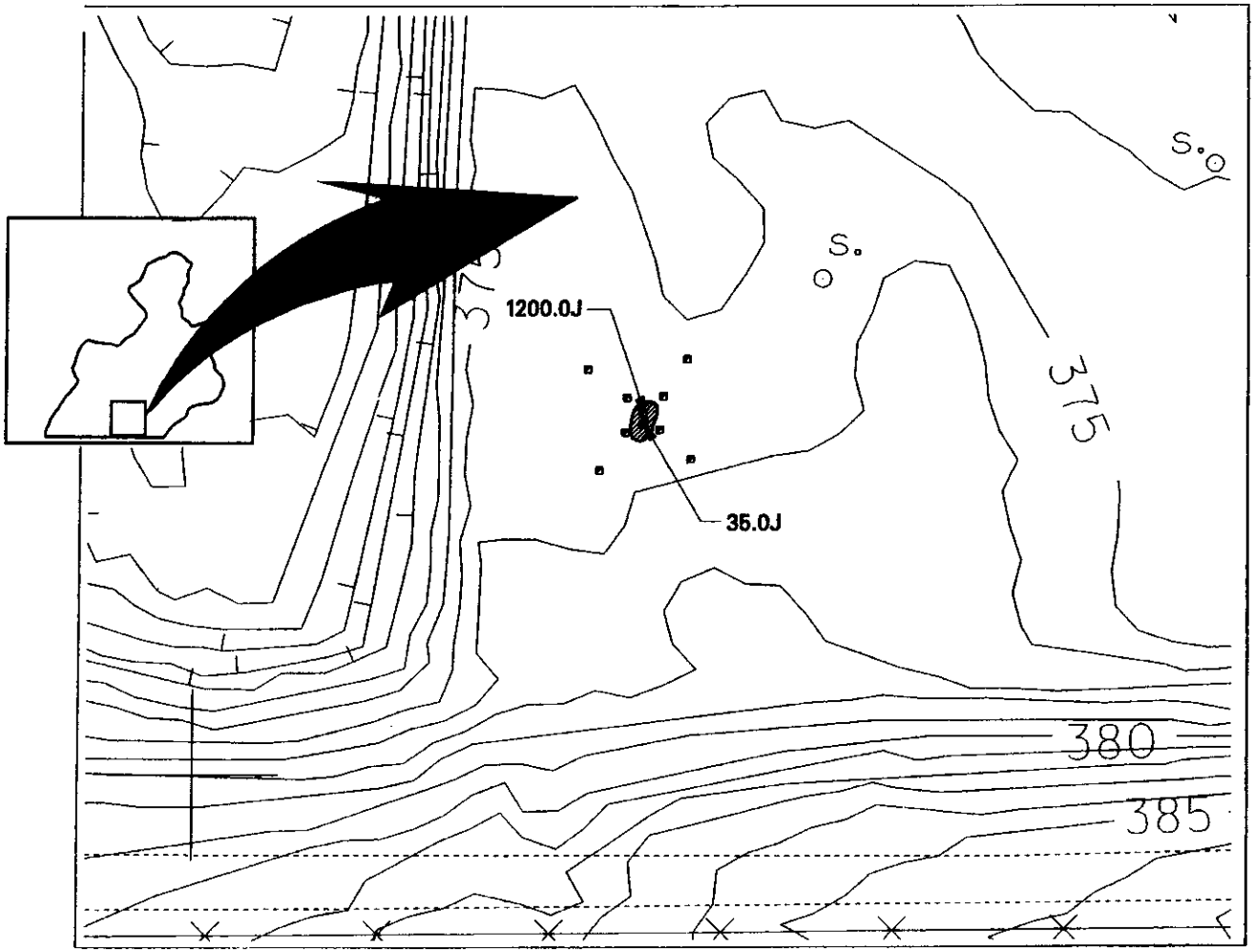
NOTE:
260.0J – J is a Laboratory Analysis Qualifier indicating an estimated quanity.

N

0 75 150 METERS
0 250 500 FEET

Horn Rapids Landfill – 4,4' DDD Distribution in Surface Soils

Fig. 4-19




LEGEND :

▪ Soil Sampling Location

4, 4' DDE Concentration ( micro–g /kg ) for values exceeding UTL of 33 micro–g /kg.

Surface Soil with 4, 4' DDE Concentrations above UTL of 33 micro–g /kg.

NOTE :

35.0J – J is a laboratory analysis qualifier indicating an estimated quantity.

Contour Interval 5 feet

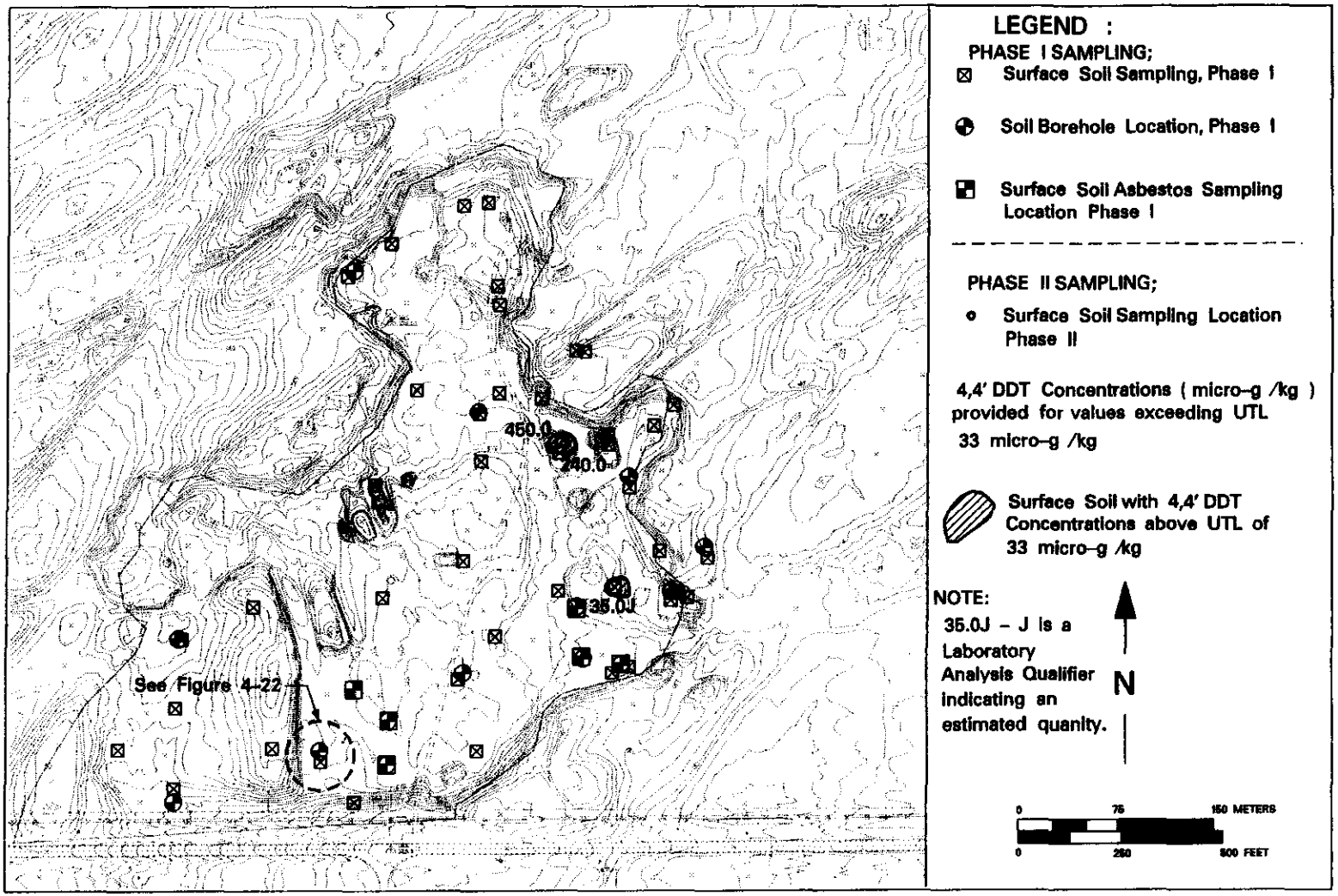
N

0 5 10 METERS

0 10 20 30 FEET

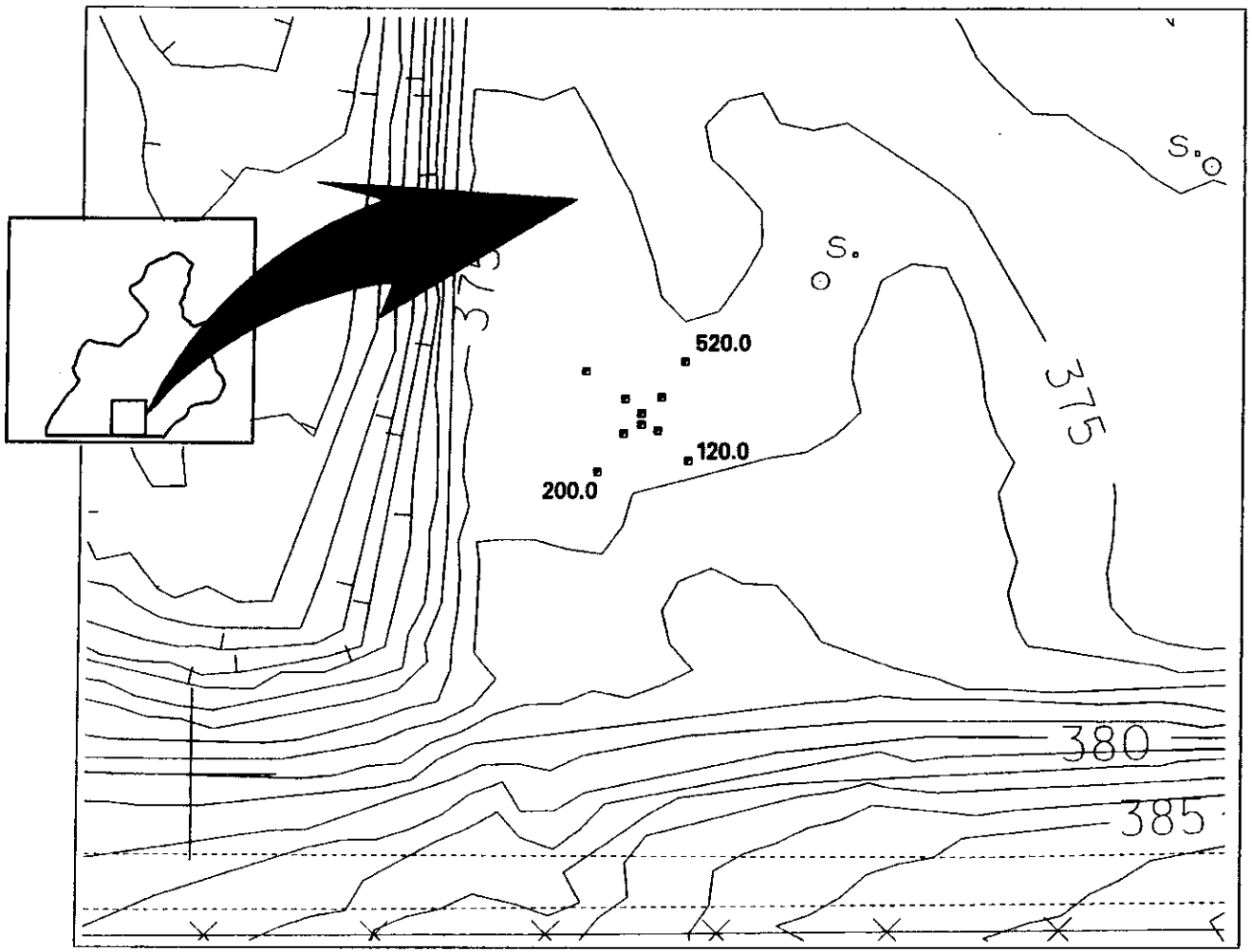
Horn Rapids Landfill – 4, 4' DDE Distribution in Surface Soils

Fig. 4–20




Horn Rapids Landfill – 4,4' DDT Distribution in Surface Soils

Fig. 4-21




LEGEND :

▪ Soil Sampling Location

4, 4' DDT Concentrations ( micro-g /kg ) for values exceeding UTL of 33 micro-g /kg. Maximum concentration shown for depth interval of 0 – 1.5 ft.

Contour Interval 5 feet

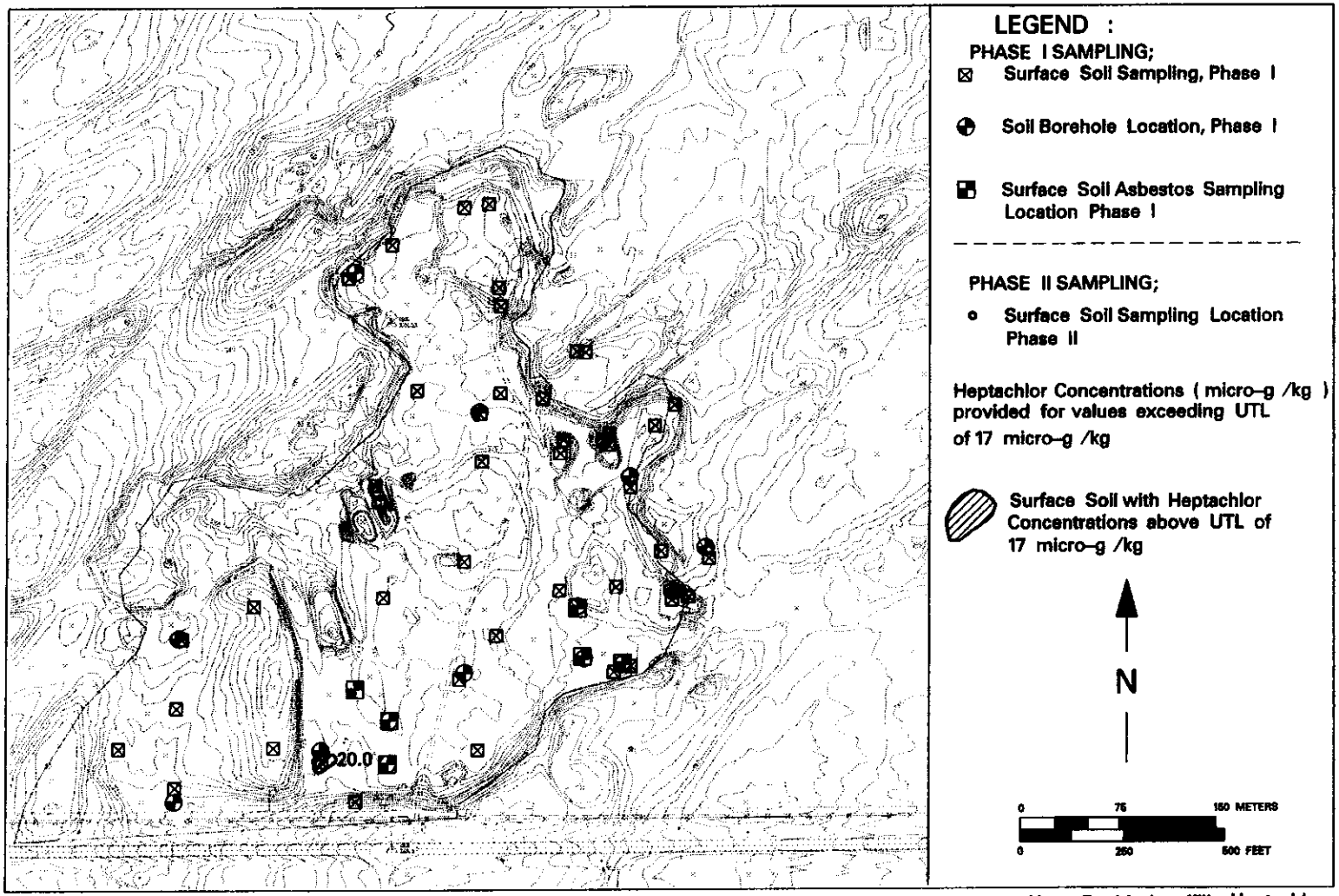
N

0 5 10 METERS

0 10 20 30 FEET

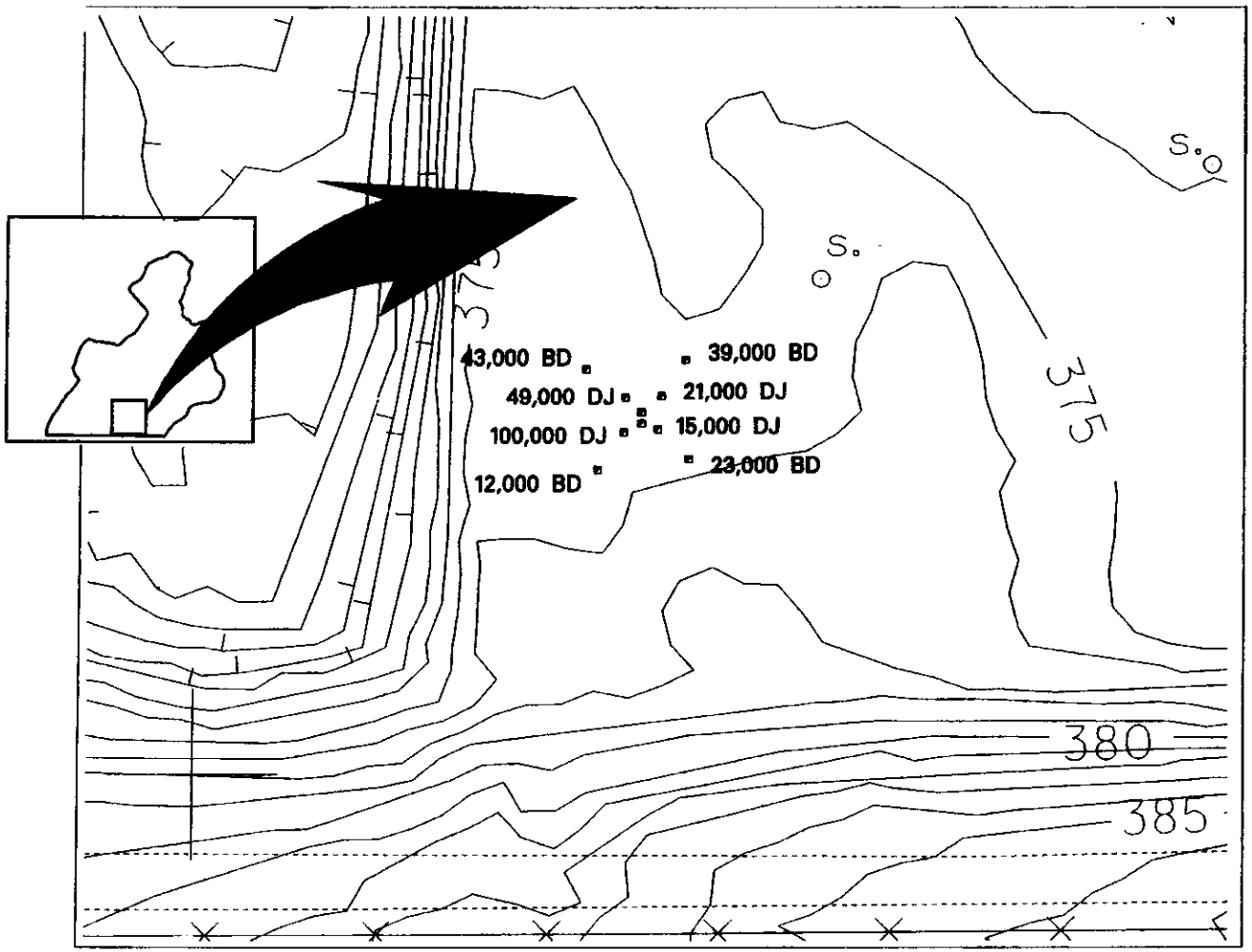
Horn Rapids Landfill – 4, 4' DDT Distribution in Surface Soils

Fig. 4–22




Horn Rapids Landfill – Heptachlor Distribution in Surface Soils

Fig. 4-23




LEGEND :

▪ Soil Sampling Location

PCB Isomer Anchor 1248 only one detected.

Aroclor 1248 Concentrations ( micro–g /kg ) for values exceeding UTL of 170 micro–g /kg.
Maximum concentration shown for the depth interval 0 – 1.5 ft.

NOTE :

B – Laboratory analysis qualifier indicating analyte was found in associated blank as well as in sample.

D – Laboratory analysis qualifier indicating compound identified at a secondary dilution factor.

J – Laboratory analysis qualifier indicating an estimated quantity.

Contour Interval 5 feet

N

0 5 10 METERS
0 10 20 30 FEET

Horn Rapids Landfill – PCB Distribution in Surface Soils

Fig. 4–24

**4.7.2.1 Source Information--TCE Plume.** Information concerning the source of the TCE plume at the HRL/SPC area was provided by: (1) soil sampling, trenching investigations, geophysical surveys, and soil-gas investigations performed at the HRL and vicinity; (2) documents and reports provided by SPC; (3) groundwater sampling at SPC property; once in the fall of 1987, four times in 1990, three times in 1991, and quarterly in 1992; and (4) quarterly groundwater sampling, 1990 to present, of the 1100-EM-1 monitoring wells.

The soil sampling, trenching investigations, geophysical surveys, and soil-gas investigations revealed no evidence of a TCE source in the vadose zone at HRL or the South Pit. The soil-gas measurements revealed the presence of TCE in the vadose zone at HRL and the South Pit, but at concentrations inconsistent with a significant TCE source in the vadose zone at those locations (see paragraph 3.7).

The only documented record of the occurrence or use of TCE near the present-day contaminant plume was at the SPC lagoon area. The work plan for the hazardous substance source evaluation performed at SPC by Geraghty & Miller, Inc., identified the use of TCE at SPC during the installation of Hypalon™ lagoon liners (page 12, SNP, 1992). TCE was used to clean the liner in preparation for bonding overlapping liner sections together (meeting minutes, October 15 1990, meeting at the SPC, formerly Advanced Nuclear Fuels (ANF), facility). SPC also provided a liner installation, cleaning, and repair history that indicated that these activities started, for the Hypalon™ liners, in 1978 and continued through 1988 (as shown in figure 6-24). The most numerous liner installation and repair efforts occurred during three time periods around the years 1979, 1983, and 1987 and 1988.

Construction drawings for the SPC lagoons and the observed groundwater levels indicated that minimum distances from lagoon liners to the water table vary from 2.6 to 4.2 m (8.5 to 13.8 ft). Construction drawings also indicated the material below the liners consists of a sand layer underlain by compacted fill material. TCE spilled or excessed during lagoon liner installation, cleaning, or repair would have a short and unobstructed pathway through the sand and fill material to groundwater.

The shape and extent of the current plume are consistent with a single-source area located at the SPC facility. If another source existed, the shape and concentration levels of the observed plume would likely appear markedly different, except for the unlikely case where the second source was located directly down-gradient of the SPC source. In addition, aquifer groundwater velocities [average of 0.4-0.5 meters per day (m/d), with up to about 1.0 m/d in the upper Hanford formation strata] are such that if TCE had been dumped at the HRL in the 1960s or early 1970's, then TCE would be found in well 699-S29-E12, which is directly down-gradient of the current observed plume (about 760 m from MW-12 and about 1,220 m from the HRL/SPC boundary within the plume). TCE has not been identified in this well since it was first sampled in 1990. Figures 2-7, 2-8, and 6-13 show the locations of groundwater sampling wells at the site.

Analysis of TCE groundwater sample concentrations over time indicated that the plume is attenuating relatively quickly and that the contaminant is currently present at relatively low concentrations. Samples from SPC well TW-9, located just down-gradient of the SPC lagoons, demonstrate this. A sample, taken from this well in December 1987, had a

TCE concentration of 420 ppb while the average of two samples taken from the same well in 1991 was 12 ppb. This relatively rapid attenuation rate indicates that the TCE source is not continuous. Concentrations at another SPC well, TW-1, showed similar attenuation from a December 1987 spike of 230 ppb to a 1991 level of 11 ppb. The relatively rapid attenuation of TCE is consistent with a low volume spike source rather than a continuous source.

Similar attenuation is apparent in down-gradient wells located within the HRL. Well MW-12 had a concentration of 110 ppb in the spring of 1990 but was about one-half of that in the summer of 1992. This reduction is also consistent with that of an attenuating plume that originated from an up-gradient slug or spike source. However, groundwater velocities are not sufficient to carry the 1987 spike to MW-12 by 1990 (paragraph 6.4.5) suggesting earlier, up-gradient releases consistent with the time-frame of TCE use at SPC. Observed values tend to support the hypothesis of a series of releases over a period of time rather than a single release event. Detailed evaluation and modeling (see section 6.0) was undertaken to carefully analyze post-usage and current conditions.

The amount of TCE in the groundwater, as indicated by measured monitoring well TCE concentrations and approximate plume dimensions, was about 75 to 110 L (20 to 30 gal) for the 1990 data, and about 57 to 83 L (15 to 22 gal) for the 1992 data. Although an additional unknown amount is adsorbed onto the host soil, volatilized, biodegraded, or attenuated by other processes, the data indicate the total original amount of TCE source released to the ground was on the order of one to three drums. The total volume of groundwater within the TCE plume is approximately 132,000 cubic meters ($m^3$) (0.5 billion gal).

The potential for future releases of TCE from the SPC facility may be minimized because future lagoon repairs, relining, and construction are planned to be performed without use of TCE. TCE is not currently used in the nuclear fuel fabrication or process support operations at SPC (Bower, 1992).

In summary, the occurrence of elevated TCE levels in groundwater samples collected near the SPC lagoons in 1987, the noncontinuous nature of the source, the estimated volume of TCE present, and the shape and extent of the plume are consistent with releases of TCE associated with lagoon liner installation, cleaning, and repair activities at SPC. Data from soil-gas surveys, geophysical investigations, and trenching activities do not support the existence of a TCE source within the HRL.

**4.7.2.2 Source Information - Nitrate Plume.** Information on potential nitrate sources was provided by groundwater sampling results from the SPC and HRL areas, and from SPC documents. The earliest data from the 1970s indicate maximum total nitrogen ($NH_3$ + $NO_3$) levels of 400 ppm, 1800 ppm, 300 ppm, and 300 ppm in SPC wells TW-1, TW-2, TW-3, and TW-9, respectively (see appendix F). The nitrate-to-total-nitrogen ratio for this data is not known; but even at low ratios, the nitrogen levels would be much higher than the 10 ppm MCL. Nitrogen was specifically included as a measurement parameter in groundwater sample analyses beginning in 1981, with detected levels consistently between 20 and 100 ppm in the SPC area down-gradient of the lagoons and facilities. Nitrate values upgradient of the SPC facilities and lagoons have been below 10 ppm (measured at TW-23,

TW-24, GM-1, and GM-2). The work plan referred to in paragraph 4.8.2.1 identifies at least eight areas of potential nitrate releases from the SPC facility including the lagoons, the Ammonia Recovery Facility (ARF), former tank farms, storage areas, etc. The inconsistent nature of nitrate peaks observed in the SPC well concentration data suggests multiple sources or, at a minimum, multiple releases within the SPC area.

**4.7.2.3 Plume Delineations.** TCE and nitrate contaminants were found only in the unconfined aquifer. The approximate horizontal distributions of TCE and nitrate at the HRL/SPC for the 1987 to 1992 period are shown in figures 4-25 and 4-26. Values from interim sampling events not shown on the figures were consistent with the trend of the indicated values, and can be found in appendixes E and F. The TCE plume extends in the direction consistent with groundwater flow, with its up-gradient end identifying the approximate source area. The earliest TCE data available, from the fall of 1987, consists of three measurements taken near the SPC lagoons. The highest of these, 420 ppb at well TW-9, is about 40 times higher than concentrations at that same well in 1992, and is over 8 times higher than the highest concentration observed in the plume in 1992. This indicates considerable natural attenuation at the site and is consistent with a low-volume, non-continuous source. Figure 4-27 shows the trend of TCE concentration levels over time for five representative wells within the plume. TW-1 and TW-9 are located at the up-gradient end (SPC area), TW-15 is located near Horn Rapids Road, and MW-12 and MW-15 are located at the down-gradient boundary of the HRL (figure 6-13 shows well locations). TW-1 and TW-9 concentrations were relatively high in 1987 but reduced relatively rapidly thereafter. Down-gradient concentrations were lower and also showed significant reduction over time. These data sets indicate a relatively low-volume, noncontinuous source and significant natural attenuation at the site. The data points in figure 4-27 were connected by cubic curvilinear regression lines that were provided to assist the viewer in connecting the data from the five different wells but were not intended to represent exact values between the actual data points. However, curvilinear regression was used instead of simple straight-line interpolation because attenuation processes are nonlinear.

The first groundwater samples to be analyzed for TCE at the HRL were taken in 1990 and revealed maximum concentrations of 110 ppb (at MW-12). Subsequent quarterly sampling showed concentrations to be steadily decreasing through the latest sampling rounds, which occurred in 1992. Concentration levels detected in 1992 at MW-12 are nearly half that of the 1990 levels. If this "attenuation" rate were to continue, using a target level of 5 ppb, the TCE concentrations would be reduced to MCL's by the year 2000. This simple extrapolation does not account for plume movement or other relevant factors (see paragraph 6.4.1). This attenuation may be due to dispersion (*i.e.*, mixing and spreading) that is a result of the high hydraulic conductivities in the upper soil strata at the site. Biodegradation and volatilization may also account for some of the attenuation. More detailed discussion on contaminant fate and transport are found in the contaminant transport and modeling section (paragraph 6.4).

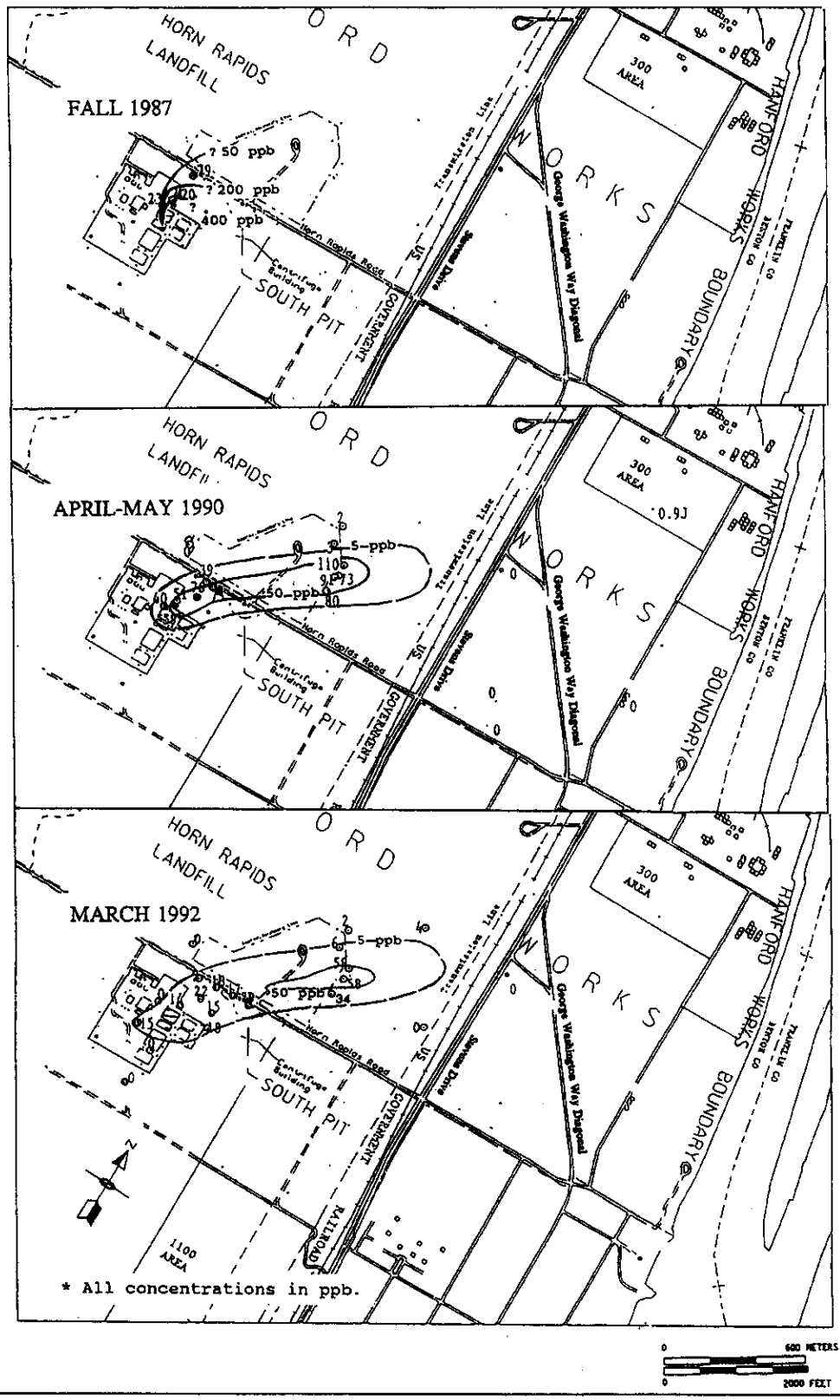
Review of existing data, from 1987 through 1992, did not allow determination, by direct observation, of the rate of movement of the plume front because of the long distances between observation wells down-gradient of HRL.

The approximate horizontal distribution of nitrate is shown in figure 4-26. The direction of plume elongation is consistent with the direction of groundwater flow, with the up-gradient end indicating the approximate source area. A comparison of the 1990 and 1992 data sets indicates that nitrate levels in the SPC area have generally decreased by about one-half, while levels near the MW-12 well cluster have stayed about the same over this short time period. The highest concentration levels of nitrate (measured as nitrogen), observed in the 1970's at TW-2, were near the SPC facility and were approximately 1,800 ppm. The concentrations observed at the MW-12 area are in the 50 ppm range.

The vertical distribution of contaminants within the unconfined aquifer is not definable, because the sampling wells are consistently screened over the same interval. Without discreet screens set at different elevations within the upper aquifer, no data were available for determining a vertical distribution. However, research on the migration of chlorinated hydrocarbons in porous media indicate that, at low concentrations (the HRL concentrations would be considered very low), differences in densities between the contaminant and the host water do not cause the plume to sink and the influence of the kinetic forces (water momentum forces) will be far greater than the gravitational forces (differences in densities) (Schwille, 1988). The exception occurs when a free, dense, non-aqueous phase of the contaminant exists. Such an occurrence would be indicated by groundwater concentrations in the 1000's or 10,000's ppm, which is three orders of magnitude higher than concentrations measured within the HRL/SPC area. Based on published research and observed concentration levels, the TCE plume in the HRL/SPC area is expected to be distributed evenly in the vertical direction throughout the unconfined aquifer. There have been no contaminants detected in groundwater samples obtained from the confined aquifer at concentrations above UTL's.

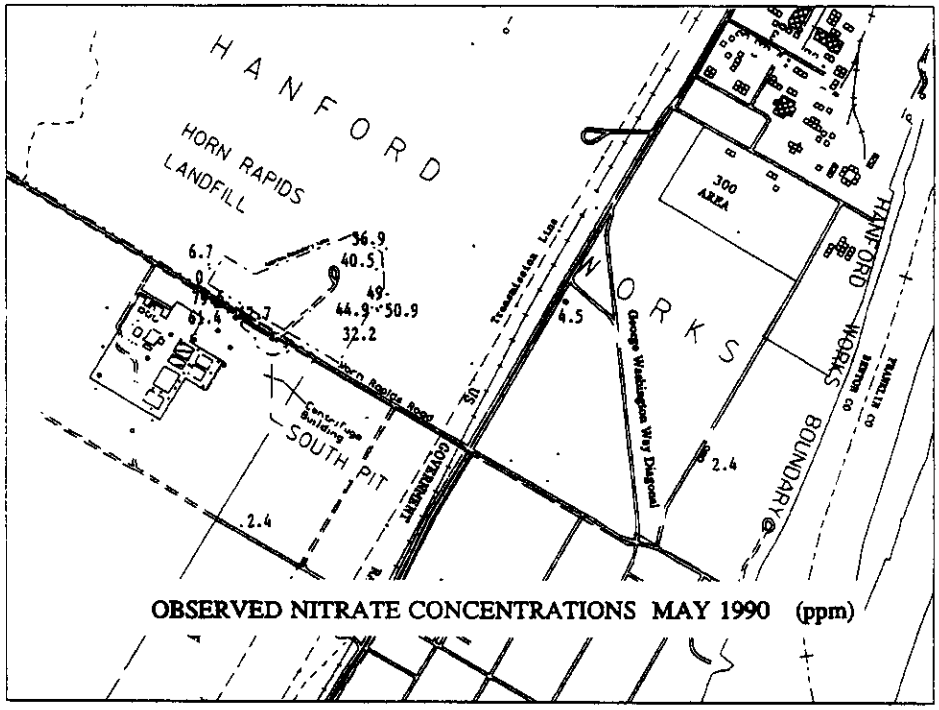
## 4.8 SUMMARY OF NATURE AND EXTENT OF CONTAMINATION

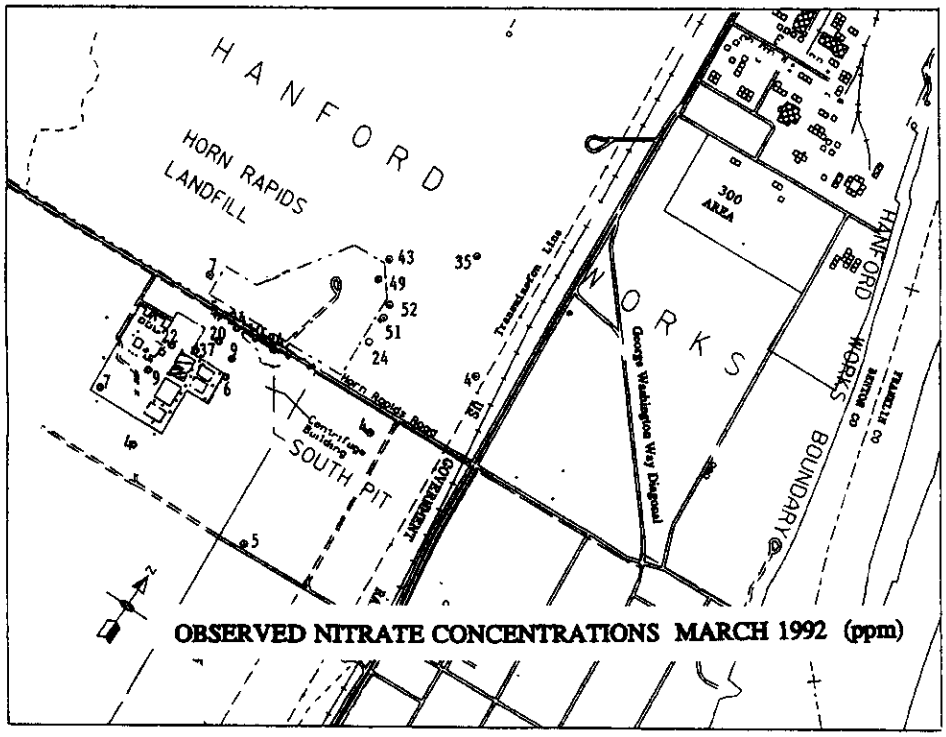
Seven subunits within the 1100-EM-1 Operable Unit have detectable soil contamination at concentrations above preliminary risk-based screening levels. These contaminants are summarized in table 4-9. Contaminants above preliminary risk-based screening levels in groundwater samples obtained from the unconfined aquifer to be considered during the risk assessment for the 1100-EM-1 Operable Unit include TCE and nitrate. In section 5.0, these contaminants, in both the soil and the groundwater, are further evaluated in a more rigorous and extensive risk assessment process to identify a list of contaminants of concern to be addressed in the remediation of the 1100-EM-1 Operable Unit.




Observed TCE Concentration Levels from 1987 to 1992 and Approximate Plume Delineations.

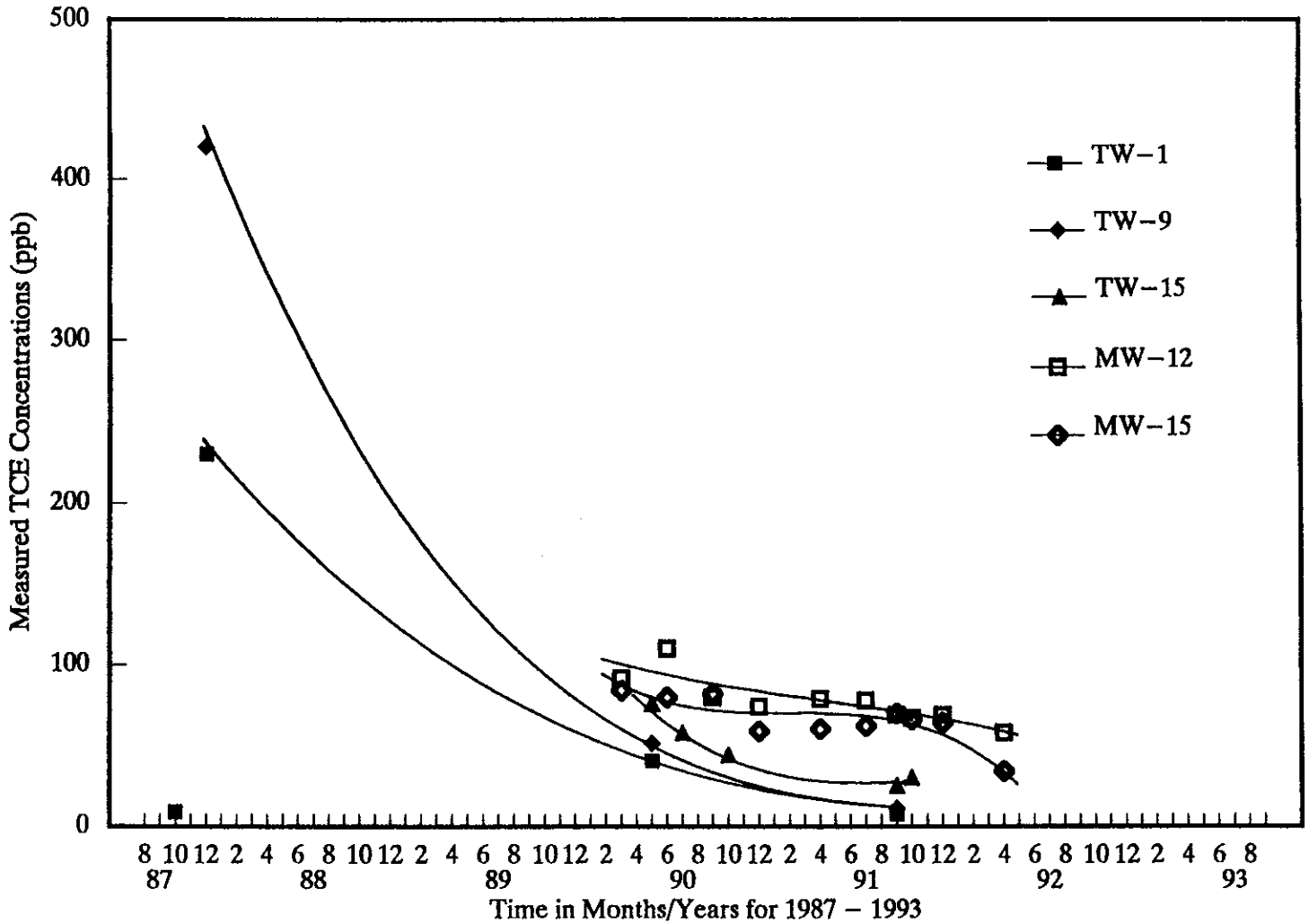
Figure 4-25



Observed Nitrate Concentration Levels in 1990 and 1992.

Figure 4-26




Trends of TCE Concentration Levels at the SPC/HRL Area.
Figure 4-27

**Table 4-9. Summary of Contaminants of Potential Concern for the 1100-EM1 Operable Unit.**

| Contaminant | 1100-1 | 1100-2 | 1100-3 | 1100-4 | UN-1100-8 | Horn Rapids Landfill | Ephemeral Pool | Ground-water |
|---|---|---|---|---|---|---|---|---|
| Antimony | | | | | | X | | |
| Arsenic | X | | | X | | X | | |
| Barium | | | | | | X | | |
| Beryllium | | | | X | | X | | |
| Chromium | | X | X | | | X | | |
| Copper | | | | | | X | | |
| Lead[a] | | | | | | –[a] | | |
| Nickel | | | | | | X | | |
| Thallium | | | | | | X | | |
| Vanadium | X | | | | | X | | |
| Zinc | | | | | | X | | |
| BEHP | | | | | X | | | |
| Beta-HCH | | | | | | X | | |
| Chlordane | | | | | X | | X | |
| DDT | | | | | | X | | |
| Heptachlor | | | | | X | X | X | |
| PCBs | | | | | | X | X | |
| Nitrate | | | | | | | | X |
| TCE | | | | | | | | X |

[a]Contaminant of interest

## 5.0 CONTAMINANTS OF CONCERN

The contaminants of concern were identified through the baseline risk assessment process. Note: The screening of contaminants for the baseline risk assessments did not strictly follow EPA Region 10 guidance but an interpretation of the HSBRAM. The exclusion of organic contaminants was done without going through the full prescreening process. The HSBRAM is currently being revised to prevent such an interpretation in the future. 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-EA 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 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 10 guidance. Contaminants were determined by comparing maximum detected concentrations of parameters to the UTL values 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 health risk based 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 (Discolored Soil Site), the Ephermeral Pool, and HRL, soil contaminants that were estimated to have an Incremental Cancer Risk (ICR) greater than 1E-06, based on the maximum dected contaminant concentrations, were evaluated using a 95-percent UCL concentration.

The exposure pathways for the industrial 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

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

| Contaminant | Pathway | | | | | | Contaminant Totals | | Subunit Totals | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Soil Ingestion | | Fugitive Dust Inhalation | | Dermal Exposure | | | | | |
| | HQ[a] | ICR[b] | HQ[a] | ICR[b] | HQ[a] | ICR[b] | HQ[a] | ICR[b] | HI[c] | ICR[b] |
| **UN-1100-6** | | | | | | | | | | |
| BEHP | 0.3 | 2E-05 | - | 2E-08 | 0.03 | 2E-06 | 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-06 | | | 0.3 | 2E-05 |
| **Ephemeral Pool** | | | | | | | | | | |
| Chlordane | 0.009 | 2E-07 | - | 6E-10 | 0.01 | 2E-07 | 0.02 | 4E-07 | | |
| PCBs | - | 9E-06 | - | 3E-08 | - | 1E-05 | - | 2E-05 | | |
| Pathway Totals | 0.009 | 9E-06 | - | 3E-08 | 0.01 | 1E-05 | | | 0.02 | 2E-05 |
| **Horn Rapids Landfill** | | | | | | | | | | |
| Arsenic | 0.001 | 2E-07 | - | 1E-08 | 0.00003 | 4E-09 | 0.001 | 2E-07 | | |
| Chromium | 0.005 | - | - | 2E-06 | 0.00009 | - | 0.005 | 2E-06 | | |
| 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 |

[a] Hazard Quotient
[b] Lifetime Incremental Cancer Risk
[c] Hazard Index
[d] Based on 30% absorption of inhaled arsenic (EPA 1992b)
- = Not Applicable

**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

exposure to soil, and fugitive dust inhalation). Potential exposures associated with groundwater and surface water were not evaluated in this BISRA. Neither groundwater nor surfacewater is withdrawn from the 1100 Area. Potable water is provided by the city of Richland. The air inhalation pathway assumes exposure to windblown contaminants in dust 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 hexavalent chromium which is a conservative assumption and unlikely to be representative of the true valence states present. Hexavalent chromium under aerobic conditions is reduced to trivalent chromium. Adverse effects have not been associated with the trivalent chromium form.

Evaluation of the potential contaminants of concern using the maximum and 95-percent UCL's 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 (Discolored Soil Site)
- 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 (Discolored Soil Site), Ephemeral Pool, and HRL is presented in table 5-3.

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, remedial actions 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 UTL 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 remedial alternatives.

**Table 5-3.** Comparison of the Baseline Industrial Incremental Cancer Risk Assessment Results using the Maximum Contaminant Concentrations and 95-percent UCL for Discolored Soil Site (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-08 | 3E-08 | | |
| | | | | 2E-05 | 3E-05 |
| Ephemeral Pool | Soil Ingestion | 9E-06 | 3E-05 | | |
| | Fugitive Dust Inhalation | 3E-08 | 9E-08 | | |
| | Dermal Exposure | 1E-05 | 3E-05 | | |
| | | | | 2E-05 | 6E-05 |
| Horn Rapids Landfill | Soil Ingestion | 2E-05 | 6E-05 | | |
| | Fugitive Dust Inhalation | 2E-08 | 3E-05 | | |
| | Dermal Exposure | 3E-05 | 8E-05 | | |
| | | | | 5E-05 | 2E-04 |

## 5.2 SUMMARY OF BASELINE RESIDENTIAL SCENARIO RISK ASSESSMENT

The 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 (Paint and Solvent Pit) | Tetrachloroethene |
| 1100-3 (Antifreeze and Degreaser Pit) | Arsenic<br>Chromium<br>Lead |
| UN-1100-6 (Discolored Soil Site) | Bis (2-ethylhexyl) phthalate (BEHP)<br>Chlordane |
| HRL | Arsenic<br>Chromium<br>PCB's<br>Nitrate<br>Tetrachlorethene<br>Trichloroethene<br>1,1,1-Trichloroethane<br>Lead |
| Ephemeral Pool | Chlordane<br>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.

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 10 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 (Discolored Soil Site)
- 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 (Discolored Soil Site), 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 HSBRAM (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),

**Table 5-4.** Comparison of the Baseline Residential Scenario Risk Assessment Results using the Maximum Contaminant Concentrations and 95-percent UCL for Discolored Soil Site (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[a] | ICR[b] | HI[a] | ICR[b] | HI[a] | ICR[b] | HI[a] | ICR[b] |
| UN-1100-6 | Soil Ingestion | 3.0 | 4E-04 | 4.7 | 6E-04 | | | | |
| | 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 | | | | |
| | | | | | | 18 | 2E-03 | 23 | 3E-03 |
| Ephemeral Pool | Soil Ingestion | 0.1 | 2E-04 | 0.2 | 5E-04 | | | | |
| | 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 | | | | |
| | | | | | | 2.5 | 1E-03 | 3.6 | 3E-03 |
| Horn Rapids Landfill | Soil Ingestion | 0.08 | 5E-04 | 1 | 1E-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 | | | | |
| | | | | | | 1.2 | 3E-03 | 5.6 | 7E-03 |

[a]Hazard Index
[b]Lifetime Incremental Cancer Risk
UCL Upper Confidence Limit
- Indicates not applicable

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 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 for 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-91-18) 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 (Discolored Soil Site). Except for a single clump of grass, there is no vegetation growing in the depression of the UN-1100-6 subunit (Discolored Soil Site). 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. Since the Swainson's hawk and long-billed curlew have been designated as candidate and monitored species, respectively, data for the exposure assessments were readily available.

### 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 calculations for the Swainson's hawk and long-billed curlew were performed according to Risk Assessment Guidance for Superfund (EPA, 1989a). 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-Hexachlorocyclohexane ($\beta$-HCH), 1,1,1--trichloro-2, 2-bis(p-chlorophenyl)ethane (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. 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 only inhabit the 1100 Area, they would be exposed to offsite contamination. It was not in the scope of this assessment to address these offsite exposures. It is probable that the contamination outside the 1100 Area is 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) were 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 diet from HRL and 100 percent of that diet was contaminated.

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. 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. 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.

# 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 atmospheric precipitation. Finally, the groundwater flow and contaminant transport model are described. Basic contaminant fate and transport principles were 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 (IRIS). 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 are 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. A trivalent form of chromium is an essential human micronutrient involved in carbohydrate metabolism. Adverse effects have not been associated with the trivalent form. The hexavalent form of chromium 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.

### 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

As a class, nitrate compounds are a variety of chemicals used in explosives, medications, dyes, food additives, and as numerous other industrial products. Nitrate occurs naturally, and the majority of dietary intake is from vegetables. The dietary contribution from drinking water is usually quite small. 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-H™ is a one-dimensional computer code developed by Pacific Northwest Laboratory to model water flow through unsaturated media employing the finite difference numerical method (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-H™ 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-H™ code was written for execution on a VAX™ 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 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 Smoot *et al.*'s 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 the 200 Area 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 $\alpha$, 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 ($\gamma$) 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 values 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 [$\Theta$]) using the formula:

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

(Jury *et al.*, 1991)

A soil residual moisture content ($\Theta r$) of zero was assigned to all vadose zone soils based on the generally coarse texture of Operable Unit soils (Fayer, 1992). Saturated

moisture content ($\Theta s$) was taken to be equal to the porosity of the soil. Soil porosity was calculated based on the formula:

$$\Theta s = (1 - (\gamma / SpG))$$

(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-H™ 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:

$$h_e = 1 / \alpha$$

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

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

$$h = h_e / (\Theta / \Theta s)^b$$

(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-H™ 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 WGEN™ and CLIGEN™ (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 CLIGEN™ and WGEN™ models. Richland N.E. weather station data was used to generate

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9 3 1 2 7 5 4 0 2 1 7

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

| Operable Subunit | Borehole Number | Sample Number | Sample Depth From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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 a | n | m | Calculated Matric Potential (cm) (h) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Background | BAP-2 | A0202 | 5.5 | 6.5 | 56 | 33 | 9 | | | | | | | | | | | | Silty Sandy GRAVEL |
| | | 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 | 1.26327 | 0.22074 | 19,923.99 | Silty Sandy GRAVEL |
| | | A0206 | 19.5 | 21.0 | 58 | 33 | 9 | 2.82E-04 | 0.00 | 0.0365 | 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 | 0.0429 | 2.20 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 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 | 1.26327 | 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 | 0.36 | 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 | 0.26362 | 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 | 2.66 | 0.15633 | 1.39591 | 0.26362 | 84.76 | 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 | 1.26139 | 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 | 1.26327 | 0.22074 | 3,685.25 | 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 | 1.26327 | 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 | 0.26362 | 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 | 1.26139 | 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 | 1.29068 | 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 | 1.26327 | 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 | 1.26327 | 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 | 0.26362 | 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 | 0.26362 | 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 | 1.26327 | 0.22074 | 960.36 | Silty Sandy GRAVEL |
| | | A1106S | 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 | 676.42 | 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 | 39.91 | Gravelly SAND |
| | | A1112S | 13.5 | 14.5 | 18 | 76 | 6 | 2.99E-04 | 0.00 | 0.0685 | 4.60 | 1.92 | 0.26 | 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 | 1.26327 | 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 | 458.51 | Silty Sandy GRAVEL |
| | | 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 | 0.36 | 2.73 | 0.15633 | 1.39591 | 0.26362 | 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 | 12.6 | 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 |

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

| Operable Subunit | Borehole Number | Sample Number | Sample Depth From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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 a | n | m | Calculated Metric Potential (cm) ($\Omega$) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DP-3 | A07038 | 2.3 | 3.3 | 41 | 40 | 19 | 6.86E-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 |
| | | A07058 | 7.1 | 8.1 | 60 | 35 | 5 | 3.64E-03 | 0.00 | 0.0461 | 2.50 | 1.92 | 0.29 | 2.69 | 0.10074 | 1.40147 | 0.28646 | 870.41 | Silty Sandy GRAVEL |
| | | A07078 | 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 |
| | | A07108 | 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 |
| | | A07118 | 15.2 | 16.0 | 5 | 93 | 2 | 2.99E-04 | 0.00 | 0.0545 | 3.90 | 1.65 | 0.39 | 2.71 | 0.17633 | 1.36246 | 0.26603 | 811.80 | Slightly Gravelly SAND |
| | DP-8 | A12028 | 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 | 3,098.05 | Silty Sandy GRAVEL |
| | | A12078 | 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 | 6,226.73 | Silty Sandy GRAVEL |
| | | A12128 | 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 |
| | | A12148 | 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 |
| | | A12158 | 20.5 | 22.2 | 17 | 73 | 10 | 1.21E-03 | 0.00 | 0.0423 | 2.50 | 1.69 | 0.38 | 2.73 | 0.30456 | 1.34559 | 0.25683 | 1,454.54 | Slightly Silty Gravelly SAND |
| | | A12168 | 23.7 | 26.4 | 19 | 73 | 8 | 1.21E-03 | 0.00 | 0.0502 | 3.00 | 1.67 | 0.37 | 2.66 | 0.30456 | 1.34559 | 0.25683 | 820.26 | Gravelly SAND |
| | | A12188 | 26.4 | 27.4 | 54 | 33 | 13 | 5.77E-04 | 0.00 | 0.0385 | 2.00 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 5,647.53 | Silty Sandy GRAVEL |
| | | A12208 | 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 | A18038 | 3.4 | 4.8 | 51 | 35 | 14 | 5.77E-04 | 0.00 | 0.0596 | 3.10 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 1,206.84 | Silty Sandy GRAVEL |
| | | A18068 | 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 |
| | | A18098 | 12.5 | 13.5 | 54 | 34 | 12 | 5.77E-04 | 0.00 | 0.0327 | 1.70 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 10,051.31 | Silty Sandy GRAVEL |
| | | A18118 | 16.5 | 17.6 | 58 | 29 | 13 | 5.77E-04 | 0.00 | 0.0327 | 1.70 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 10,051.31 | Silty Sandy GRAVEL |
| | | A18138 | 20.0 | 21.7 | 46 | 35 | 17 | 5.77E-04 | 0.00 | 0.0442 | 2.30 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 3,466.57 | Silty Sandy GRAVEL |
| | HRL-3 | A20038 | 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 |
| | | A20068 | 8.0 | 9.3 | 66 | 24 | 8 | 5.77E-04 | 0.00 | 0.0577 | 3.00 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 1,353.19 | Silty Sandy GRAVEL |
| | | A20088 | 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 |
| | | A20118 | 17.6 | 18.8 | 61 | 29 | 10 | 5.77E-04 | 0.00 | 0.0556 | 2.90 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 1,523.06 | Silty Sandy GRAVEL |
| | | A20138 | 22.0 | 23.2 | 68 | 25 | 7 | 5.77E-04 | 0.00 | 0.0687 | 3.57 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 730.40 | Silty Sandy GRAVEL |
| | HRL-4 | A22038 | 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 |
| | | A22068 | 8.2 | 9.7 | 66 | 24 | 10 | 5.77E-04 | 0.00 | 0.0462 | 2.40 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 2,966.78 | Silty Sandy GRAVEL |
| | | A22098 | 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 |
| | | A22118 | 17.4 | 18.9 | 59 | 28 | 13 | 5.77E-04 | 0.00 | 0.0414 | 2.15 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 4,370.21 | Silty Sandy GRAVEL |
| | | A22138 | 21.5 | 23.5 | 71 | 22 | 7 | 5.77E-04 | 0.00 | 0.0604 | 3.14 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 1,151.31 | Silty Sandy GRAVEL |
| | HRL-5 | A15038 | 3.8 | 6.0 | 60 | 35 | 5 | 1.76E-04 | 0.00 | 0.1347 | 7.00 | 1.92 | 0.29 | 2.69 | 0.20954 | 1.34125 | 0.25443 | 49.48 | Silty Sandy GRAVEL |
| | | A15068 | 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 |
| | | A15098 | 11.8 | 13.1 | 59 | 28 | 13 | 5.77E-04 | 0.00 | 0.0414 | 2.15 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 4,370.21 | Silty Sandy GRAVEL |
| | | A15118 | 15.5 | 16.0 | 51 | 30 | 19 | 5.77E-04 | 0.00 | 0.0304 | 1.58 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 13,002.79 | Silty Sandy GRAVEL |
| | | A15148 | 21.9 | 22.8 | 48 | 32 | 20 | 5.77E-04 | 0.00 | 0.0308 | 1.60 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 12,416.36 | Silty Sandy GRAVEL |
| | HRL-6 | A16038 | 7.1 | 9.4 | 66 | 32 | 2 | 1.76E-04 | 0.00 | 0.3174 | 16.50 | 1.92 | 0.29 | 2.70 | 0.20954 | 1.34125 | 0.25443 | (-137.19) | Sandy GRAVEL |
| | | A16068 | 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 |
| | | A16098 | 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 |
| | | A16108 | 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 |
| | | A16118 | 21.5 | 23.0 | 51 | 35 | 14 | 5.77E-04 | 0.00 | 0.0481 | 2.50 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 2,573.23 | Silty Sandy GRAVEL |
| | | A16148 | 24.2 | 25.0 | 32 | 41 | 27 | 5.77E-04 | 0.00 | 0.0292 | 1.52 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 14,989.41 | Silty Sandy GRAVEL |
| | | A16158 | 25.0 | 25.2 | 36 | 38 | 26 | 8.88E-04 | 0.00 | 0.0281 | 1.46 | 1.92 | 0.29 | 2.69 | 0.05474 | 1.26139 | 0.21960 | 73,128.95 | Silty Sandy GRAVEL |
| | | A16168 | 25.8 | 27.8 | 74 | 20 | 6 | 5.77E-04 | 0.00 | 0.0641 | 3.33 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 933.15 | Silty Sandy GRAVEL |
| | HRL-7 | A23028 | 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 | 436.25 | Silty Sandy GRAVEL |
| | | A23058 | 7.3 | 8.4 | 58 | 30 | 12 | 5.77E-04 | 0.00 | 0.0481 | 2.50 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 2,573.23 | Silty Sandy GRAVEL |
| | | A23098 | 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 |
| | | A23118 | 15.3 | 16.5 | 64 | 23 | 13 | 5.77E-04 | 0.00 | 0.0341 | 1.77 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 8,668.39 | Silty Sandy GRAVEL |
| | | A23138 | 19.0 | 20.0 | 56 | 29 | 15 | 5.77E-04 | 0.00 | 0.0371 | 1.93 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 6,436.56 | Silty Sandy GRAVEL |
| | HRL-8 | A14038 | 2.5 | 4.4 | 79 | 16 | 5 | 5.77E-04 | 0.00 | 0.0616 | 3.20 | 1.92 | 0.29 | 2.69 | 0.09123 | 1.26327 | 0.22074 | 1,074.00 | Silty Sandy GRAVEL |
| | | A14058 | 7.5 | 8.2 | 24 | 54 | 22 | 1.38E-05 | 0.00 | 0.0471 | 2.45 | 1.92 | 0.28 | 2.66 | 0.15633 | 1.39591 | 0.28362 | 576.40 | Gravelly Silty SAND |
| | | A14068 | 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 | 0.0467 | 2.40 | 1.92 | 0.29 | 2.69 | 0.15633 | 1.39591 | 0.28362 | 661.43 | [illegible]dy 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 | 1.26327 | 0.22074 | 29,069.82 | [illegible]dy GRAVEL |

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

| Operable Subunit | Borehole Number | Sample Number | Sample Depth From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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 a | n | m | Calculated Matric Potential (cm) (h) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HRL | HRL-9 | 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 | 68.69 | 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 | 29,069.82 | Silty Sandy GRAVEL |
| | | 2 | 21.0 | 22.0 | 63 | 33 | 4 | 2.28E-04 | 0.00 | 0.0791 | 3.80 | 1.92 | 0.29 | 2.69 | 0.25119 | 1.60079 | 0.37531 | 36.83 | 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 | 0.28 | 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 | 1,282.52 | Silty Sandy GRAVEL |
| | MW-3 | A2403 | 2.5 | 4.1 | 14 | 63 | 23 | 6.88E-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 | 696.11 | 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 | 3.6 | 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 | 1,803.06 | 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 | 0.0436 | 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 | 2,601.57 | SAND |
| | | 2 | 3.5 | 4.0 | 9 | 68 | 23 | 6.88E-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 | 7,198.91 | 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 | 1.67 | 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 | Borehole Number | Sample Number | Sample Depth From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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 a | n | m | Calculated Metric Potential (cm) (h) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Monitoring Wells | 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 | 0.0446 | 2.33 | 1.92 | 0.29 | 2.70 | 0.09632 | 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 | 1.36E-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 | 1.36E-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 | 78.06 | GRAVEL |
| | | 4 | 21.5 | 22.0 | 58 | 31 | 11 | 1.36E-05 | 0.00 | 0.0265 | 1.36 | 1.92 | 0.29 | 2.69 | 0.15633 | 1.39591 | 0.28362 | 2,895.39 | 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 | 1.26327 | 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 | 0.15206 | 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 | 7.26 | 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 | 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:
1. Bulk density values estimated from table 3.5, Geotechnical Engineering Analysis and Design, R.E. Hunt.
2. 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.
3. Soil porosity calculated from (1-(bulk density/specific gravity)). Soil porosity is assumed equal to the saturated moisture content.
4. Soil in-situ moisture calculated from (((bulk density * weight % measured)/0.996)/100). Units in cubic cm./cubic cm. 0.996 = grams water per cubic cm.
5. Soil residual moisture value of zero was the recommended value for sands and gravels per Mr. Michael Fayer, PNL.
6. Van Genuchten parameters derived from first converting lab gradations to exclude partical 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.
7. Soil Conductivity at Lab Saturation was obtained in the same method as the van Genuchten parameters (see note 6).
8. Calculated matric potential was obtained using an HP26S calculator and the formula;
   (((((in-situ moisture - residual moisture)/(saturated moisture - residual moisture)) ^ (1/-m)) - 1) ^ (1/n))/a.
9. Shaded rows indicate questionably high in-situ moisture values. Not intended for use.
10. 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 From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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) | SpG | Brooks-Corey Parameters he | b | b' | Calculated Matric Potential (cm) (h) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 1.60 | 1.92 | 0.29 | 2.69 | 10.96131 | 3.53020 | 3.00000 | 18,971.36 | 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 | 3.96105 | 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 | 4.92E-11 | 0.00 | 0.0602 | 3.60 | 1.67 | 0.38 | 2.71 | 5.67118 | 2.75693 | 3.00000 | 936.28 | Slightly Silty Slightly Gravelly SAND |
| DP-7 | A0101 | 0.7 | 2.0 | 54 | 36 | 10 | 1.36E-05 | 5.70E-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 | 0.0306 | 1.60 | 1.92 | 0.29 | 2.69 | 3.96105 | 1.66448 | 3.00000 | 162.91 | Silty Sandy GRAVEL |
| | A0109 | 28.4 | 30.0 | 25 | 62 | 13 | 2.82E-04 | 1.20E-09 | 0.00 | 0.0693 | 3.70 | 1.60 | 0.41 | 2.73 | 3.96105 | 1.66448 | 3.00000 | 101.01 | Slightly Silty Gravelly SAND |
| BAP-1 | A1002S | 2.2 | 4.2 | 26 | 55 | 19 | 1.36E-05 | 3.23E-09 | 0.00 | 0.1427 | 8.90 | 1.60 | 0.40 | 2.68 | 6.39672 | 2.52583 | 3.00000 | 88.06 | 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 | 8.8 | 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 | 2,486.75 | 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 | 2.75693 | 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 | 0.0461 | 2.50 | 1.92 | 0.29 | 2.69 | 4.77236 | 2.93040 | 3.00000 | 868.60 | Silty Sandy GRAVEL |
| | A0412S | 16.0 | 17.0 | 60 | 32 | 8 | 1.36E-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 | 2.66 | 5.67118 | 2.75693 | 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 | 0.0306 | 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 | 1.36E-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 | 12.6 | 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 | 1.36E-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 |
| | A1106S | 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 | 2.75693 | 3.00000 | 691.36 | Gravelly SAND |
| | A1110S | 9.2 | 11.5 | 21 | 72 | 7 | 2.99E-04 | 6.30E-07 | 0.00 | 0.1807 | 10.80 | 1.67 | 0.37 | 2.66 | 5.67118 | 2.75693 | 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 | 2.75693 | 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 | 4,436.91 | Slightly Silty Gravelly SAND |
| | A1117S | 21.6 | 22.1 | 45 | 49 | 6 | 2.82E-04 | 1.12E-08 | 0.00 | 0.0577 | 3.00 | 1.92 | 0.29 | 2.69 | 3.96105 | 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 | 363.70 | 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 | 3.96105 | 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 | 1.36E-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 | A0602S | 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 |
| | A0604S | 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 | 3.96105 | 1.66448 | 3.00000 | 68.19 | Silty Sandy GRAVEL |
| | A0606S | 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 |
| | A0607S | 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 | 2,636.06 | Slightly Gravelly SAND |
| | A0609S | 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 | 3.96105 | 1.66448 | 3.00000 | 64.18 | Silty Sandy GRAVEL |
| | A0611S | 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 |

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

| Borehole Number | Sample Number | Sample Depth From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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) | SpG | Brooks-Corey Parameters he | b | b' | Calculated Matric Potential (cm) (h) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DP-3 | A07036 | 2.3 | 3.3 | 41 | 40 | 19 | 8.88E-04 | 4.00E-13 | 0.00 | 0.0269 | 1.50 | 1.92 | 0.29 | 2.69 | 11.58480 | 3.18969 | 3.00000 | 17,460.08 | Silty Sandy GRAVEL |
| | A07058 | 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 | 2.49065 | 3.00000 | 843.87 | Silty Sandy GRAVEL |
| | A07078 | 10.1 | 10.8 | 14 | 81 | 5 | 2.99E-04 | 3.03E-10 | 0.00 | 0.0796 | 4.40 | 1.67 | 0.37 | 2.66 | 5.67118 | 2.75893 | 3.00000 | 495.64 | Gravelly SAND |
| | A07108 | 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 | 765.47 | SAND |
| | A07118 | 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 | Slightly Gravelly SAND |
| DP-8 | A12028 | 2.5 | 3.7 | 41 | 47 | 12 | 3.64E-03 | 4.05E-11 | 0.00 | 0.0269 | 1.50 | 1.92 | 0.29 | 2.69 | 9.92654 | 2.49065 | 3.00000 | 3,012.09 | Silty Sandy GRAVEL |
| | A12078 | 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 | 11.56480 | 3.18969 | 3.00000 | 5,976.00 | Silty Sandy GRAVEL |
| | A12128 | 15.1 | 16.1 | 54 | 40 | 6 | 2.82E-04 | 8.60E-10 | 0.00 | 0.0365 | 2.00 | 1.92 | 0.29 | 2.69 | 3.98105 | 1.66448 | 3.00000 | 112.37 | Silty Sandy GRAVEL |
| | A12148 | 16.3 | 16.7 | 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 | 103.81 | Silty Sandy GRAVEL |
| | A12158 | 20.5 | 22.2 | 17 | 73 | 10 | 1.21E-03 | 4.99E-12 | 0.00 | 0.0423 | 2.50 | 1.69 | 0.36 | 2.73 | 2.53447 | 2.89360 | 3.00000 | 1,461.80 | Slightly Silty Gravelly SAND |
| | A12168 | 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 |
| | A12188 | 26.4 | 27.4 | 54 | 33 | 13 | 5.77E-04 | 9.84E-13 | 0.00 | 0.0365 | 2.00 | 1.92 | 0.29 | 2.69 | 10.96131 | 3.53020 | 3.00000 | 13,076.73 | Silty Sandy GRAVEL |
| | A12208 | 30.2 | 31.4 | 54 | 39 | 7 | 2.82E-04 | 2.06E-09 | 0.00 | 0.0442 | 2.30 | 1.92 | 0.29 | 2.69 | 3.98105 | 1.66448 | 3.00000 | 89.05 | Silty Sandy GRAVEL |
| HRL-2 | A18038 | 3.4 | 4.8 | 51 | 35 | 14 | 5.77E-04 | 6.09E-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 |
| | A18068 | 8.0 | 8.9 | 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 |
| | A18098 | 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 |
| | A18118 | 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 |
| | A18138 | 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 |
| HRL-3 | A20038 | 2.8 | 4.4 | 54 | 34 | 12 | 2.82E-04 | 7.73E-09 | 0.00 | 0.0544 | 2.83 | 1.92 | 0.29 | 2.69 | 3.98105 | 1.66448 | 3.00000 | 63.06 | Silty Sandy GRAVEL |
| | A20068 | 8.0 | 9.3 | 68 | 24 | 8 | 5.77E-04 | 5.82E-11 | 0.00 | 0.0577 | 3.00 | 1.92 | 0.29 | 2.69 | 10.96131 | 3.53020 | 3.00000 | 3,125.56 | Silty Sandy GRAVEL |
| | A20088 | 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 |
| | A20118 | 17.6 | 18.8 | 61 | 29 | 10 | 5.77E-04 | 4.14E-11 | 0.00 | 0.0556 | 2.90 | 1.92 | 0.29 | 2.69 | 10.96131 | 3.53020 | 3.00000 | 3,522.93 | Silty Sandy GRAVEL |
| | A20138 | 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 | 1,091.35 | Silty Sandy GRAVEL |
| HRL-4 | A22038 | 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 | 2.49065 | 3.00000 | 392.33 | Silty Sandy GRAVEL |
| | A22068 | 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 |
| | A22098 | 13.6 | 14.4 | 37 | 48 | 15 | 2.82E-04 | 1.66E-08 | 0.00 | 0.0616 | 3.20 | 1.92 | 0.29 | 2.69 | 3.98105 | 1.66448 | 3.00000 | 51.39 | Silty Sandy GRAVEL |
| | A22118 | 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 |
| | A22138 | 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 |
| HRL-5 | A15038 | 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 |
| | A15058 | 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 | 2.49065 | 3.00000 | 317.82 | Silty Sandy GRAVEL |
| | A15098 | 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 |
| | A15118 | 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 | 30,056.18 | Silty Sandy GRAVEL |
| | A15148 | 21.9 | 22.8 | 48 | 32 | 20 | 5.77E-04 | 1.04E-13 | 0.00 | 0.0306 | 1.60 | 1.92 | 0.29 | 2.69 | 10.96131 | 3.53020 | 3.00000 | 26,752.63 | Silty Sandy GRAVEL |
| HRL-6 | A16038 | 7.1 | 9.4 | 66 | 30 | 2 | 1.78E-04 | 4.16E-04 | 0.00 | 0.3174 | 16.60 | 1.92 | 0.29 | 2.70 | [illegible] | [illegible] | [illegible] | 3.02 | Silty GRAVEL |
| | A16068 | 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 |
| | A16098 | 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 |
| | A16108 | 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 |
| | A16118 | 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 |
| | A16148 | 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 |
| | A16158 | 25.0 | 25.2 | 36 | 38 | 26 | 5.88E-04 | 5.73E-14 | 0.00 | 0.0281 | 1.46 | 1.92 | 0.29 | 2.69 | 18.29784 | 3.55379 | 3.00000 | 69,980.69 | Silty Sandy GRAVEL |
| | A16168 | 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 | 2,162.36 | Silty Sandy GRAVEL |
| HRL-7 | A23028 | 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 | 2.49065 | 3.00000 | 425.82 | Silty Sandy GRAVEL |
| | A23058 | 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 |
| | A23098 | 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 | 2.49065 | 3.00000 | 843.87 | Silty Sandy GRAVEL |
| | A23118 | 15.3 | 16.5 | 64 | 23 | 13 | 5.77E-04 | 2.66E-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 |
| | A23138 | 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-8 | A14038 | 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 |
| | A14058 | 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 |
| | A[illegible] | 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 | 1.82676 | 3.56379 | 3.00000 | 8,117.74 | Silty Sandy GRAVEL |
| | [illegible] | 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 | [illegible] GRAVEL |
| | A[illegible] | 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 | 66,824.21 | [illegible] GRAVEL |

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

| Borehole Number | Sample Number | Sample Depth From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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) | SpG | Brooks-Corey Parameters he | b | b' | Calculated Matric Potential (cm) (h) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 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 | 3.96105 | 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 | 9.20E-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 | 3.96105 | 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 | 3.96105 | 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 | 3.96105 | 1.66448 | 3.00000 | 95.69 | 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 | 3.96105 | 1.66448 | 3.00000 | 57.22 | Silty Sandy GRAVEL |
| | A1913S | 27.9 | 30.3 | 81 | 17 | 2 | 3.64E-03 | 4.39E-06 | 0.00 | 0.0693 | 3.60 | 1.92 | 0.29 | 2.69 | 9.92654 | 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 | 3.80 | 1.92 | 0.29 | 2.69 | 3.96105 | 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 | 3.96105 | 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 | 0.26 | 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 | 4.29E-09 | 0.00 | 0.0477 | 2.48 | 1.92 | 0.28 | 2.65 | 3.96105 | 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 | 3.96105 | 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 | 3.96105 | 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 | 3.96105 | 1.66448 | 3.00000 | 104.37 | Sandy GRAVEL |
| | 5 | 34.5 | 35.0 | 75 | 22 | 3 | 2.82E-04 | 1.22E-10 | 0.00 | 0.0263 | 1.47 | 1.92 | 0.29 | 2.69 | 3.96105 | 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 | 0.0677 | 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 | 5.26E-13 | 0.00 | 0.0400 | 2.08 | 1.92 | 0.32 | 2.61 | 10.96131 | 3.53020 | 3.00000 | 16,276.64 | Silty Sandy GRAVEL |
| | 2 | 43.0 | 44.4 | 80 | 19 | 1 | 5.73E-04 | 3.36E-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 | 2.88E-04 | 4.90E-10 | 0.00 | 0.0352 | 1.83 | 1.92 | 0.29 | 2.69 | 3.96105 | 1.66448 | 3.00000 | 130.26 | 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 | 2,946.40 | 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 | 93,898.02 | 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 | 0.0666 | 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 | 6.66 | 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 | 3.96105 | 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 | 26.5 | 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 | 33.5 | 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 |

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

| Borehole Number | Sample Number | Sample Depth From | Sample Depth To | Soil Gradations LAB % G | % S | % M | 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) | SpG | Brooks-Corey Parameters he | b | b' | Calculated Matric Potential (cm) (h) | Wentworth Soil Classification |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MW-13 | 1 | 9.5 | 10.0 | 62 | 35 | 3 | 1.78E-04 | 5.75E-11 | 0.00 | 0.0595 | 2.78 | 1.92 | 0.29 | 2.70 | 4.77236 | 2.93040 | 3.00000 | 666.80 | Sandy GRAVEL |
| | 2 | 13.0 | 13.5 | 47 | 51 | 2 | 5.73E-04 | 1.47E-11 | 0.00 | 0.0446 | 2.33 | 1.92 | 0.29 | 2.70 | 11.56460 | 3.18069 | 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 | 3.96105 | 1.66448 | 3.00000 | 87.77 | Silty Sandy GRAVEL |
| | 4 | 17.5 | 18.0 | 86 | 12 | 2 | 2.82E-04 | 1.17E-06 | 0.00 | 0.0574 | 2.94 | 1.95 | 0.28 | 2.72 | 3.96105 | 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 | 7.6 | 8.8 | 53 | 39 | 8 | 1.38E-05 | 9.09E-10 | 0.00 | 0.0866 | 4.50 | 1.92 | 0.29 | 2.69 | 6.39672 | 2.52583 | 3.00000 | 131.16 | 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 | 3.96105 | 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 | 3.96105 | 1.66448 | 3.00000 | 79.92 | GRAVEL |
| | 4 | 21.5 | 22.0 | 58 | 31 | 11 | 1.38E-05 | 6.66E-14 | 0.00 | 0.0265 | 1.38 | 1.92 | 0.29 | 2.69 | 6.39672 | 2.52583 | 3.00000 | 2,566.27 | Silty Sandy GRAVEL |
| MW-15 | 1 | 5.0 | 7.0 | 54 | 36 | 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 | 3.96105 | 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 | 1,496.01 | 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 | 2,661.52 | 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 | 3.96105 | 1.66448 | 3.00000 | 141.66 | 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 | 3.96105 | 1.66448 | 3.00000 | 108.11 | Gravelly SAND |
| | 7 | 37.0 | 38.0 | 52 | 41 | 7 | 2.82E-04 | 5.60E-06 | 0.00 | 0.1401 | 7.26 | 1.92 | 0.26 | 2.59 | 3.96105 | 1.66448 | 3.00000 | 11.05 | Silty Sandy GRAVEL |
| Sum | | | | ********** | | | 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 | |
| n | | | | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | 168 | |
| Average | | | | 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:

1. Bulk density values estimated from table 3.5, Geotechnical Engineering Analysis and Design, R.E. Hunt.
2. 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.
3. Soil porosity calculated from (1-(bulk density/specific gravity)). Soil porosity is assumed equal to the saturated moisture content.
4. Soil in-situ moisture calculated from (((bulk density * weight % measured)/0.998)/100). Units in cubic cm./cubic cm. 0.998 = grams water per cubic cm.
5. Soil residual moisture value of zero was the recommended value for sands and gravels per Mr. Michael Fayer, PNL.
6. Brooks-Corey parameters were derived from converting Van Genuchten functions using the formulas:
   he = 1/a
   b = 1/(n-1)
   b' = (1+l) where l is taken as 2.0 for the Burdine conductivity model.
7. Soil Conductivity at Lab Saturation was obtained in the same method as the van Genuchten parameters (see note 6).
8. Calculated matric potential was obtained using an HP28S calculator and the formula;
   h = he/(THETA/THETA s) ^ b
9. Shaded rows indicate questionably high in-situ moisture values. Not intended for use.
10. Wentworth Soil Classification entries based on laboratory particle size gradations, NOT on field log gradations.

weather data with CLIGEN™. 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. CLIGEN™ computed precipitation values were extracted from the output file and input into the WGEN™ portion of the Hydrologic Evaluation of Landfill Performance (HELP) Model (Schroeder, *et al.*, 1992) to generate solar radiation values (Langleys). WGEN™ generated solar radiation units were substituted for CLIGEN™ data because WGEN™ simulates radiation based on rainfall occurrence, a more reasonable estimation than the CLIGEN™ 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-H™ 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-H™ 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-H™. However, an UNSAT-H™ 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-H™ 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-H™ 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-H™ 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

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

| Node Number | Node Depth (cm) "Z(n)" | Node Depth (ft) | Initial Elevation Head (cm) "H(n)" | Soil Type "MAT(n)" | Plant Root Growth "NTROOT(n)" |
|---|---|---|---|---|---|
| 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 |

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

| Node Number | Node Depth (cm) "Z(n)" | Node Depth (ft) | Initial Elevation Head (cm) "H(n)" | Soil Type "MAT(n)" | Plant Root Growth "NTROOT(n)" |
|---|---|---|---|---|---|
| 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 |

9 3 1 2 7 4 0 2 5 8

Table 6-4 UNSAT-H™ Input Listing, 1 of 2

| Parameter Description | Plants Modeled | Plants Not Modeled |
|---|---|---|
| **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 | $0.24 cm^2/s$ | $0.24 cm^2/s$ |
| Number of Soil Types | 4 | 4 |
| Number of Analysis Nodes | 100 | 100 |
| **Soil Property Description Options:** | | |
| Saturated Soil Water Content | $0.29 cm^3/cm^3$ | $0.29 cm^3/cm^3$ |
| 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 |

Table 6-4 UNSAT-H™ Input Listing, 2 of 2

| Parameter Description | Plants Modeled | Plants Not Modeled |
|---|---|---|
| **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 ---------- | |

9 3 1 2 7 4 0 2 6 0

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

| YEAR | PRECIPITATION (cm) | (in) | YEAR | PRECIPITATION (cm) | (in) | YEAR | PRECIPITATION (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 |

Table 6-6 Initial Suction Heads, Plants Modeled

| NODE | HEAD (cm) | NODE | HEAD (cm) | NODE | HEAD (cm) |
|---|---|---|---|---|---|
| 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 | | |

9 3 1 2 7 4 0 2 6 2

Table 6-7 Initial Suction Heads, Plants Not Modeled

| NODE | HEAD (cm) | NODE | HEAD (cm) | NODE | HEAD (cm) |
|---|---|---|---|---|---|
| 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 | | |

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

| Year | Yearly Precipitation | 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 |

9 3 1 2 7 4 0 2 6 4

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

| Year | Yearly Precipitation | Yearly Precipitation (inches) | Actual Transpiration | Actual Evaporation | Total Base Drainage | Final Moisture Storage | Mass Balance 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 | 8.5998E+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.**



9 3 1 2 7 5 4 0 2 5 5

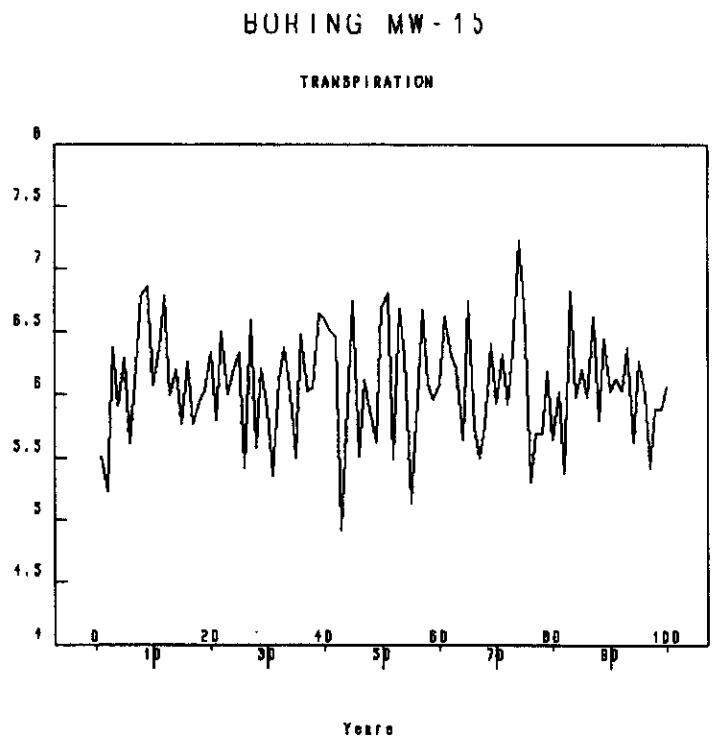


Figure 6-1: Actual Plant Transpiration as Computed by UNSAT-H (cm).

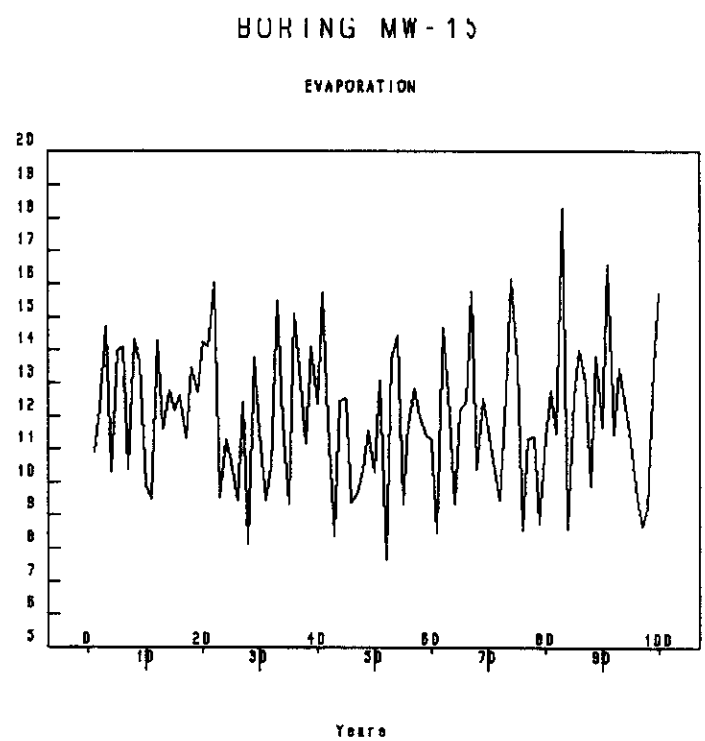


Figure 6-2: Actual Evaporation as Computed by UNSAT-H for a Vegetated Site (cm).

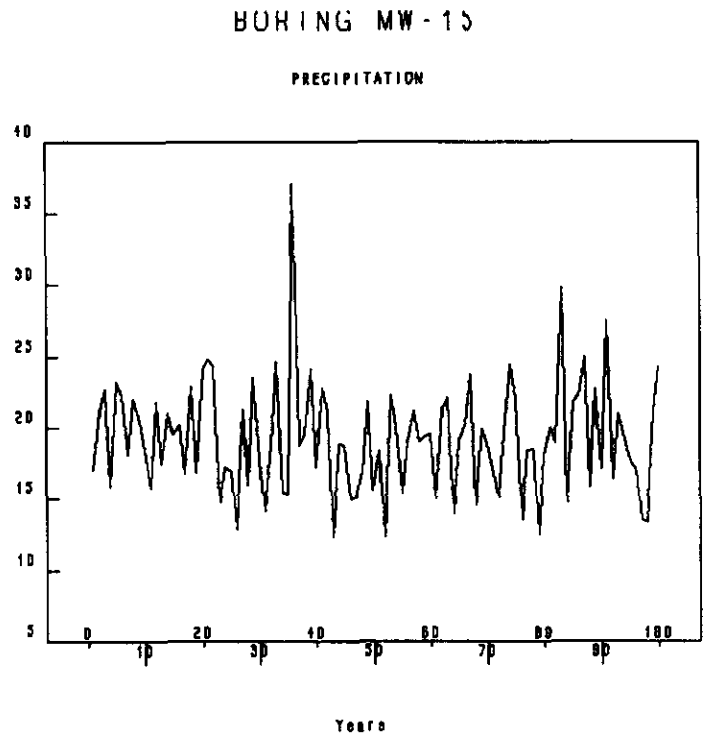


Figure 6-3: Precipitation Values Used in UNSAT-H Simulation (cm).

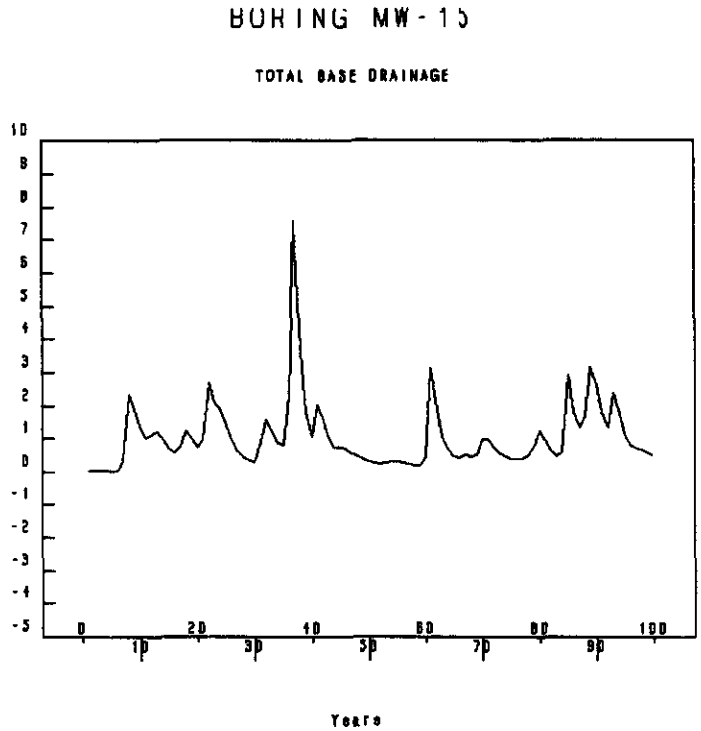


Figure 6-4: Total Soil Column Base Drainage (Recharge) to the Water Table for a Vegetated Site (cm).

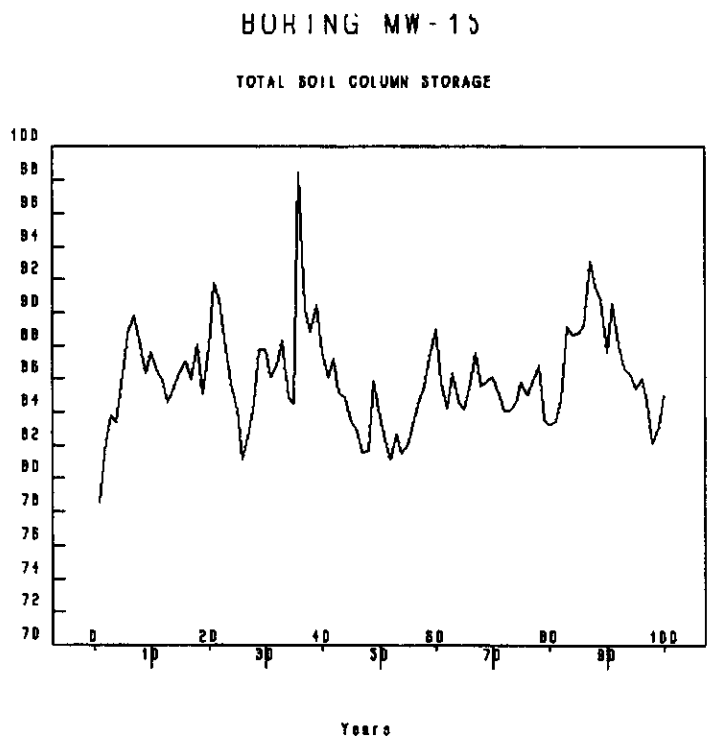


Figure 6-5: Final Yearly Soil Column Moisture Storage as Calculated By UNSAT-H (cm).

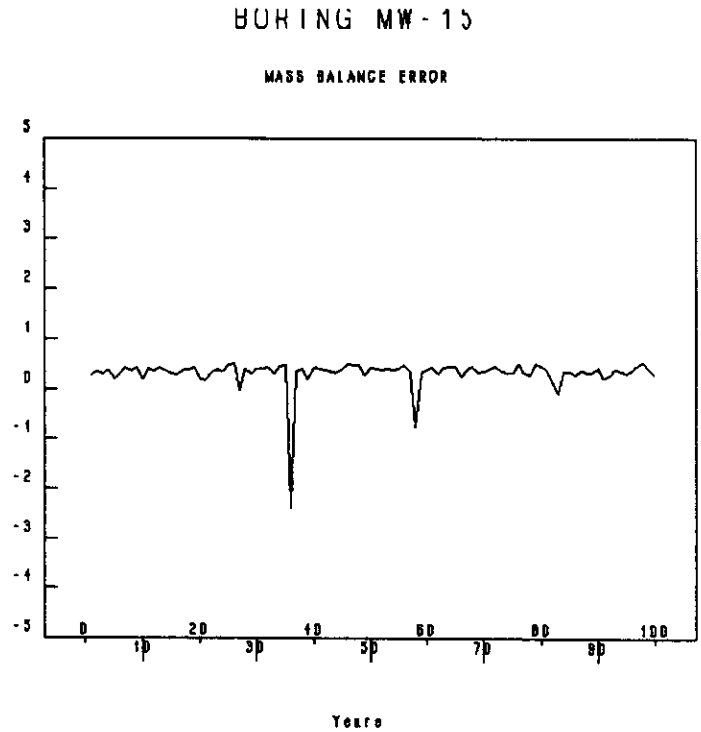


Figure 6-6: UNSAT-H Mass Balance Errors for Each Year of the Simulation (%).

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9 3 1 2 7 5 4 0 2 5 9

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

| Year | Yearly Precipitation | Yearly Precipitation (inches) | 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 |

9 3 1 2 7 4 0 2 7 0

**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 | 8.9618E+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**



9 3 1 2 7 5 4 0 2 7 1

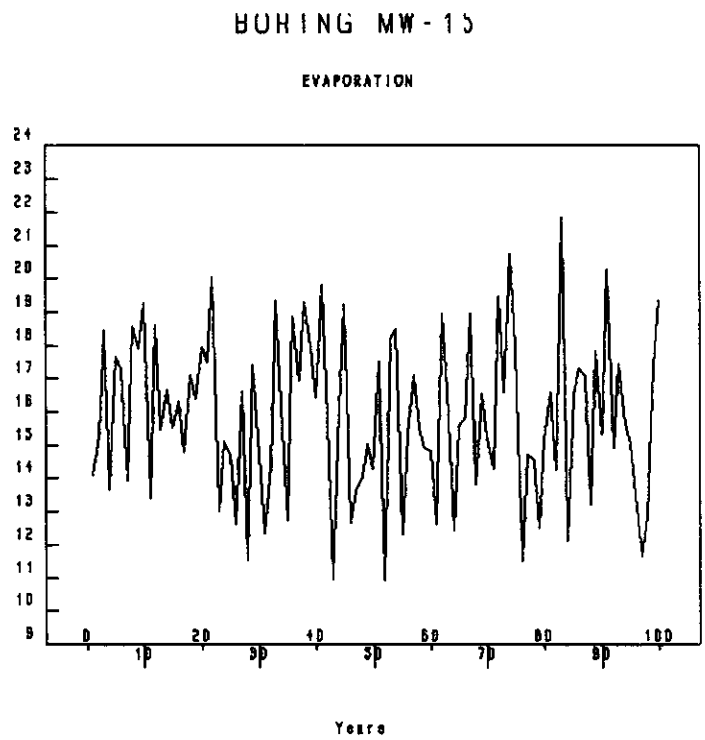



Figure 6-7: Actual Evaporation as Computed by UNSAT-H for an Unvegetated Site (cm).

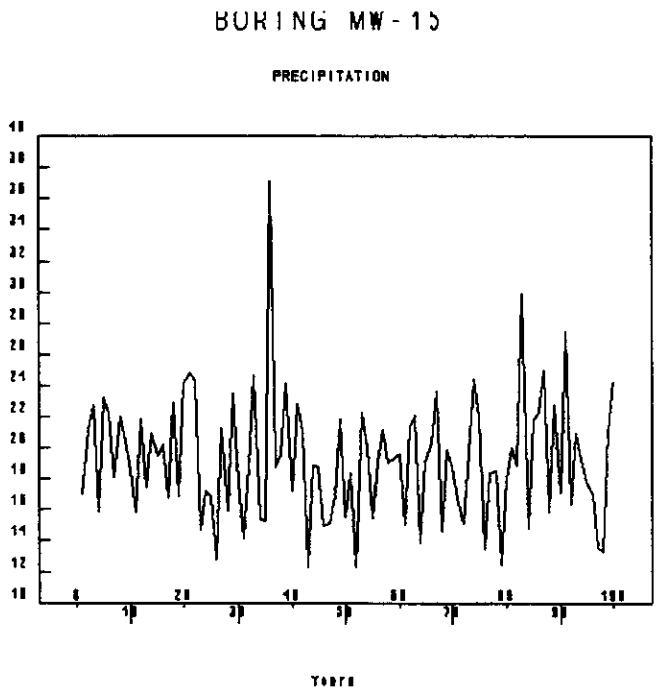



Figure 6-8: Precipitation Values Used in UNSAT-H Simulation (cm).

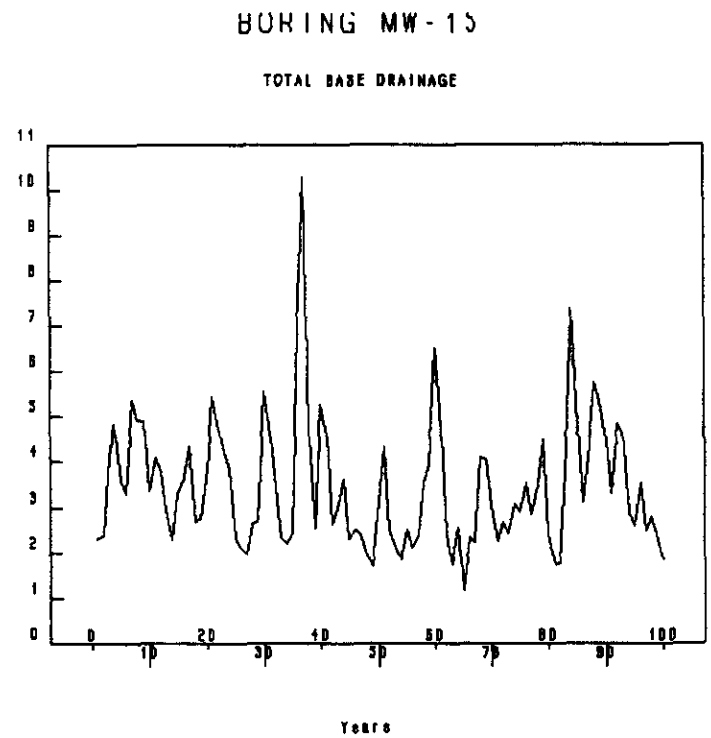



Figure 6-9: Total Soil Column Base Drainage (Recharge) to the Water Table for an Unvegetated Site (cm).

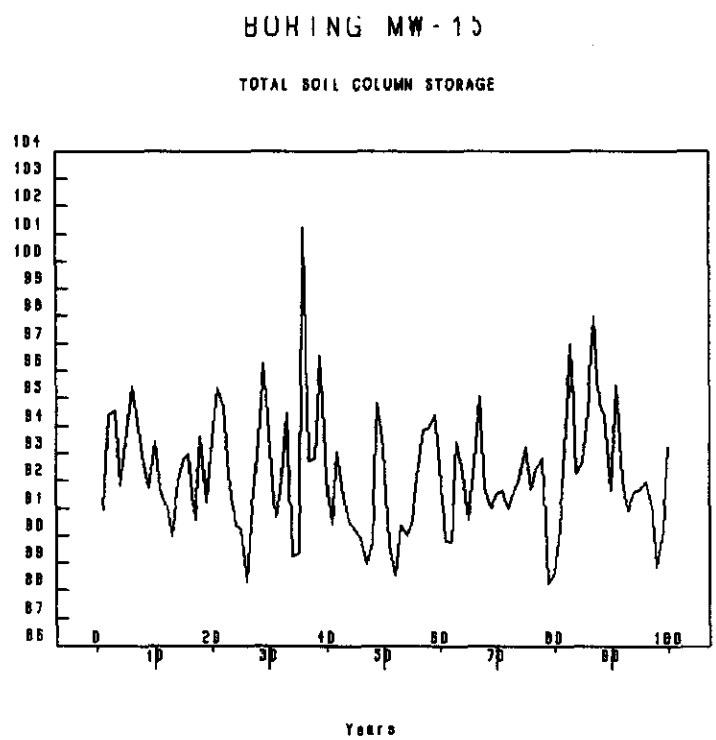



Figure 6-10: Final Soil Column Moisture Storage as Calculated by UNSAT-H for an Unvegetated Site (cm).

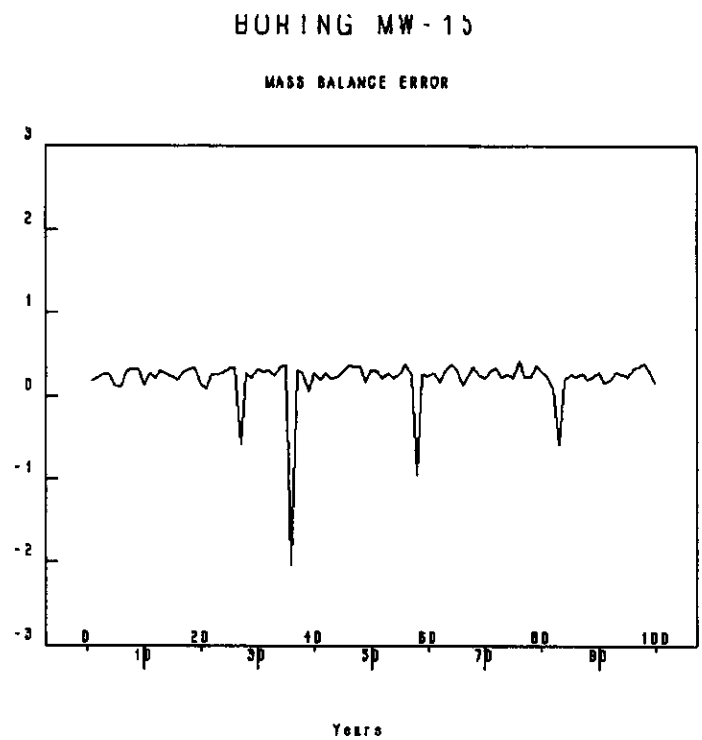



Figure 6-11: UNSAT-H Yearly Simulation Mass Balance Errors (%).

9 3 1 2 7 4 0 2 7 4

## 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 groundwater 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 although effects of these features were included in model boundary conditions. As discussed in section 2.4.3, the North Richland well field operation has not had, and is not likely to have, an effect on contaminant plume movement at the SPC/HRL area. In the unlikely event that seasonal recharge mounding does extend to the plume area in the future, its effect would be to temporarily redirect the groundwater flow gradient further northward from its current northeast direction. The resulting effects from this would likely increase contaminant travel times to down-gradient locations, such as the Columbia River, and increase contaminant dispersion by spreading the plume.

Observed groundwater 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 up-gradient (western) boundary of the study area, data from well MW-8 show water table fluctuations of about 0.3 m (1 ft) caused mainly by seasonal increases in up-gradient 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 model 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 only been detected 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 were 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.

Positive pressure head differences, occurring between the confined and unconfined aquifers, were observed at the western boundary of the HRL, just west of Stevens Drive, and near the Columbia River.These observations indicated upward pressure head differences of 2.0 m (6.6 ft) up-gradient of HRL, 0.3 m (1.0 ft) near Stevens Drive, and less than 0.1 m (0.3 ft) 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 and is thus more mobile and more responsive to dispersion processes than TCE. In addition, as current nitrate levels are only five times greater than the nitrate MCL compared to TCE levels that are ten times greater than the TCE MCL, it was estimated prior to the detailed contaminant transport analysis that nitrate levels would be reduced to clean-up levels much faster than TCE. As described in section 4.8.2.3, the extent of the nitrate plume could not be completely defined. Therefore, only limited simulation of nitrate contaminant transport, supplemental to the TCE transport analysis, has been performed to date.

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

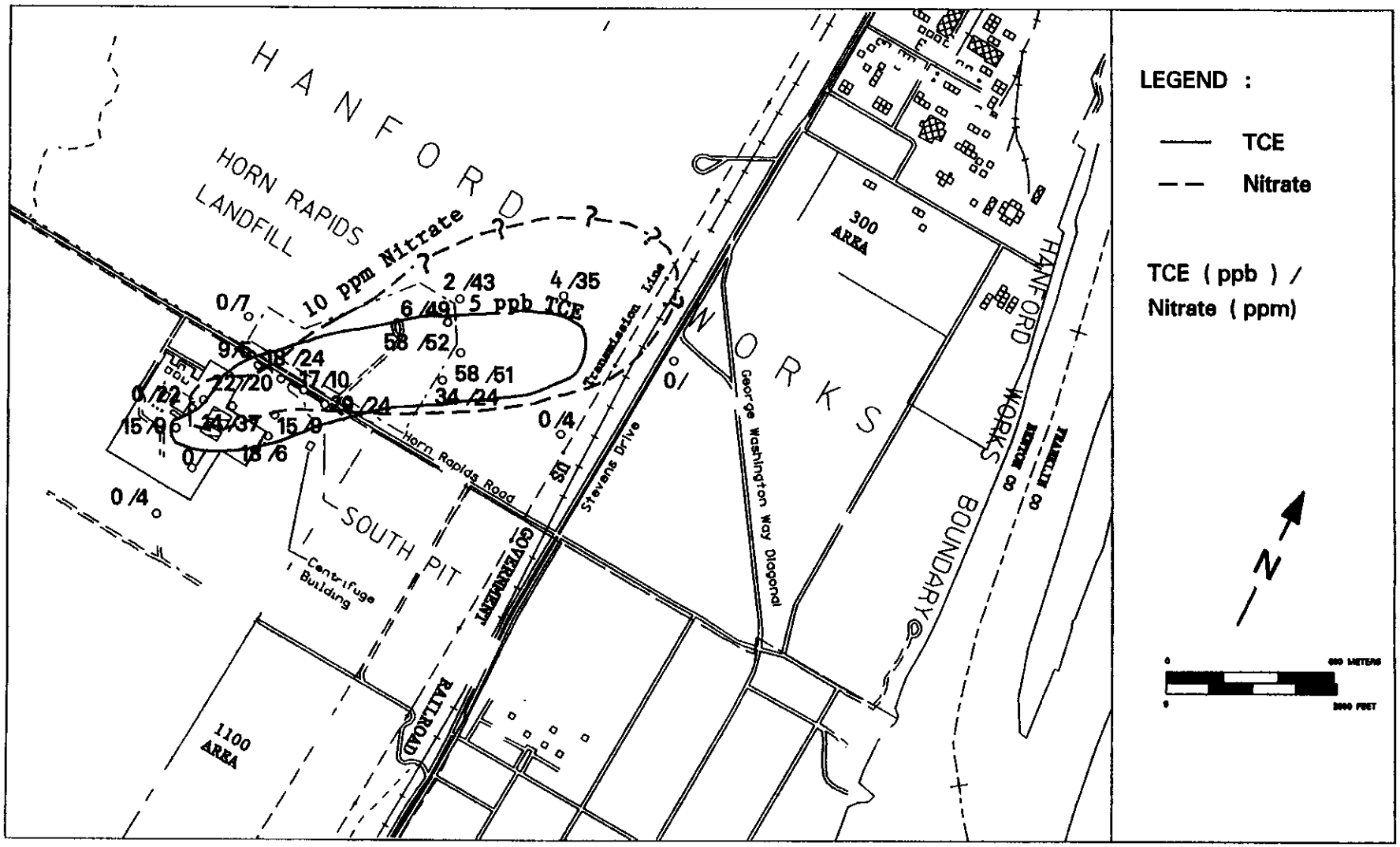
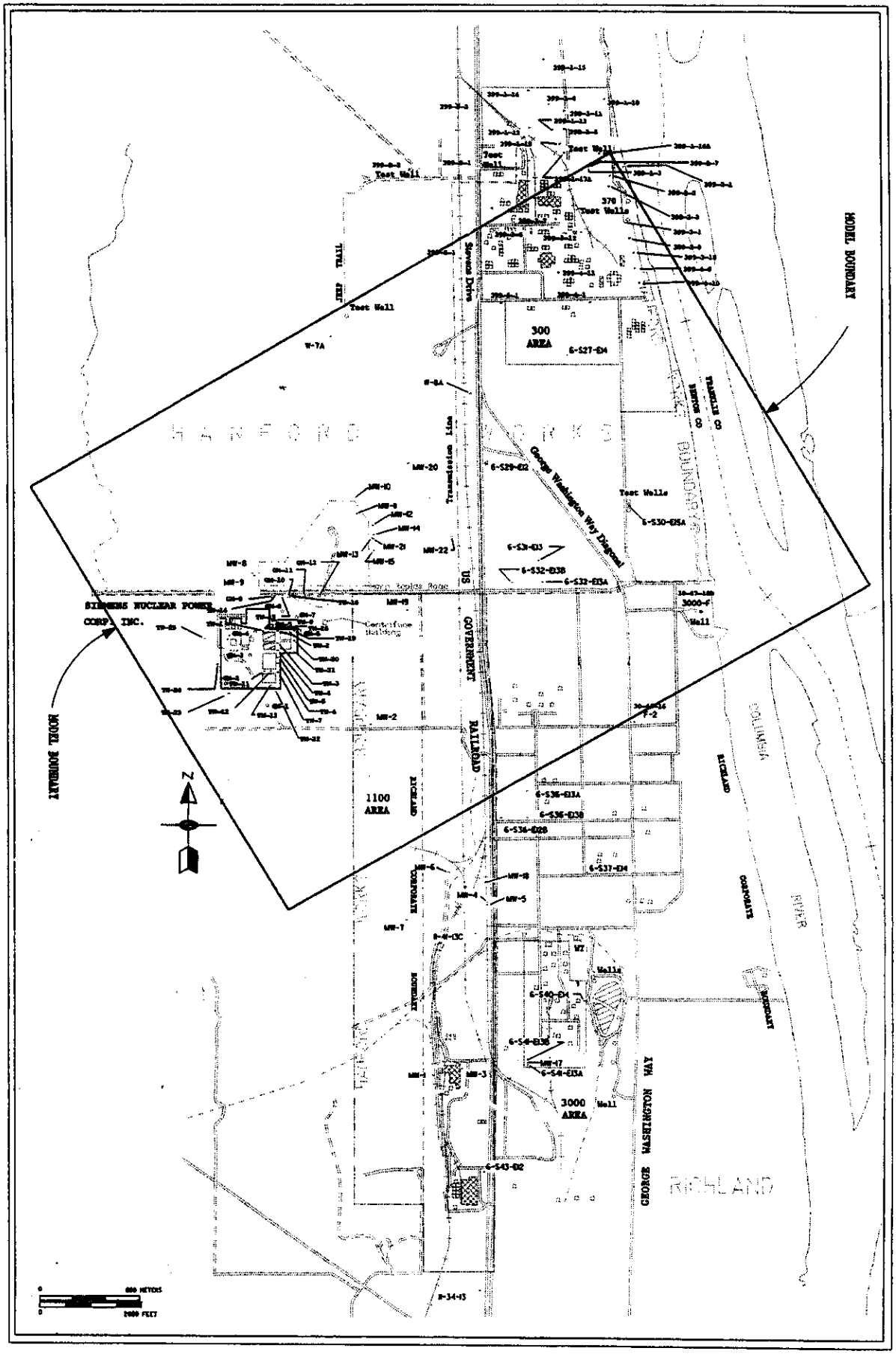



Figure 6–12. TCE and Nitrate Concentration Data and Approximate Plume Extents, Spring 1992.




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

Figure 6-13



9 3 1 2 7 . 4 1 2 7 8

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.

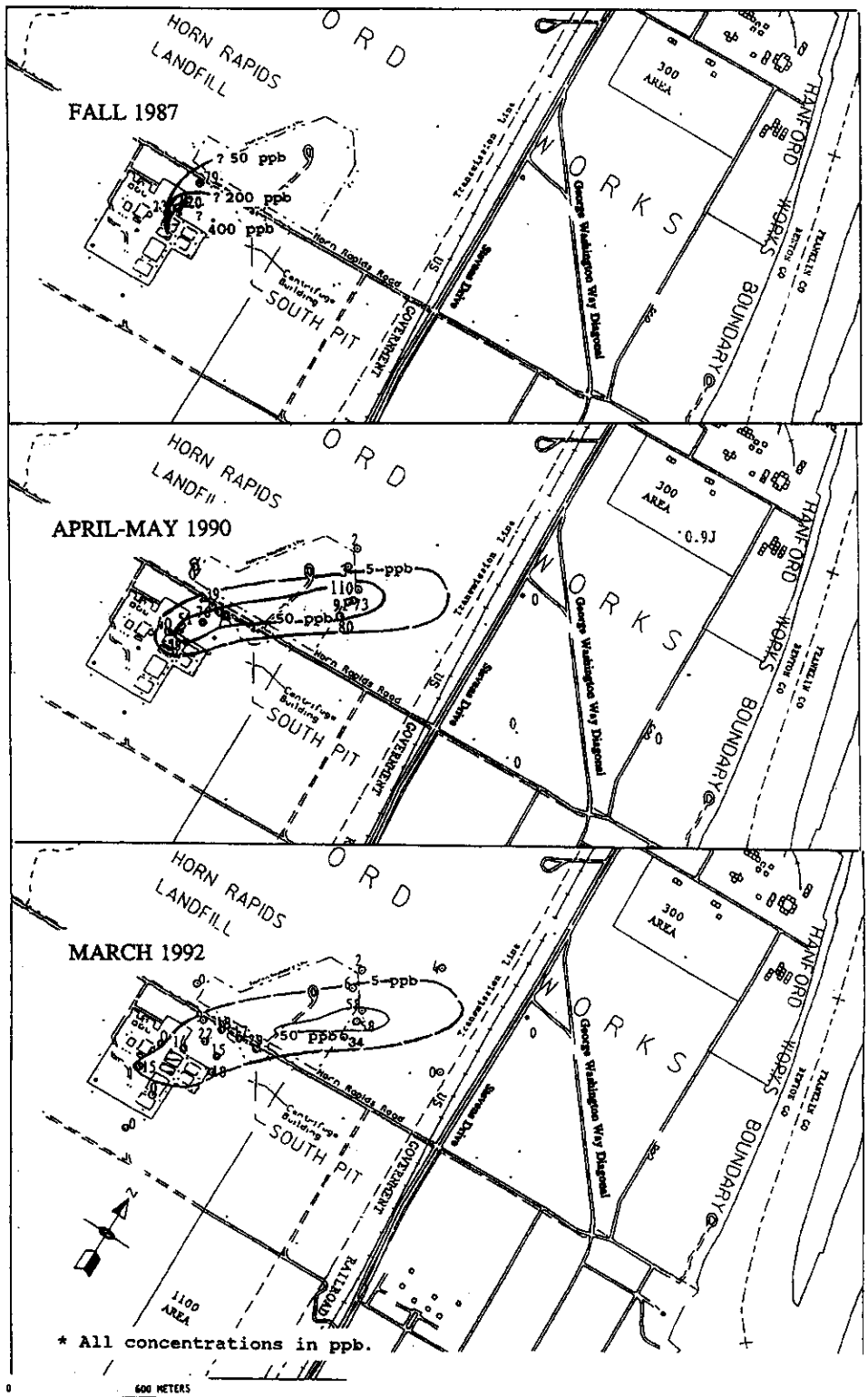
The available TCE data for the earliest (fall, 1987), latest (March, 1992), and one intermediate (April through May, 1990) sampling rounds, determined the approximate extent of the plume through time as shown in figure 6-14. Data indicates that in the 5-year period from 1987 to 1992, natural attenuation 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 decrease 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.

### 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 PORFLOW™, a finite-difference software package developed by Analytical & Computational Research, Inc. (ACRI), Los Angeles, California. Version 2.4 was used, which, for the scope used in this is 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.




TCE Data and Approximate Plume Delineations.

Figure 6-14



9 3 1 2 7 4 0 2 3 0

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

| Remedial Investigation | Feasibility Study |
|---|---|
| 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 |

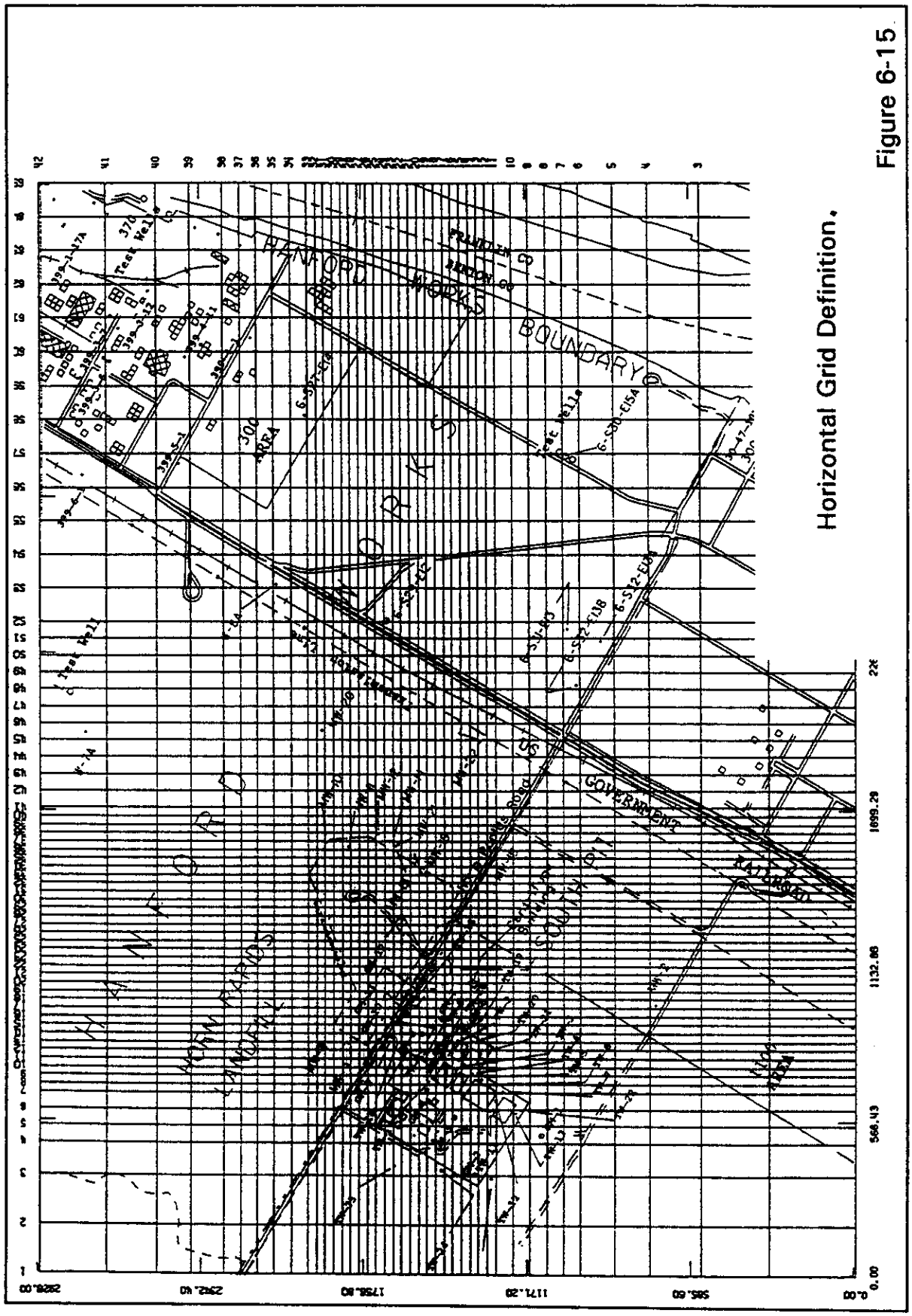
The analysis approach focused on predicting the transport and persistence of TCE for the following reasons. The current maximum nitrate levels (50 to 60 ppm) are closer to the nitrate MCL of 10 ppm than current maximum TCE levels (50 to 60 ppb) are to the TCE MCL of 5 ppb. Also, because of adsorption of TCE, its 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 down-gradient 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.

9 3 1 2 7 4 0 2 3 2

**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 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 $km^2$ (about 4.5 $mi^2$). 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 (up-gradient 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 up-gradient 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 down-gradient toward the Columbia River).




Horizontal Grid Definition.

Figure 6-15

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 water levels in wells near the river showed that the water elevations were higher than 97 percent, 48 percent, and 7 percent of observed 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.

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.

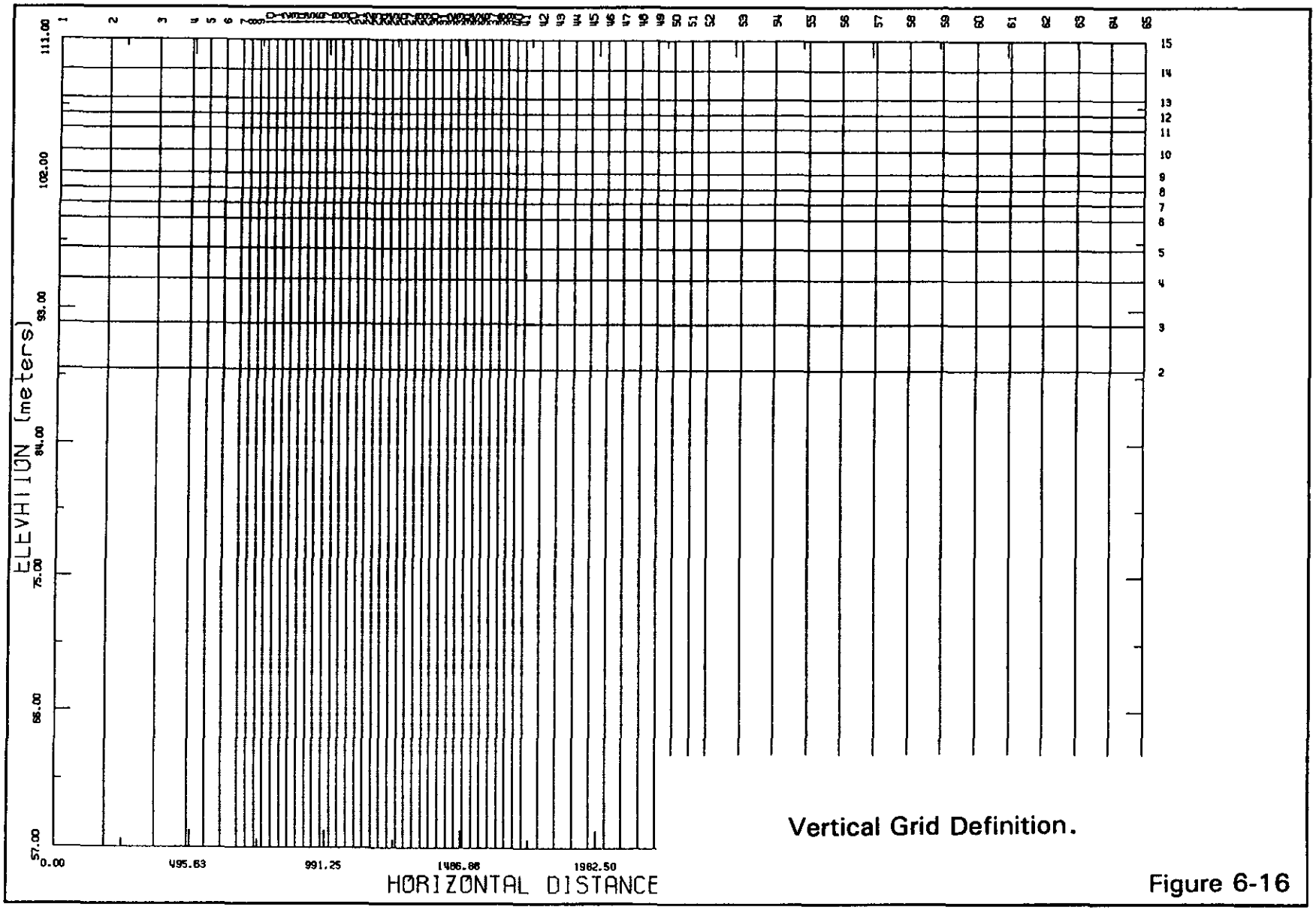
**Table 6-11. 1100-EM-1 Groundwater Model Boundary Conditions**

| Location | Type | Range |
|---|---|---|
| Southwest Horizontal (Upgradient Boundary) | Constant Head Nodes | 108.7 to 109.2[1](Upper)[2]<br>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]<br>104.35 to 104.7(Avg.)<br>103.65 to 104.0(Low) |
| Northwest Horizontal | Constant Flux and Constant Head Nodes (Columns 56- 65) | Flux = 0<br>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

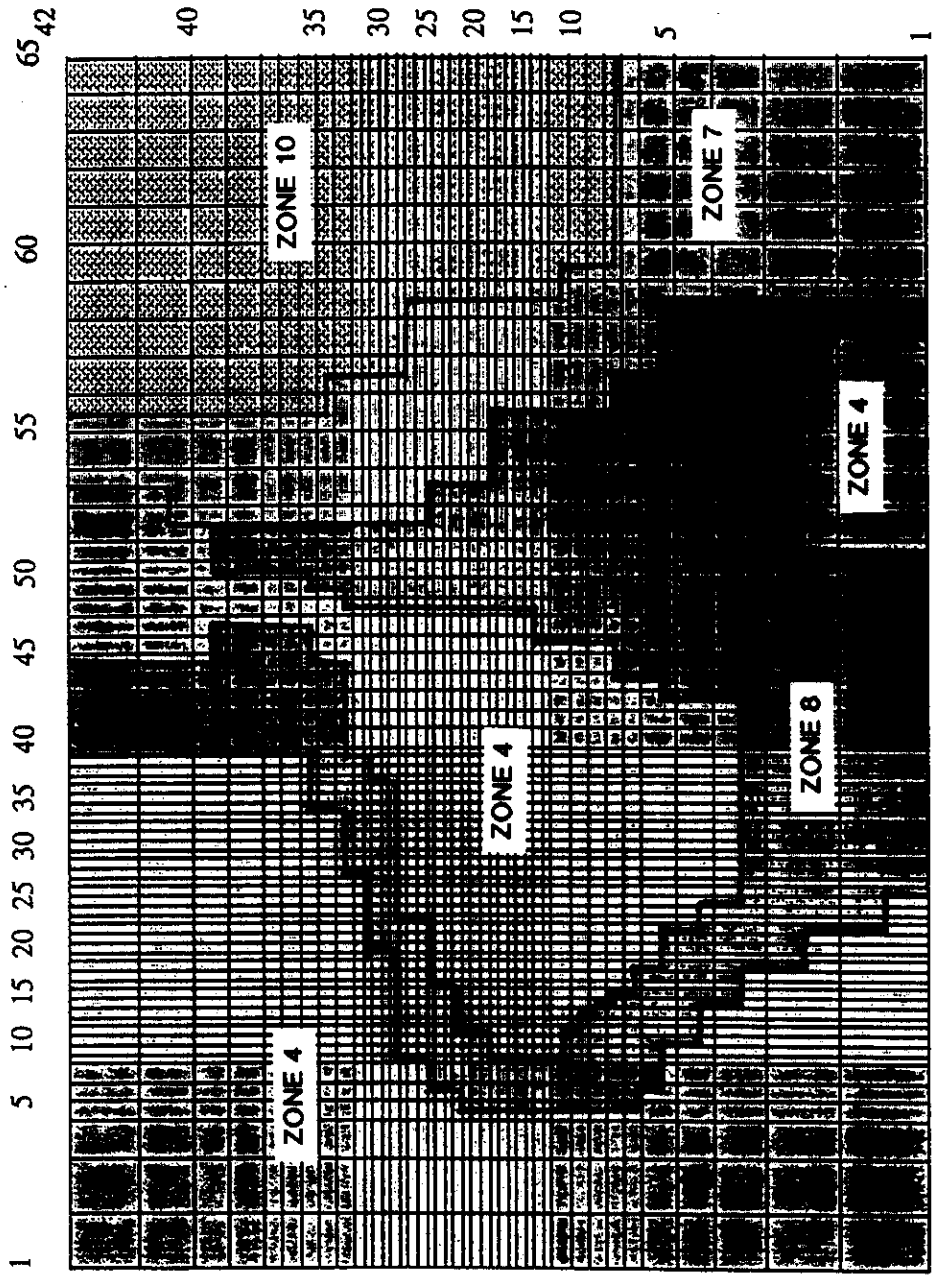
[2] Upper and Lower refer to the model layers representing strata above and below the silt aquitard

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



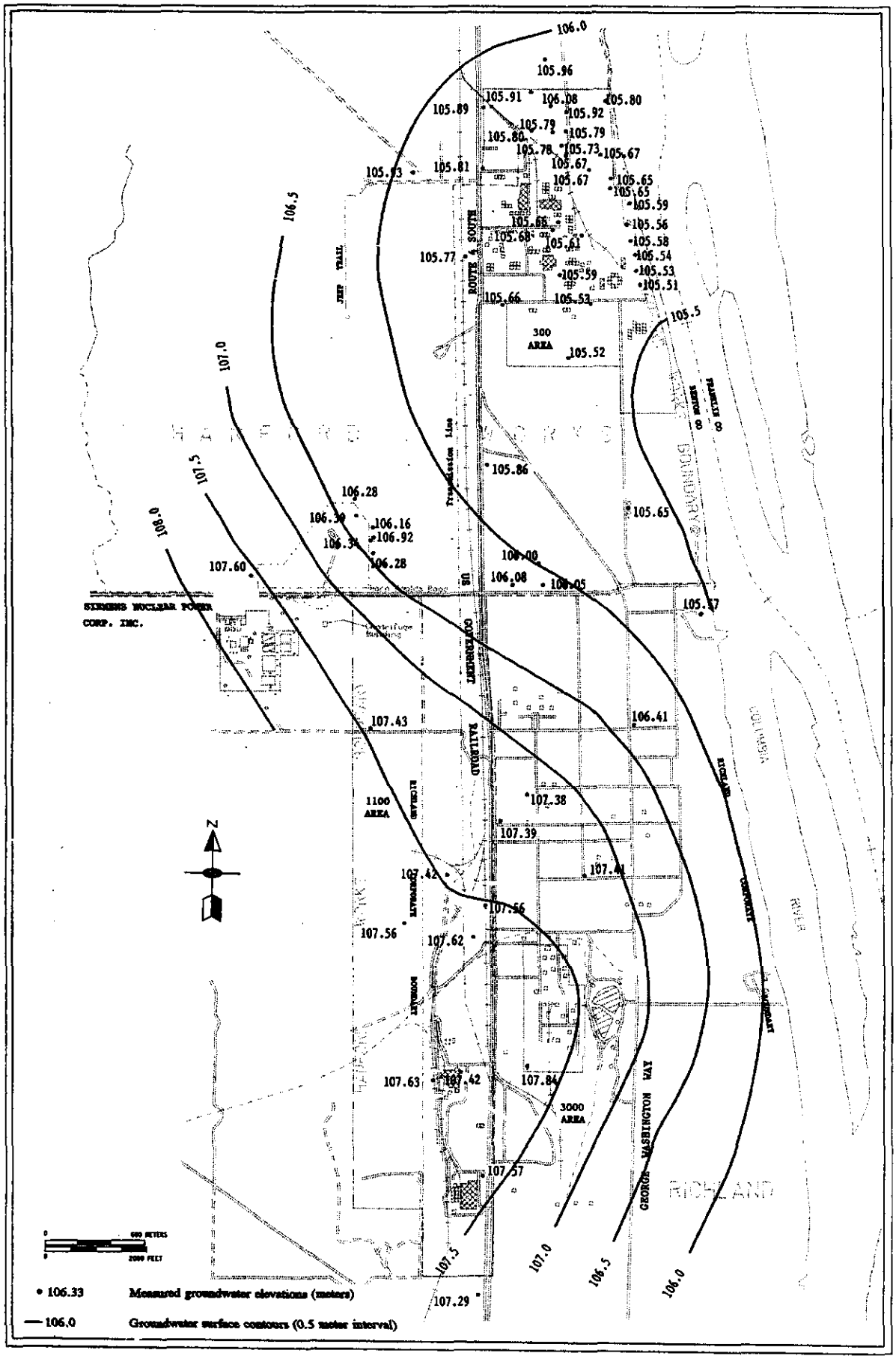

Vertical Grid Definition.

Figure 6-16




Hydrofacies Zone Designation
Layer 12.

Figure 6-17

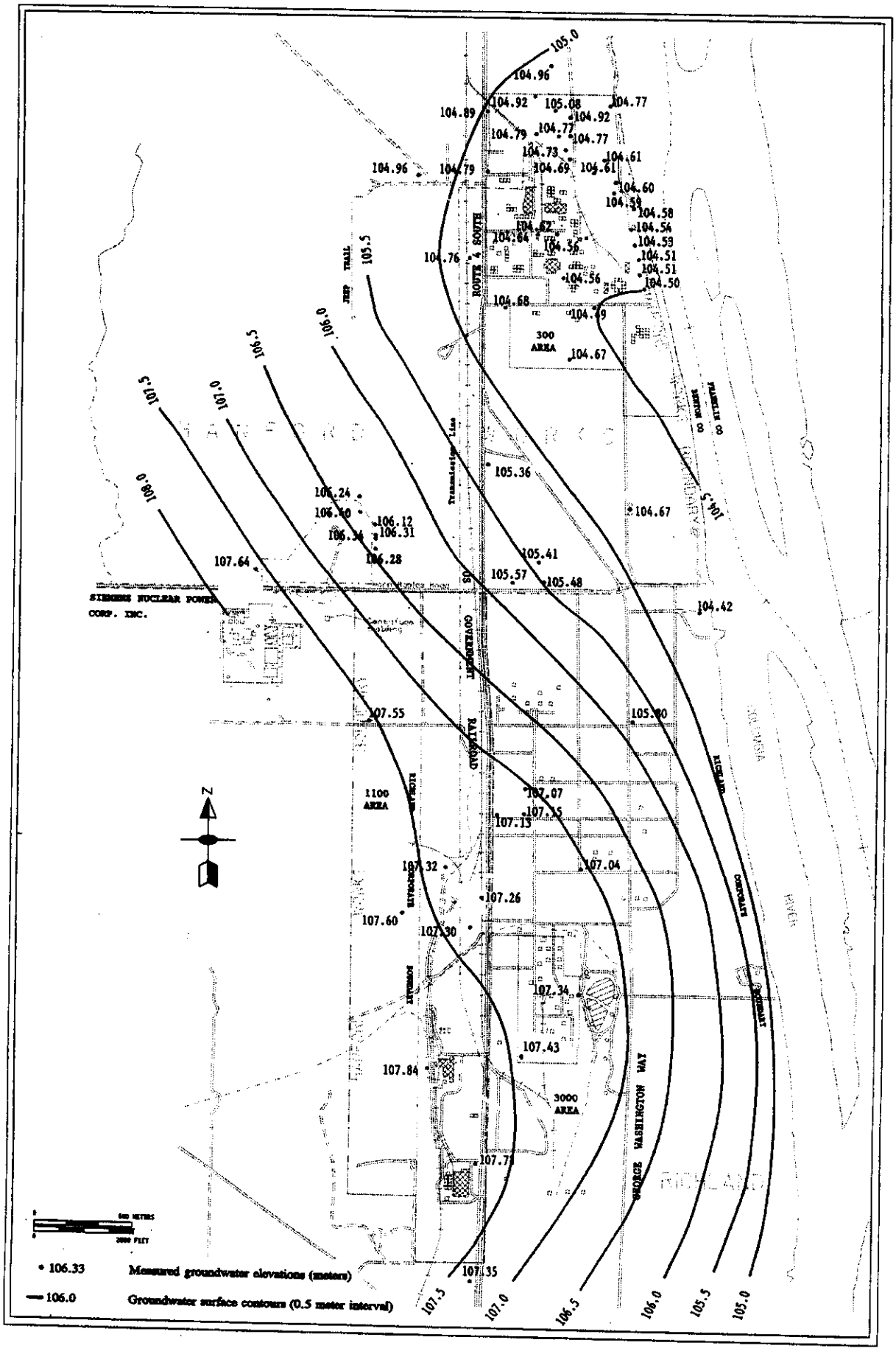



Groundwater Levels and Potentiometric Surface Contours, June 25-27, 1990.



Figure 6-18

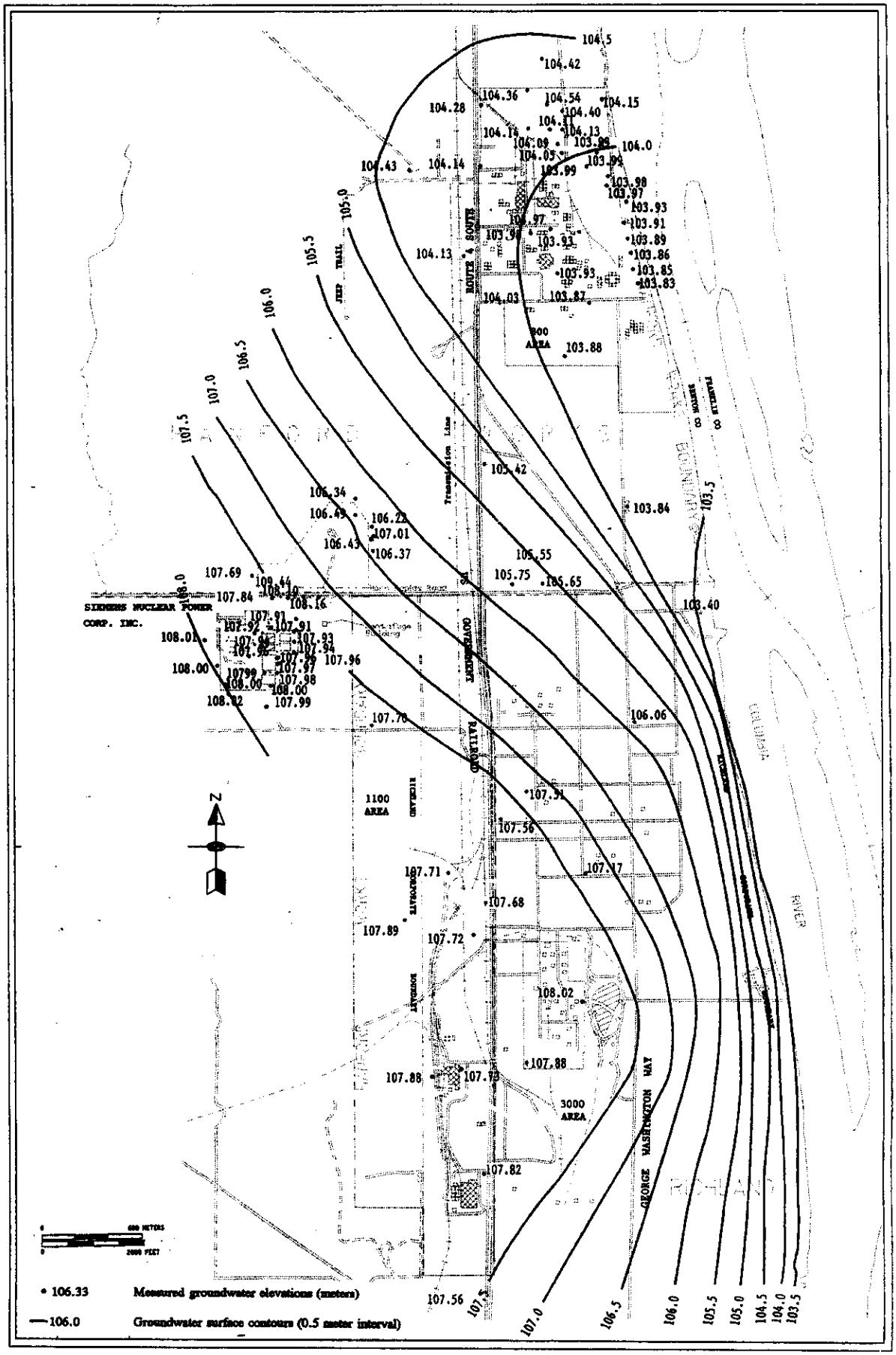
9 3 1 2 7 4 7 2 3 8




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



Figure 6-19




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

Figure 6-20



9 3 1 2 7 4 1 2 9 0

**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 steps 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 TCE source was limited to a history of lagoon liner installation and repair at SPC (see source discussion in section 4). 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

**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 | $K_h' = K_h$ x .50 (all) | 0.007 | 0.045 | 0.095 |
| 2 | 1c62 | $K_h' = K_h$ x .25 (all) | 0.151 | 0.428 | 0.476 |
| 3 | 1c63 | $K_h' = K_h$ x 2.0 (all) | -0.245 | -0.236 | -0.109 |
| 4 | 1c64 | $K_h' = K_h$ x 4.0 (all) | -0.304 | -0.297 | -0.147 |
| 5 | 1c65 | $K_h' = K_h$ x .50 (all) | -0.189 | -0.172 | -0.042 |
| 6 | 1c66 | $K_h' = K_h$ x .25 (all) | -0.215 | -0.197 | -0.042 |
| 7 | 1c67 | $K_h' = K_h$ x 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 | $K_h' = K_h$ x .25 (Hanford) | 0.109 | 0.213 | 0.387 |
| 17 | 1c78 | $K_h' = K_h$ x .50 (Hanford) | -0.037 | 0.016 | 0.123 |
| 18 | 1c79 | $K_h' = K_h$ x 2.0 (Hanford) | -0.245 | -0.254 | -0.144 |
| 19 | 1c80 | $K_h' = K_h$ x 4.0 (Hanford) | -0.323 | -0.346 | -0.209 |
| 20 | 1c81 | $K_h' = K_h$ x .25 (Up Ringd) | -0.151 | -0.140 | -0.044 |
| 21 | 1c82 | $K_h' = K_h$ x .50 (Up Ringd) | -0.154 | -0.140 | -0.039 |
| 22 | 1c83 | $K_h' = K_h$ x 2.0 (Up Ringd) | -0.158 | -0.120 | -0.008 |
| 23 | 1c84 | $K_h' = K_h$ x 4.0 (Up Ringd) | -0.189 | -0.111 | 0.020 |
| 24 | 1c85 | $K_h' = K_h$ x .25 (Silt) | -0.146 | -0.129 | -0.023 |
| 25 | 1c86 | $K_h' = K_h$ x 4.0 (Silt) | -0.145 | -0.127 | -0.023 |
| 26 | 1c87 | $K_h' = K_h$ x .25 (Lo Ringd) | -0.112 | -0.100 | -0.044 |
| 27 | 1c88 | $K_h' = K_h$ x 4.0 (Lo Ringd) | -0.152 | -0.112 | 0.041 |

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**Table 6-13. Contaminant Transport Sensitivity Analysis**

| Parameter Varied | 1988 Max C (ppb) | 1992 Max C (ppb) | 2000 Max C (ppb) |
|---|---|---|---|
| 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 |

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. 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.

Model sensitivity to the primary factors influencing groundwater flow velocities is described above. A sensitivity analysis on the uncertainty associated with the delineation of stratigraphic boundaries was not performed mainly due to lack of a reasonable means of doing so. However, exact stratigraphic representation was not necessary to predict accurate contaminant travel times or dispersion rates since these are dependent on groundwater velocities which, in turn, depend on hydraulic conductivities and total pressure head gradients. The modeling analysis emphasized calibration to observed hydraulic conductivities and total pressure head gradients, thus emphasizing the accuracy of predicted travel times, attenuation rates, and other velocity-dependent processes. Any error introduced by non-exact stratigraphic boundary definition has little effect on the velocity-dependent processes but has a greater effect on volume calculations such as those involved with predicting aquifer response to large scale pumping. Because of this, the greater the pumping rate of any simulated extraction-treatment scenario, the greater the associated uncertainty in predicted sustainable pumping rates and effects on groundwater gradients.

Although the grid mesh size was, by convention, adequate for the model applications in this study, the predictions of aquifer response to the extraction-treatment scenarios would be improved by increasing mesh density near the extraction wells.

**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.

The contaminant sensitivity analysis assisted in determining ranges of model input data sets, used in the analysis to represent unconservative (high attenuation) and conservative (low attenuation) simulations.

### 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, it was determined 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 extends the farthest). One additional source spike was added in 1983, at the next earlier period of increased TCE use because the simulation with one source spike did not match the observed data. The result is 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 (shown in figure 6-27), near the earliest recorded use of TCE, the simulated values produced 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 line. This diagonal line, as shown in figure 6-13 and other figures of this section, is a construct defined by a straight line beginning at the intersection of George Washington Way and Horn Rapids Road, then running in a northwest direction along George Washington Way, and continuing in this same direction beyond the point where George Washington Way turns due west to eventually intersect with Stevens Drive. This construct defines a convenient line that is roughly parallel to the potentiometric contours and perpendicular to the prevailing groundwater flow (and the path of the contaminant plumes) in this area. Discussions dealing with the modeled plume migration and remediation scenarios will refer to this line (George Washington Way diagonal or George Washington Way diagonal line) to demarcate its movement.

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 ($\eta_{tot}$) = 0.23, effective porosity ($\eta_{eff}$) = 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 $\eta_{tot}$ and a $\eta_{eff}$ 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 ($\eta_{tot}$) = 0.32, effective porosity ($\eta_{eff}$) = 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 line. 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 125 and 91 L (33 and 24 gal) 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



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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**

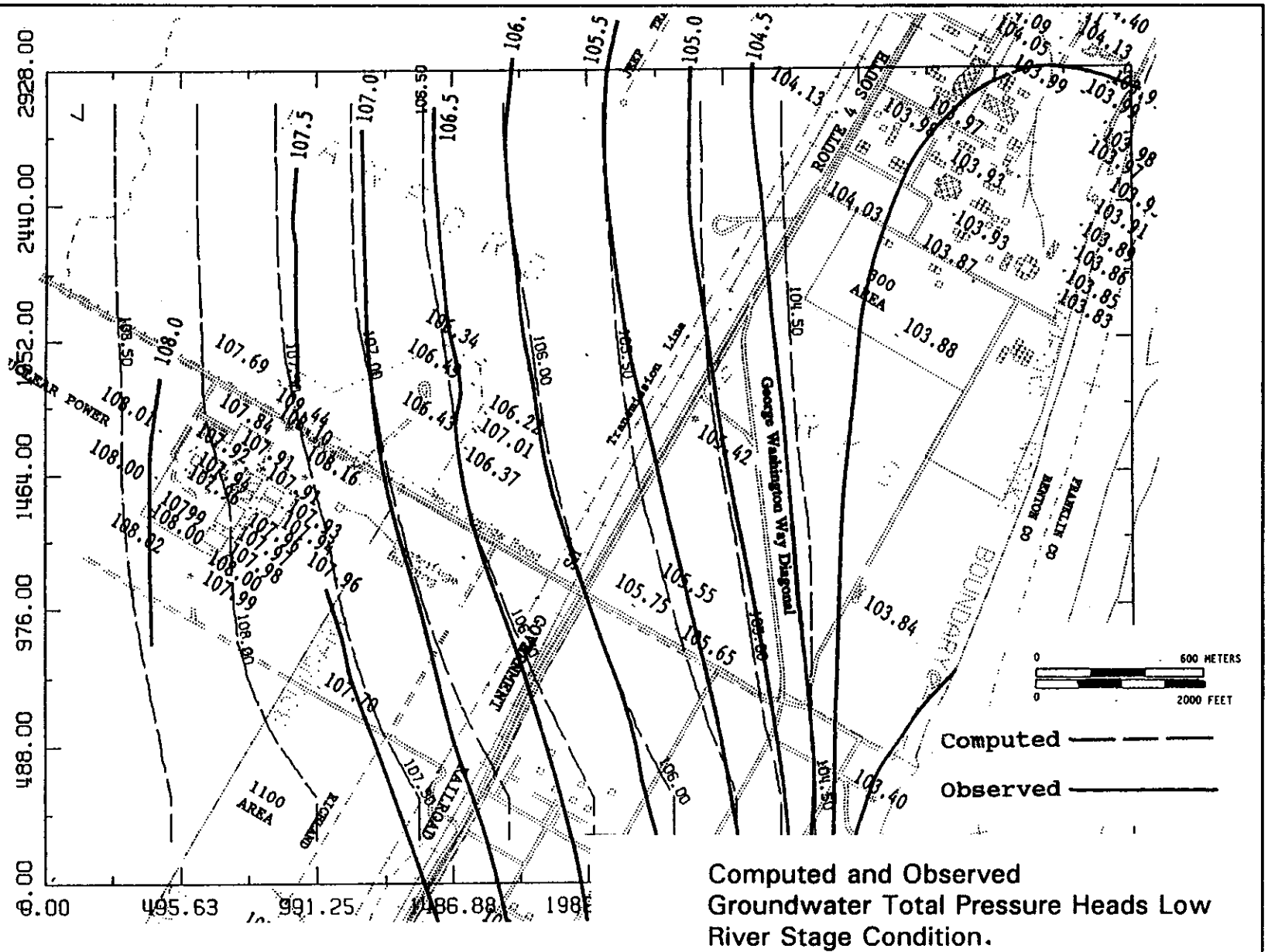
| WELL # | SEPTEMBER 24-27, 1990 | | | FEB 27 - MARCH 2, 1990 | | | JUNE 25 - 27, 1990 | | |
|---|---|---|---|---|---|---|---|---|---|
| | OBS meters | CALC meters | DIFF meters | OBS meters | CALC meters | DIFF meters | OBS meters | CALC meters | DIFF meters |
| 399-1-17A | 104.05 | 104.01 | 0.04 | 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 |

## 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 and second values were used in the unconservative and conservative simulations, respectively.

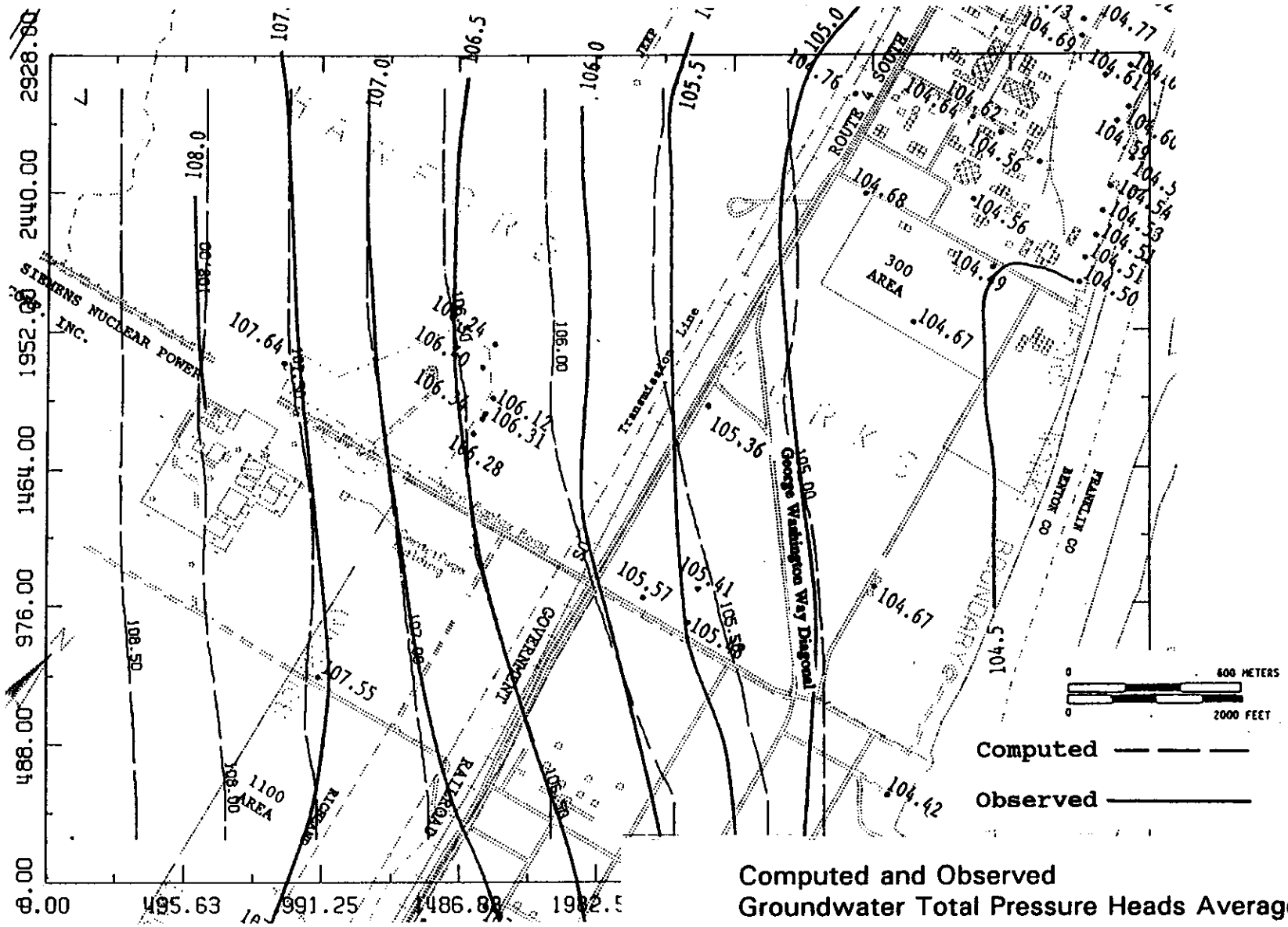



Computed and Observed
Groundwater Total Pressure Heads Low
River Stage Condition.

Figure 6-21

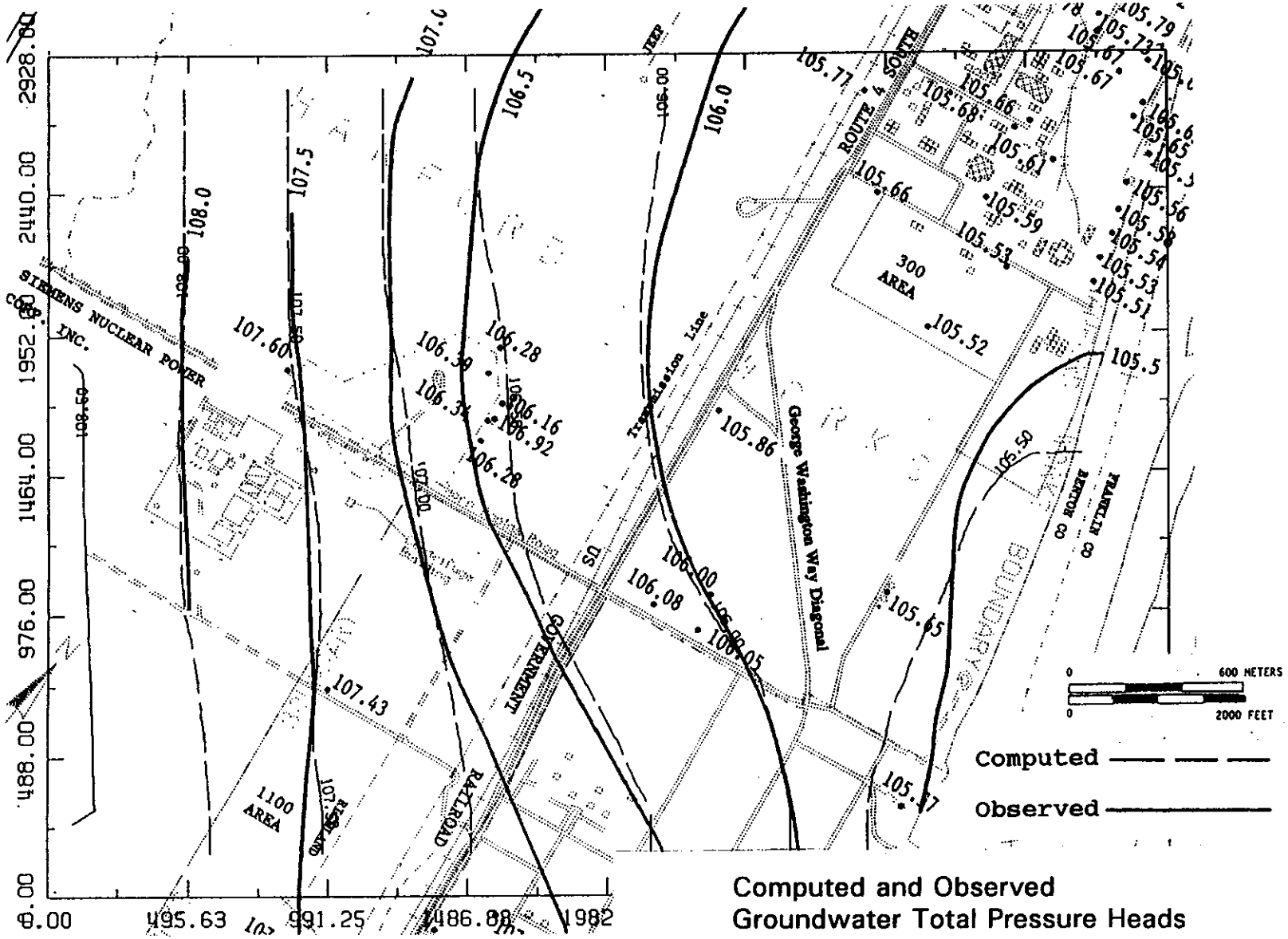


Figure 6-21
Page 1 of 1



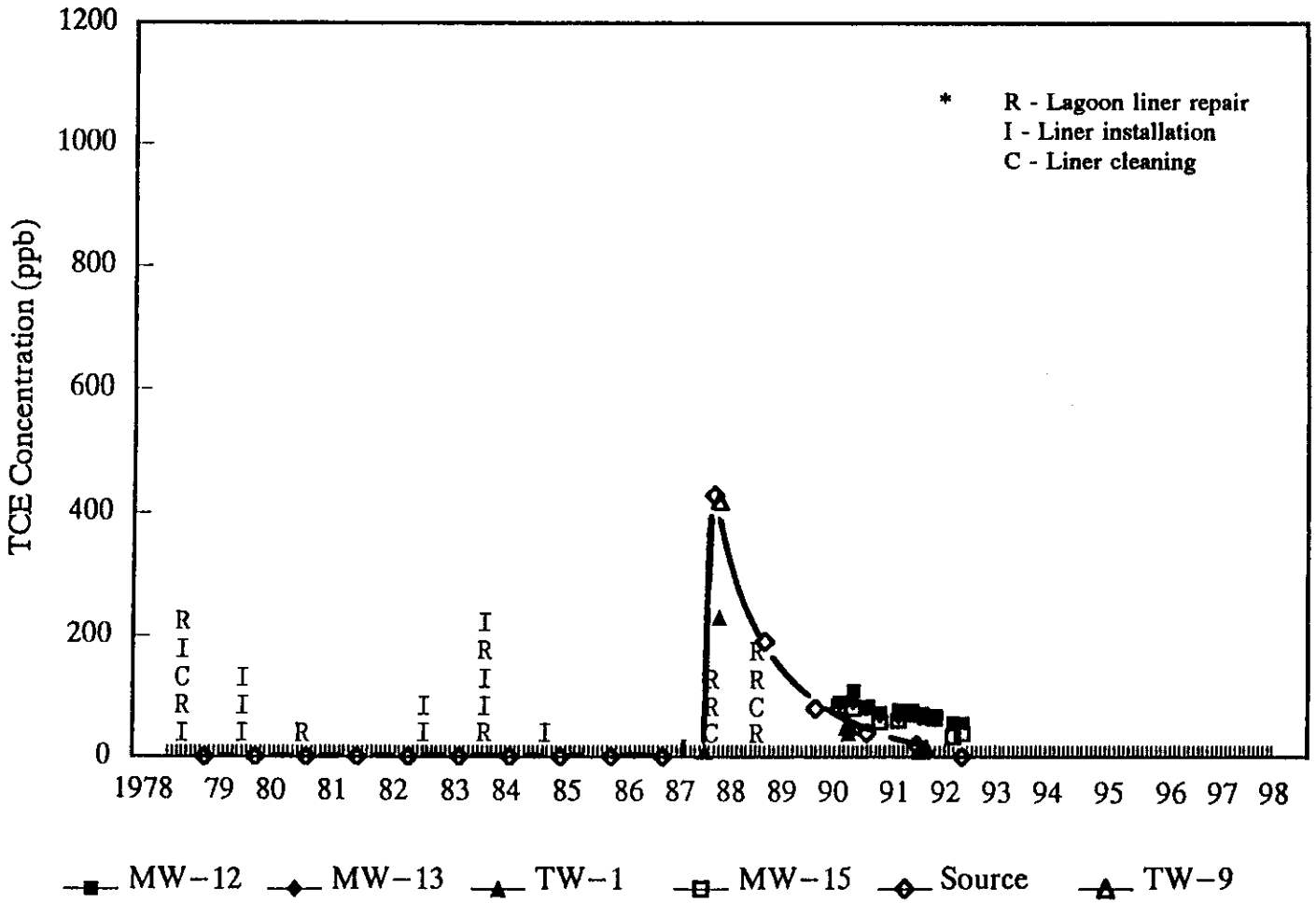

Computed and Observed
Groundwater Total Pressure Heads Average
River Stage Condition.

Figure 6-22



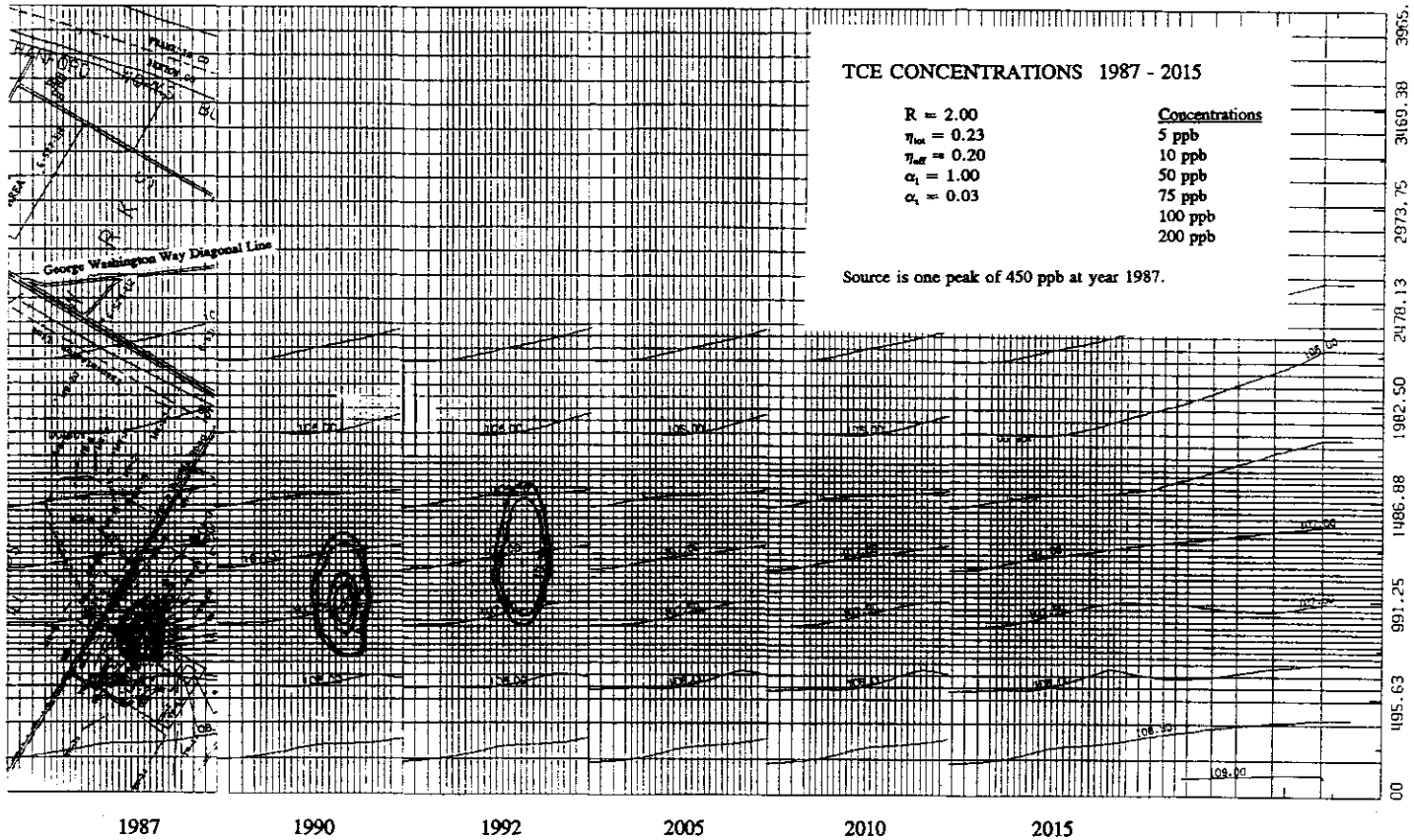

Computed and Observed
Groundwater Total Pressure Heads
High River Stage Condition.

Figure 6-23




Observed TCE Concentrations and Model Source Spike of 450 ppb.

Figure 6-24




Computed TCE Plumes With One Source Peak in 1987.

Figure 6-25

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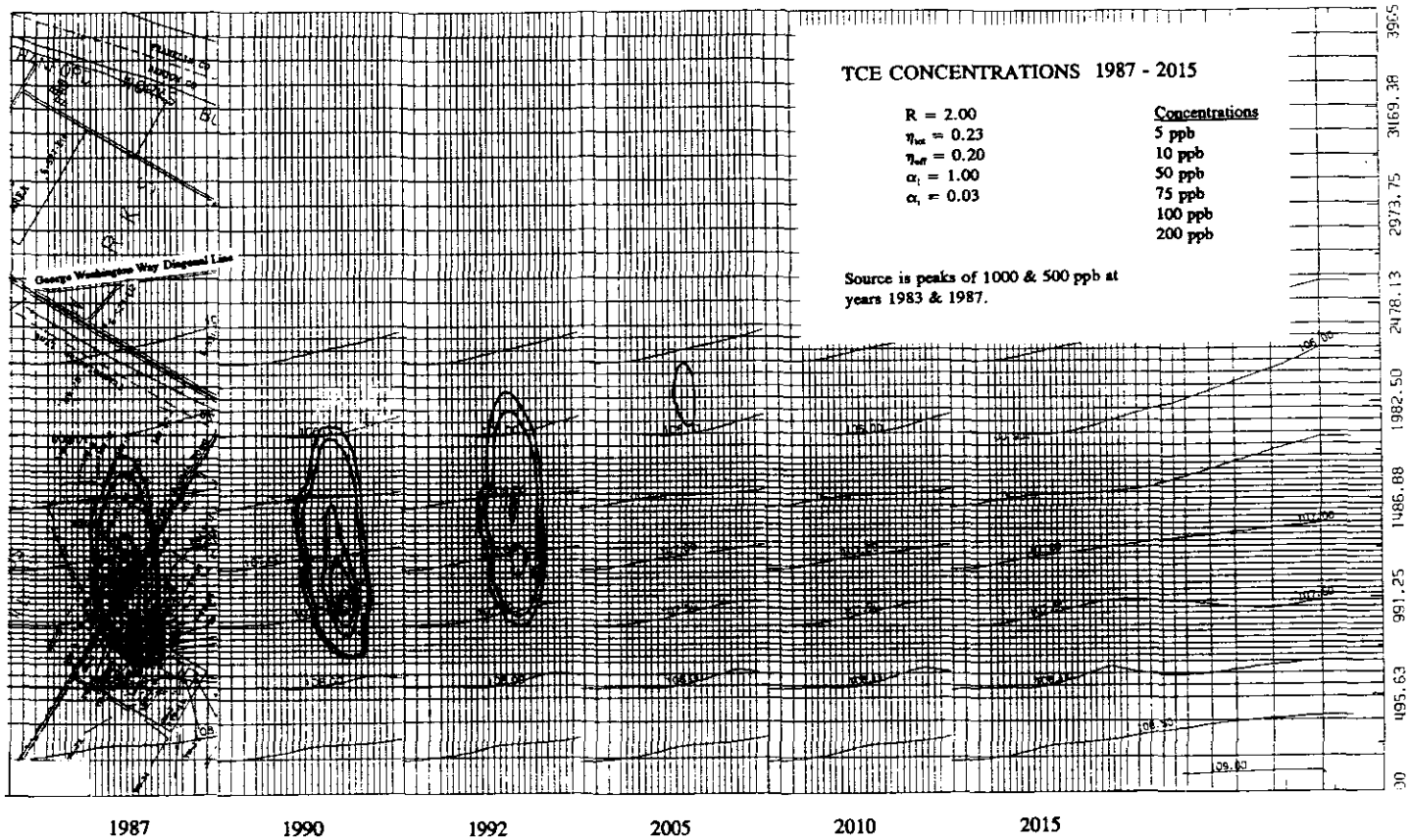


Computed TCE Plumes With Source Peaks in 1983 and 1987.

Figure 6-26

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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 57 to 83 L (15 to 22 gal) for the 1992 data (section 4.7.2).

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.

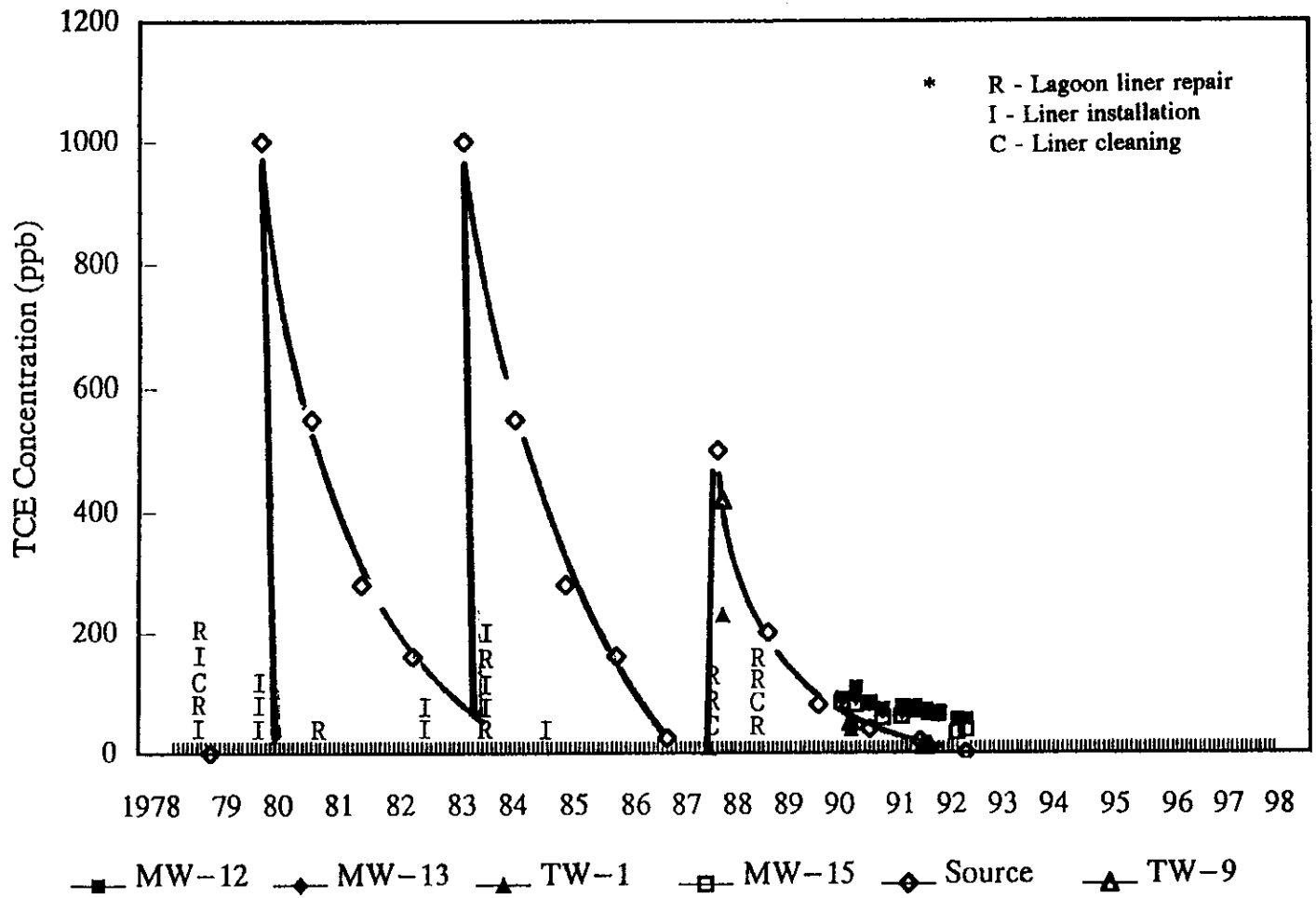
Reported contaminant transport values, for another groundwater modeling study involving TCE migration at the Fort Lewis, Washington site (USACE, 1990), were: retardation factor (R) of 3.0, dispersivity factors of 0.75 ($\alpha_l$, longitudinal) and 0.075 ($\alpha_t$, transverse), and porosity values ($\eta$) 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.

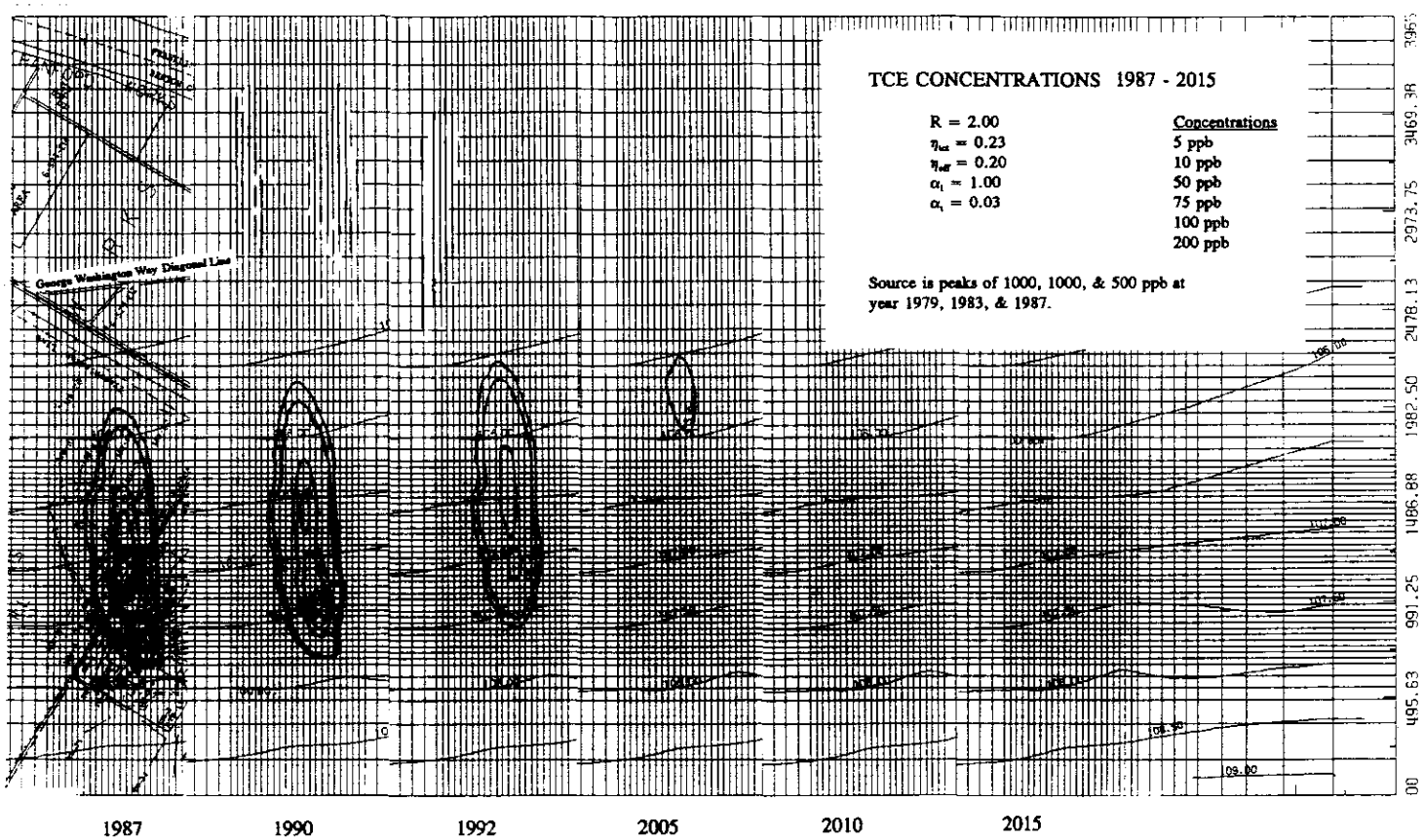
**6.4.6.1 Baseline Scenario Results.** The migration of TCE was simulated using both the unconservative and conservative contaminant transport parameters with results shown in figures 6-28 and 6-29, respectively. These simulation results predict that the TCE plume will attenuate to below 5 ppb between the years 2007 and 2017 and will not cross the George Washington Way diagonal line in concentrations above 5 ppb. The maximum predicted concentration 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 future 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 allowed to fluctuate.




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

Figure 6-27




Computed TCE Plumes With Source Peaks in 1979, 1983, and 1987.
Unconservative Calibration.

Figure 6-28

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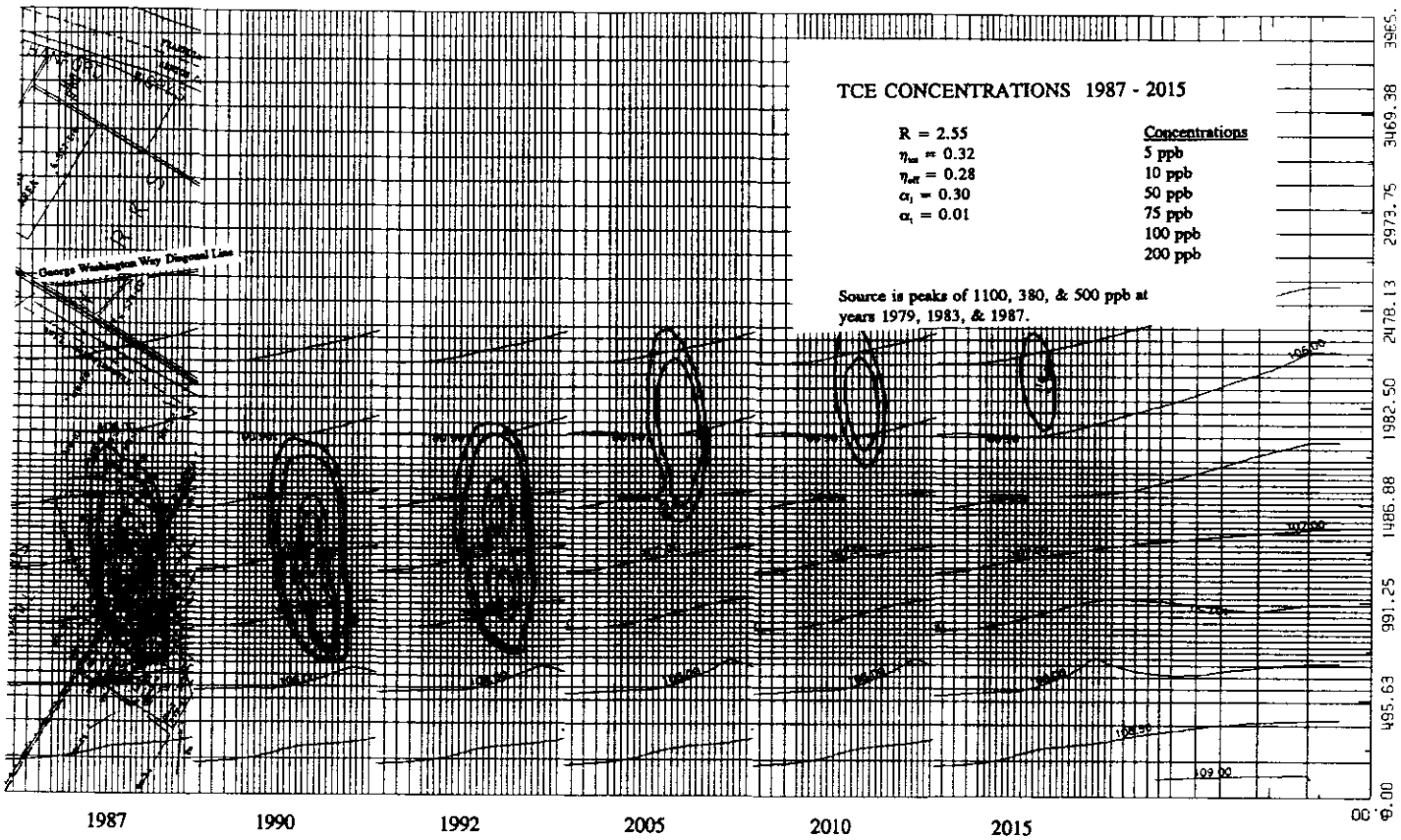


Computed TCE Plumes with Source Peaks in 1979,1983, and 1987.
Conservative Calibration.

Figure 6-29



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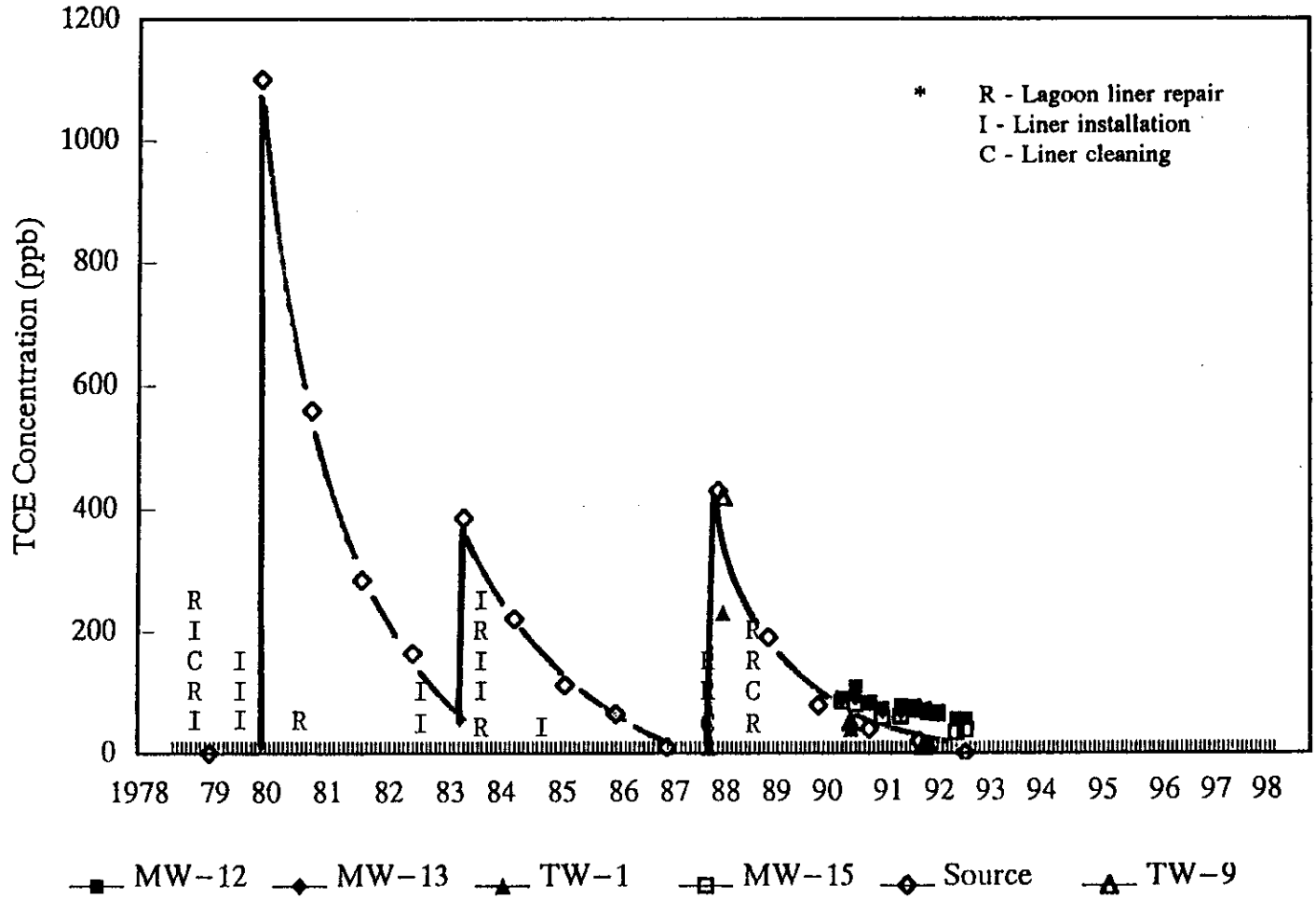



Observed TCE Concentrations and Model Sourve Spikes of 1500, 380, and 400 ppb.

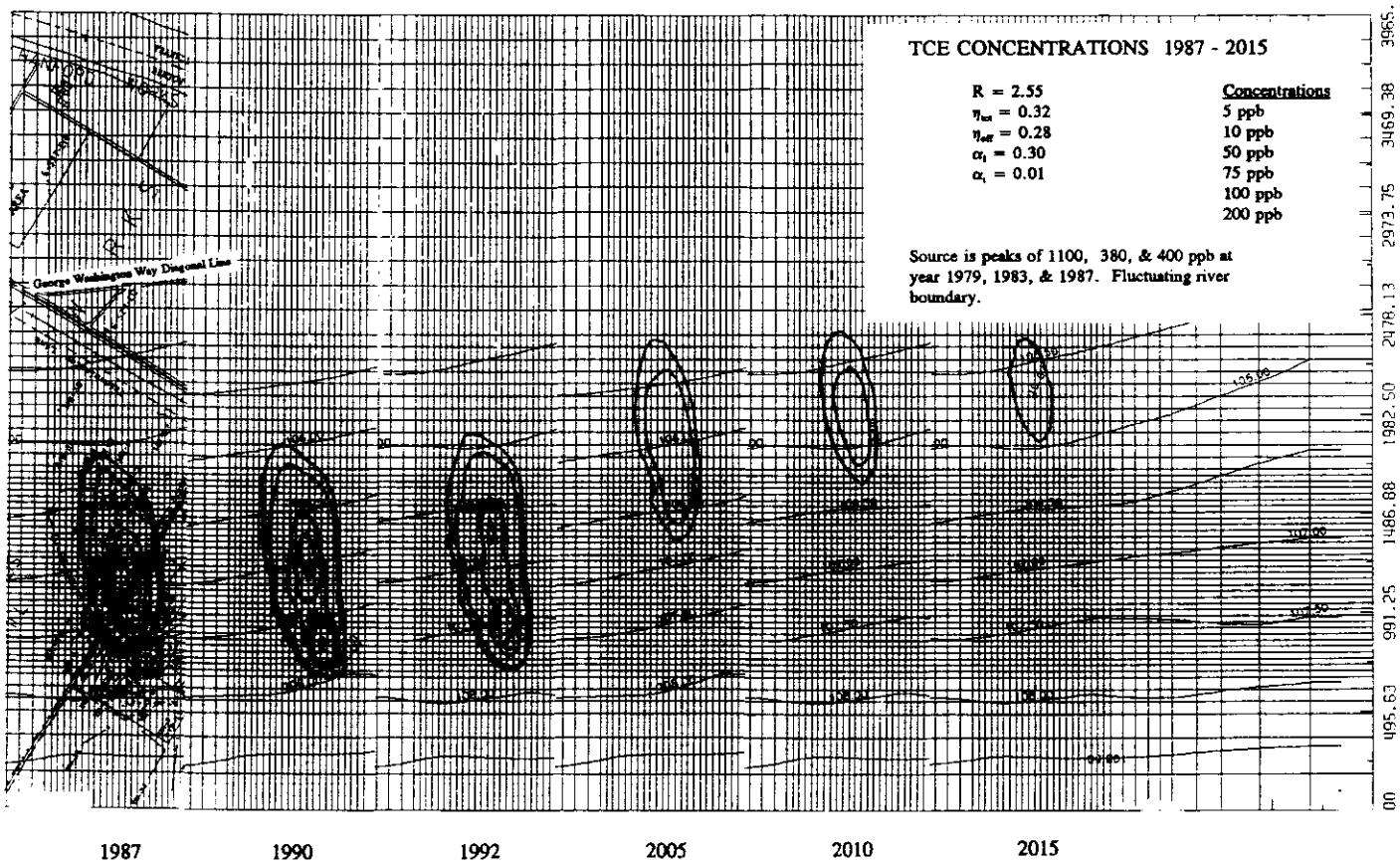
Figure 6-30

**6.4.6.2 Remediation Scenario Results.** The RI/FS study included consideration of extraction-treatment-infiltration (pump and treat or extraction-infiltration) scenarios which were the only action remediation scenarios analyzed with the model. A preliminary optimization of possible site extraction-infiltration scenarios was conducted 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 could only be placed in increasingly less effective locations. 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 down-gradient 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).




Computed TCE Plumes With Fluctuating River Boundary.

Figure 6-31

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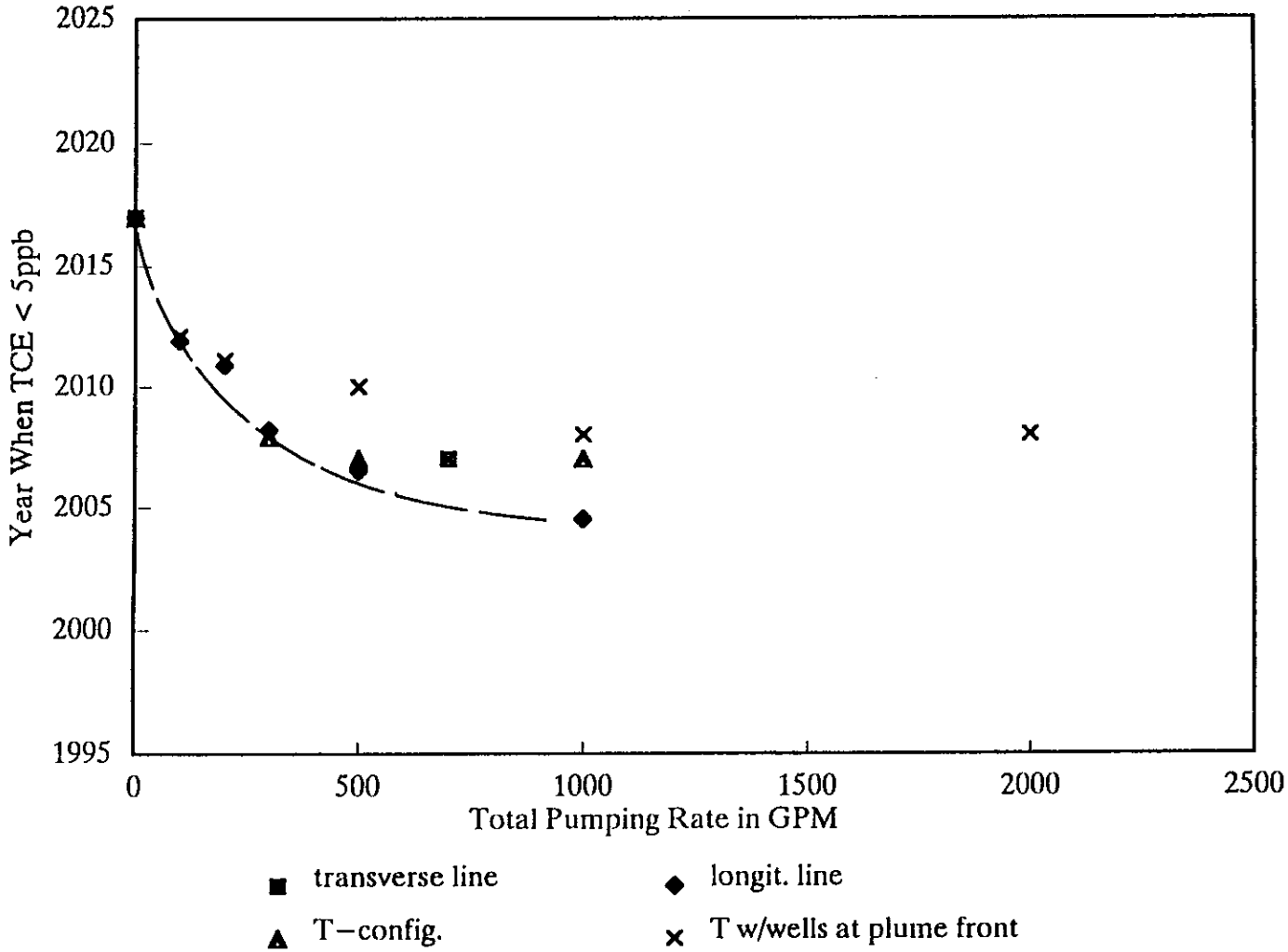


Results of a Preliminary Extraction-Infiltration Well Configuration Optimization

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.

As discussed earlier in the sensitivity analysis section, the scenario with the largest pumping rate also has the largest uncertainty in terms of predicted aquifer response. The uncertainty results mainly from the relatively steep drawdown near the wells and from stratigraphic uncertainty. Further simulation, with finer grid mesh density near the extraction wells, is recommended if more detailed pump and treat designs, beyond the scope of this RI/FS-EA report, are desired.

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 is subject to greater dispersion than TCE. Because of this, and because the nitrate concentrations are closer to MCL's than TCE, nitrate was 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 does not appear to be leveling off. As discussed earlier, if current reduction rates in the MW-12 area wells were to continue, 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.

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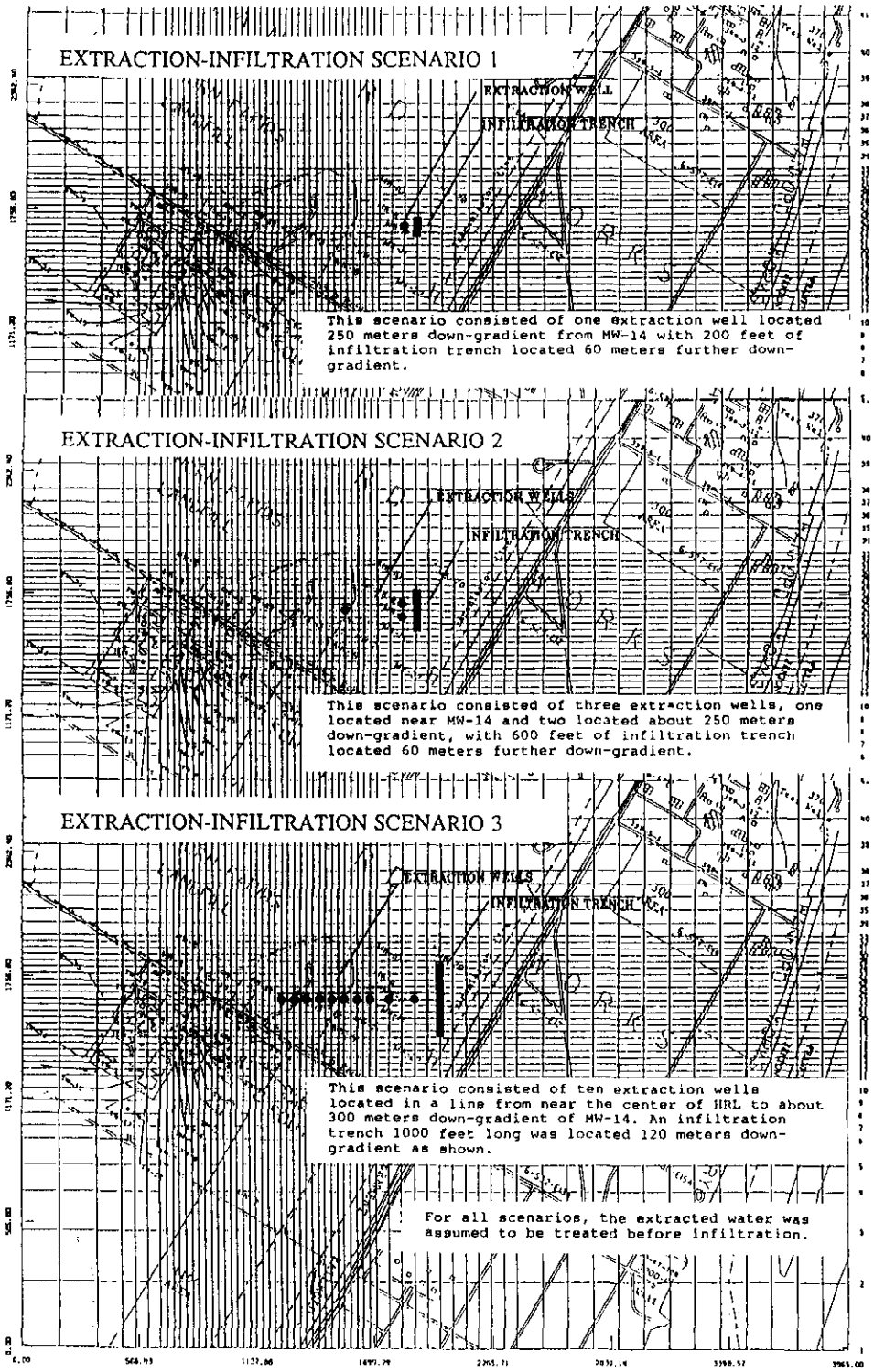


Well Configurations for Extraction-Infiltration Scenarios 1-3.

Figure 6-33

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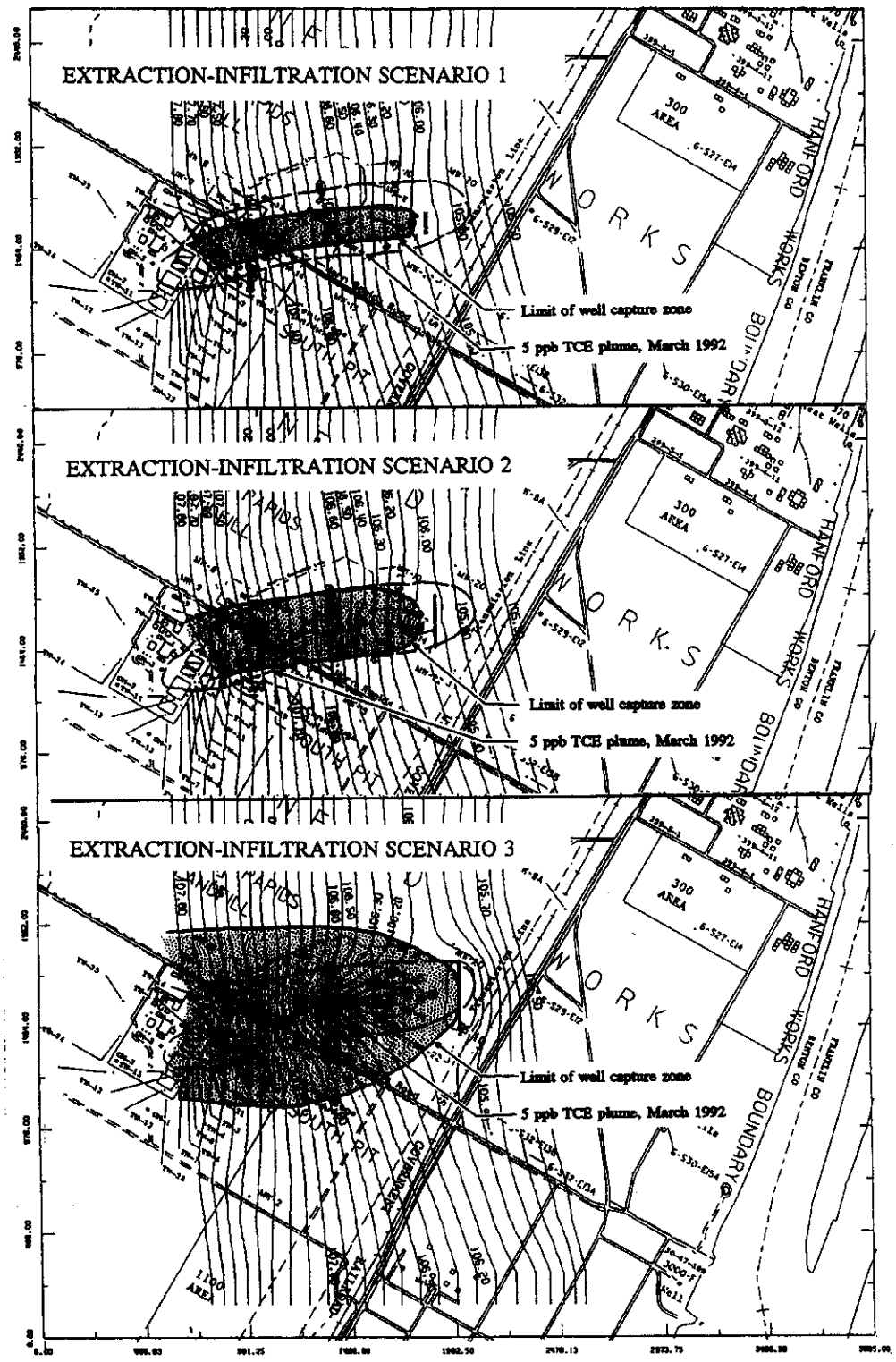


Well Capture Zones for Extraction-Infiltration Scenarios 1-3.

Figure 6-34



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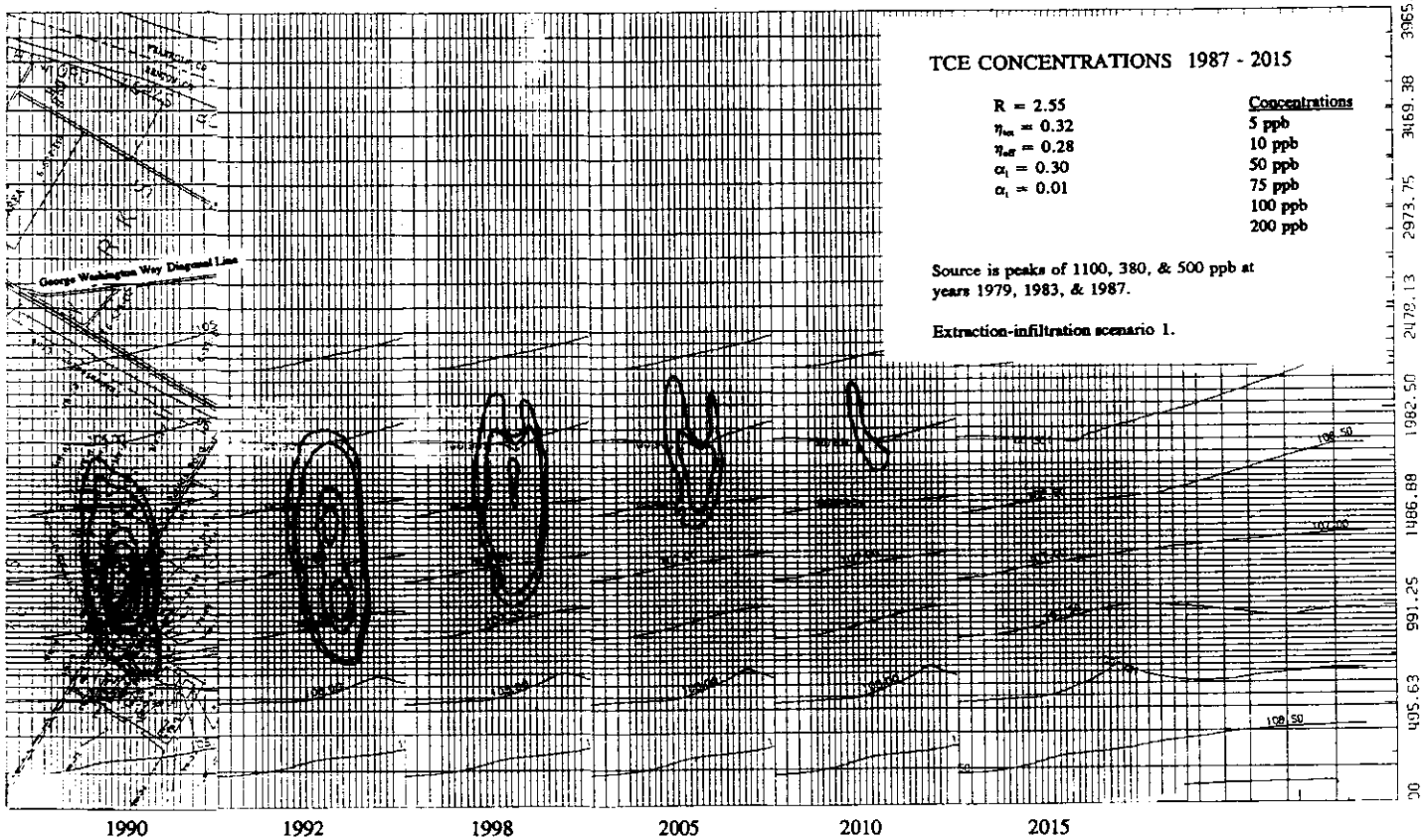
9 3 1 2 7 5 4 7 3 1 9




Computed TCE Plumes for Extraction-Infiltration Scenario 1.

Figure 6-35

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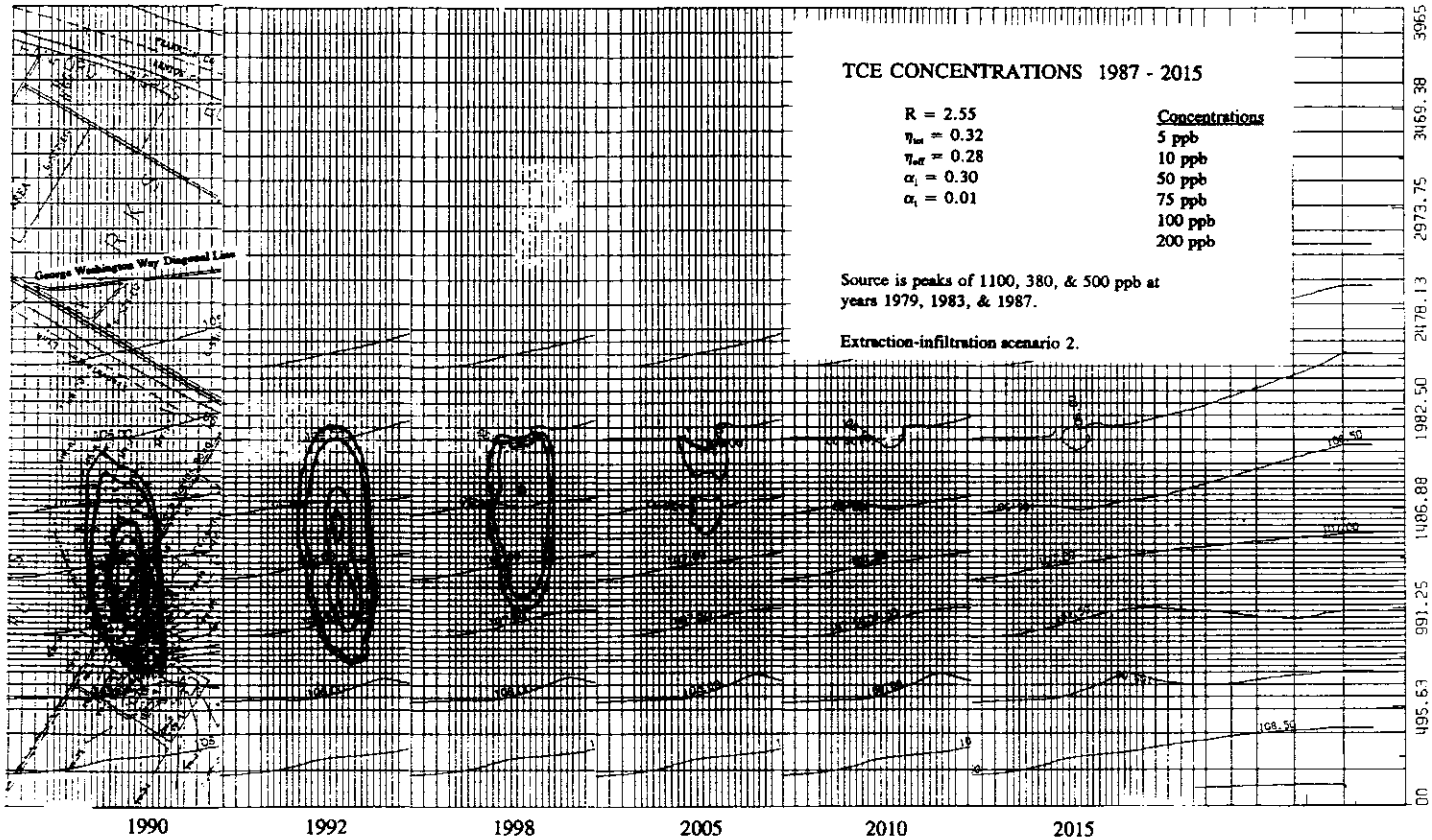


Computed TCE Plumes for
Extraction-Infiltration Scenario 2

Figure 6-36

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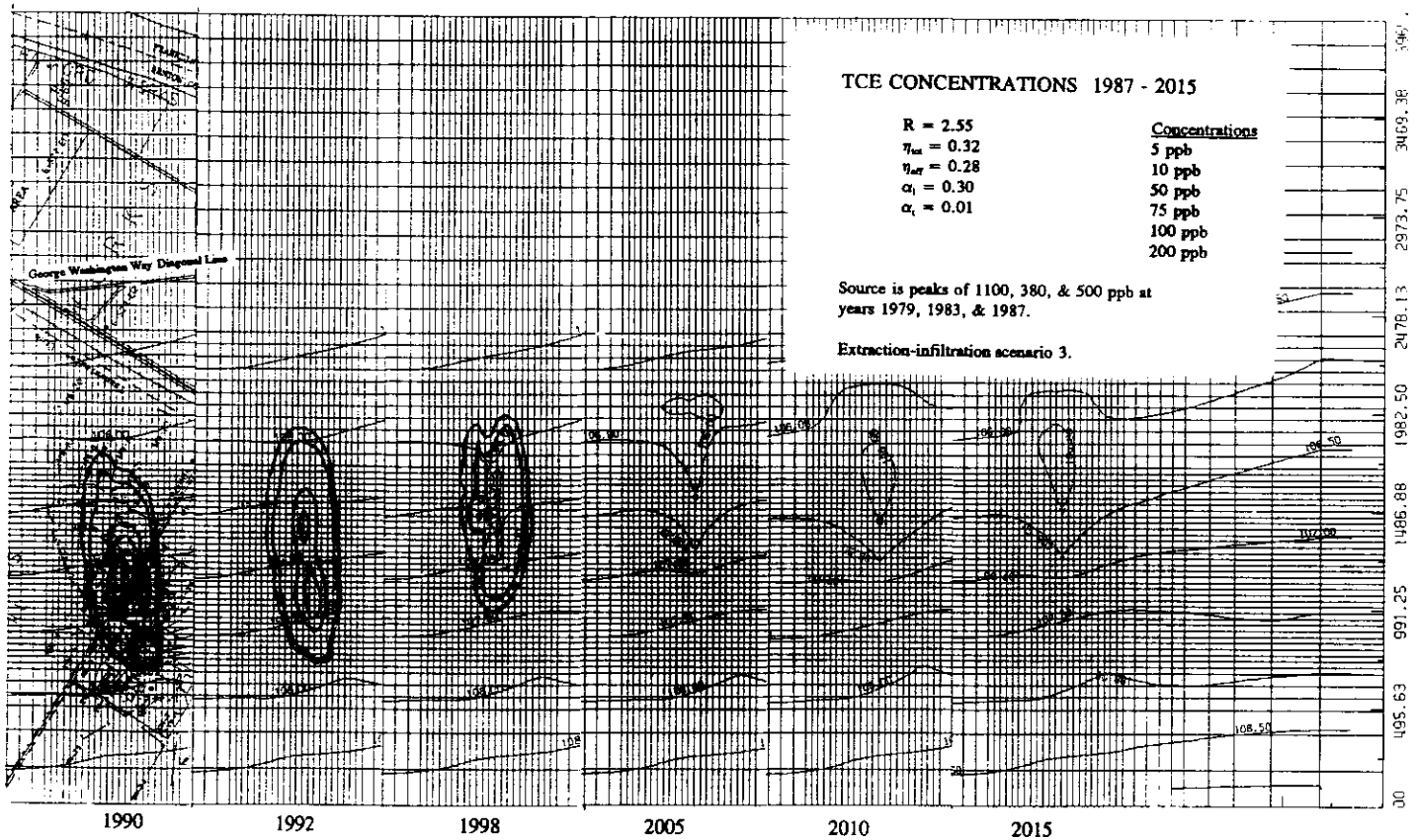


Computed TCE Plumes for Extraction-Infiltration Scenario 3.

Figure 6-37

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

| | Start of Operation | Treatment Rate,# Wells | Predicted End of Operation | Predicted Date when Conc. < 5 ppb |
|---|---|---|---|---|
| 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

The objectives of this section 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.

## 7.1 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. 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 (section 5 and appendix L).

### 7.1.1 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 potential threat to human health. The NCP requires that the overall incremental cancer risk at a site not exceed the range of 1E-06 to 1E-04. 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 1E-04, 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 under an industrial use scenario. The maximum calculated incremental cancer risk from any one subunit, based on the 95-percent UCL, is 5E-05 for the industrial, and 3E-03 for the residential future scenario. These subunits are:

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

Contaminants detected in soils and identified as posing potential incremental cancer risks to human health at these three subunits include: BEHP at the Discolored Soil Site; PCB's at HRL; and PCB's at the Ephemeral Pool. There were no soil contaminants identified for which a hazard quotient greater than 1 was calculated.

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 for the site because: (1) downgradient users are supplied by Richland's water distribution system, and (2) the Phase I and II RI determined that the North Richland well field is not impacted by the contaminant plume and is not at risk. The

uncontrolled land use future uncertainty assessment using residential exposure indicates a higher risk than the industrial scenario. However, that risk (3E-05) is within the acceptable risk range.

TCE in groundwater was calculated to have an ICR of 3E-05 for the uncertainty risk assessment. Generally, where groundwater is a potential source of drinking water, clean up requirements are set at levels which reduce the ICR to 1E-06 or to MCL's. Because of the uncertain use of the aquifer as a potential source of drinking water in the long term future, TCE was identified as a contaminant of concern. The hazard quotient (HQ) associated with nitrate in the groundwater for the uncertainty risk assessment was calculated to be 0.8. Typically, a contaminant of concern has a HQ of 1 or greater. If nitrate were the lone groundwater contaminant, remedial actions addressing it would not be justified under this scenario. Nitrate in groundwater is considered a contaminant to be addressed in conjunction with remedial actions targeted for TCE. By itself, nitrate in groundwater is not used as an indicator of groundwater contamination nor a driver of a remedial action in this report.

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

### 7.1.2 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.

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

The Phase II RI study looked at the potential for leaching of soil contaminants from the HRL soils to the aquifer. As discussed in section 4 of this report, and in further detail in sections 5.2 and 5.3 of the Phase I RI (DOE/RL-90-18), the potential for migration of inorganic or organic contaminants is minimal. In summary, this conclusion is based on the following factors: the predominantly low concentrations of contaminants in surface and subsurface soils; the infrequency of detection of the contaminants throughout the site; the low rainfall due to the desert climate; the low infiltration rate to the groundwater table identified in section 6 of this report [approximately between 1.04 and 3.46 cm/year (0.41 and 1.36 in/year)]; the hydrophobic nature of the organic contaminants of concern; the low solubility of the inorganic contaminants identified as contaminants of concern; depth to the groundwater table (20 to 25) feet; and the fact that no soil contaminants have been detected at elevated levels in the groundwater monitoring network at the HRL, some 20 years since its closure. Based on these facts, this pathway was not considered under existing land- and water-use conditions.

**7.1.2.2 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).

### 7.1.3 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 (RfD's). While not ARAR's, these chemical-specific advisory levels may factor into the establishment of protective cleanup goals (EPA, 1988).

Location specific ARAR's are requirements based on the physical location, such as a floodplain, where an action may take place. Based on referenced descriptions, there are no cultural resource areas such as archaeologic and/or historic sites; no endangered or threatened species and their critical habitats; nor environmentally important natural resource areas such as floodplains, wetlands, important farmlands, and/or aquifer recharge zones in the areas evaluated for remedial actions. Therefore, potential location specific ARAR's addressing remedial actions at these sites are not pertinent.

Action specific ARAR's are requirements placed on particular remedial actions as they relate to the management of hazardous wastes. Typically these include requirements for transportation, storage, or disposal of hazardous wastes.

The ARAR's and TBC's for the operable unit are comprehensively discussed in appendix M.

### 7.1.4 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 the 1100-EM-1 Area 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 be expected to remain unchanged due to the presence of established commercial and industrial facilities that could be readily utilized by the private sector.

### 7.1.5 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. Those 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).

**7.1.5.1 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.

Selection of the appropriate ARAR's for the determination of these PRG's is discussed in appendix M. In summary, the 1100-EM-1 Operable Unit was determined to meet the industrial criteria set forth in MTCA. Under this scenario, if overall site risks are such that remedial actions are required, PRG's would be based on MTCA Method C requirements. For the Discolored Soil Site and the Ephemeral Pool it was determined that setting PRG's to levels associated with the more stringent MTCA residential requirements was practicable. This determination was based on the following factors: the relatively small volume of material contaminated at each site; the availability of technologies which can attain these cleanup levels; the low risks to remedial workers when instituting these actions; and the possibility of achieving unrestricted closure. For the Discolored Soil Site, the MTCA Method B cleanup goal was determined to be 71 mg/kg for BEHP in soil. For the Ephemeral Pool, because there is only one contaminant of concern, the MTCA Method A cleanup goal of 1 mg/kg of PCB's in soil was evaluated.

For PCB's contaminated soil at the HRL the MTCA Method C cleanup goal of 17 mg/kg was evaluated as a PRG. Reasons for this approach were: the PCB's contaminated area lies within a larger area containing asbestos contamination: the risks to human health and the environment associated with fugitive dust as a result of excavating in asbestos containing soils; and because the possibility of attaining unrestricted closure is minimal due to the past history of the subunit as a landfill.

Appendix M also concludes that the groundwater under HRL is not a current or potential future drinking water source and meets the MTCA criteria to disqualify it as such. However, the goals put forth in EPA and MTCA guidance are to return usable groundwaters to their beneficial uses in a timeframe that is reasonable given the particular circumstances of the site. PRG's for groundwater were based on the most stringent of applicable Federal or state requirements, which were determined to be SDWA MCL's. MCL's for TCE and nitrate as nitrogen are 5 $\mu$g/l and 10 mg/l, respectively. The points or alternate points of compliance with MCL's will be as determined by EPA and Ecology. Proposed points of compliance are discussed in section 8.0 as part of the selection of alternative remedies.

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.

**7.1.5.2 Remediation Timeframe.** Soil and groundwater remediation will generally be accomplished in timeframes that are appropriate for the risks associated with 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 were not 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 given the particular circumstances.

### 7.1.6 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 exceeding ARAR's. All RAO's 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.

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.

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.

- **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.

b. Prevent inhalation of fugitive dust from soils that may contain asbestos fibers.

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.

### 7.1.7 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 through existing institutional controls and the use of the domestic water supply system.

## TABLE 7-1. RESIDUAL RISKS ASSOCIATED WITH SOIL PRG's (INDUSTRIAL SCENARIO)

| 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.

## TABLE 7-2. RESIDUAL RISKS ASSOCIATED WITH GROUNDWATER PRG's (RESIDENTIAL SCENARIO)[1]

| 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.

b. Attain the SDWA MCL of 5 $\mu$g/l for TCE at the designated point of compliance. The point of compliance is to be defined by EPA and Ecology. Monitoring for compliance will be performed at the defined point.

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.

### 7.1.8 Residual Risks Post-Achievement of PRG's

Residual risks after meeting PRG's were calculated based on the industrial land use scenario for soils and the uncertain residential land use scenario for groundwater. These risks 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 3E-05 based on the 95-percent UCL to 2E-06 for a 93-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.

## 7.2 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 7.3 and section 8.0. The following paragraphs describe the general response actions, and include identification of areas and volumes of contaminated soils and groundwater.

### 7.2.1 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. It should be noted that there is a significant amount of uncertainty in any volume calculation which relies on limited soil sampling results. Further compounding the uncertainty at this operable unit is the fact that the majority of samples taken were surface samples; there is very little information concerning the depth of the contaminants. However, because of the insoluble nature of the contaminants of concern and their presumed origin, contamination is expected to be confined to near surface soils. The areal extent of contamination at all subunits used in the following estimates were conservatively assumed by either setting the boundaries of the contaminated areas at sample locations at which no contaminant was detected, or by extrapolating from sample locations at which contaminants were detected to points at which the level of contamination was presumed to be zero. For groundwater, the estimates are based on modelling results that used Phase I and II RI groundwater sampling results as input.

**7.2.1.1 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 origin of the PCB contamination at the Ephemeral Pool is unknown. The PCB contamination at 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 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 $m^3$ (440 $yd^3$).

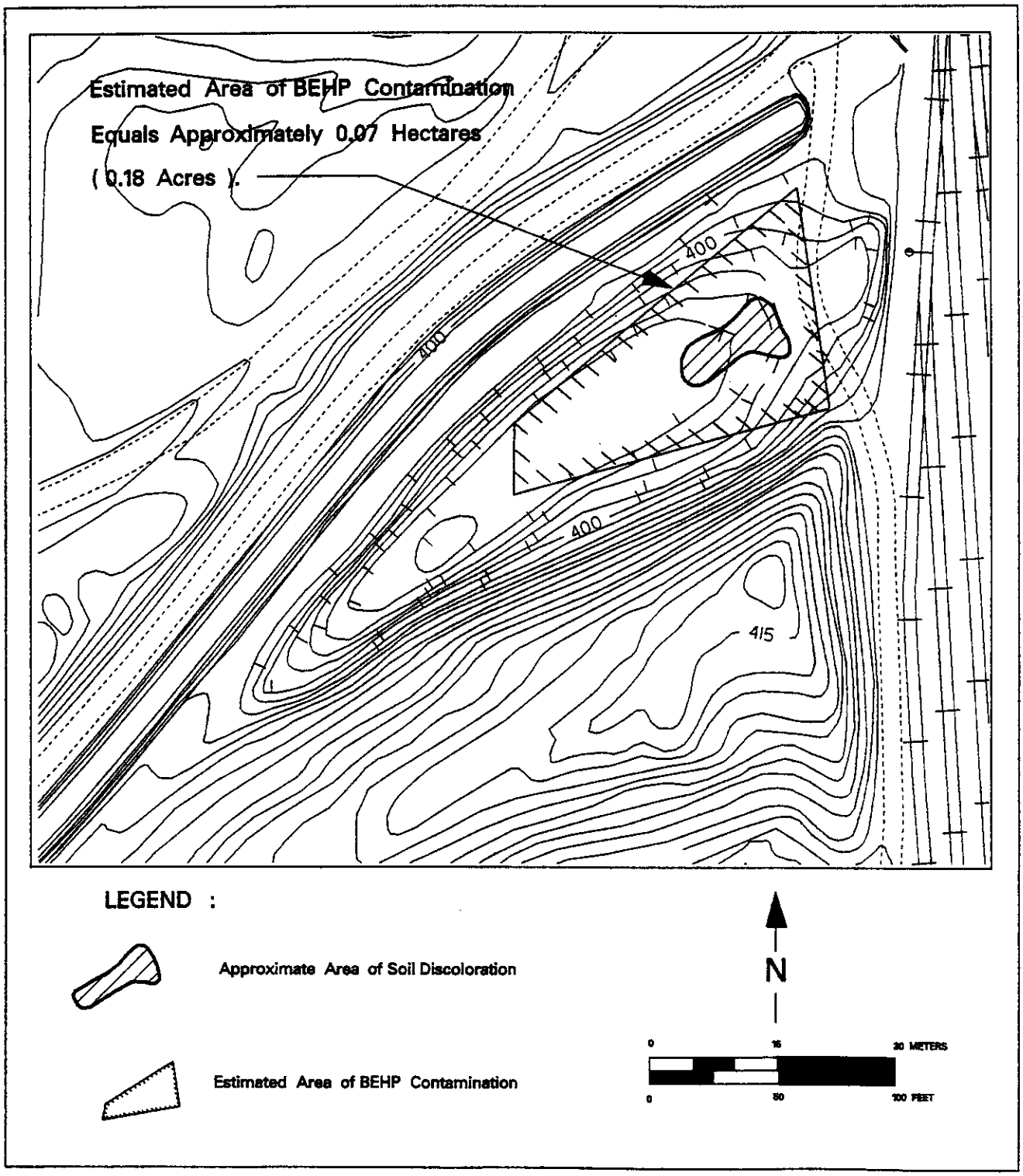



Figure 7-1. Estimated Area of BEHP Contamination at the UN-1100-6 Operable Subunit

- 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). Because no PCB's contamination was detected at location 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) amsl. 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. 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 $m^3$ (340 $yd^3$).

- HRL--HRL was investigated in both the Phase I and Phase 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 boring, along the diagonals of the sampled area, to a point where PCB concentrations would be zero. Using the most conservative of these extrapolations, the contaminated area is 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 $m^3$ (600 $yd^3$).

### 7.2.2. Extent and Volume of Groundwater Contamination

The source of groundwater contamination at and downgradient of the HRL is believed to have originated from activities conducted offsite. The present length and width of the TCE plume is 1.6 km (1 mi) and 0.3 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 (1.3 mi) and its width is also 0.8 km (0.2 mi). The TCE and nitrate plumes are shown in figure 6-12 of section 6.0.

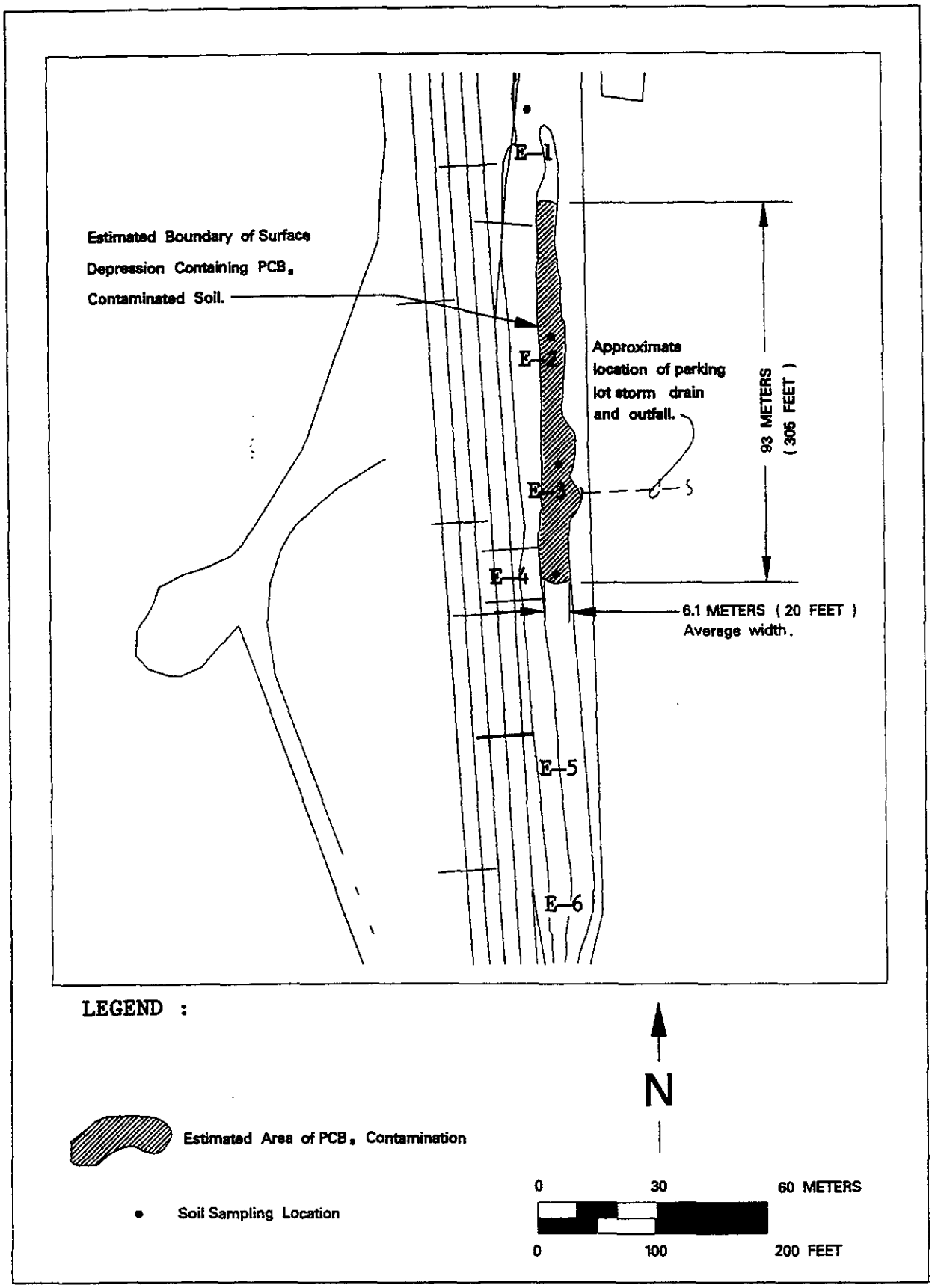
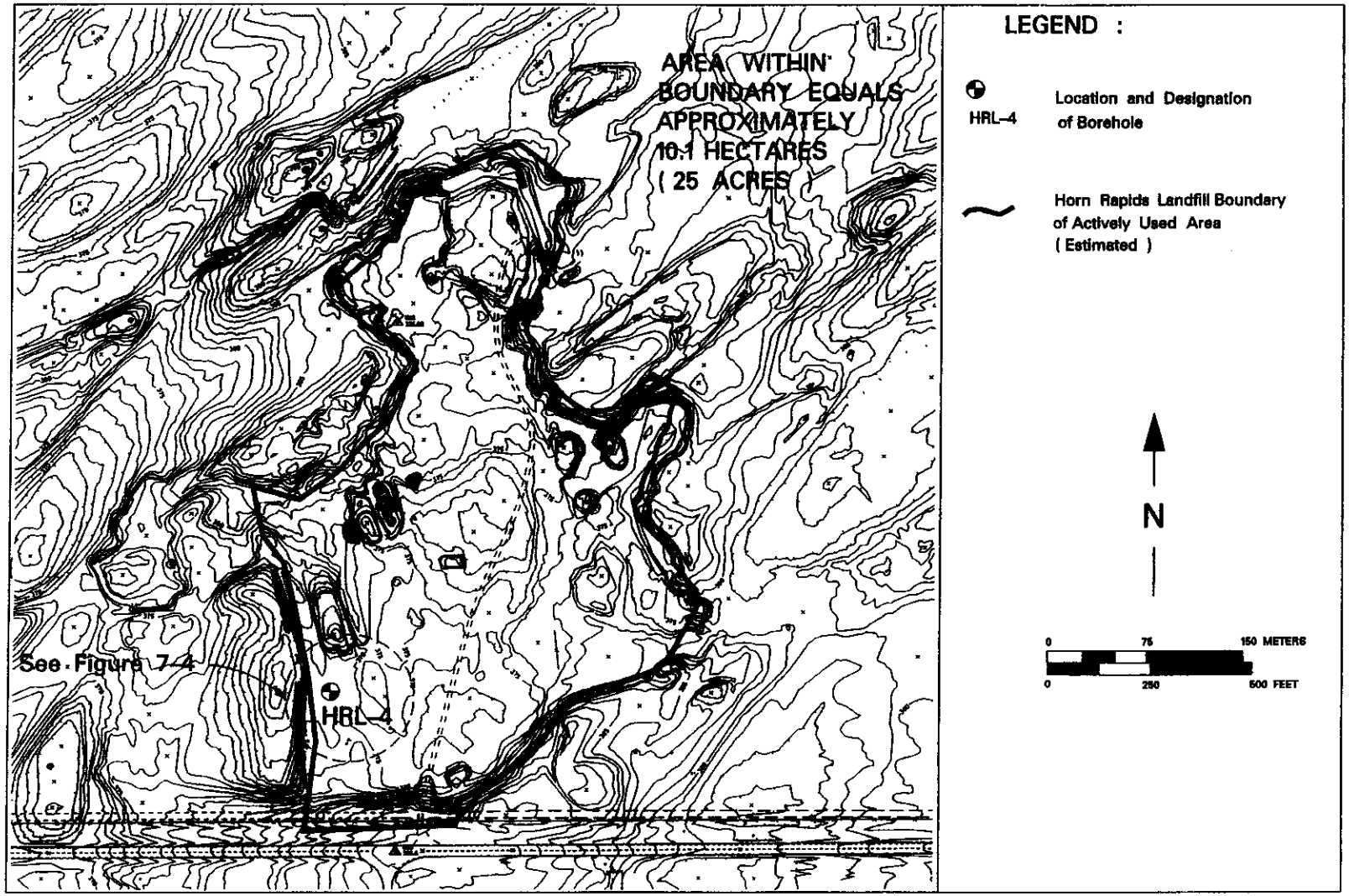
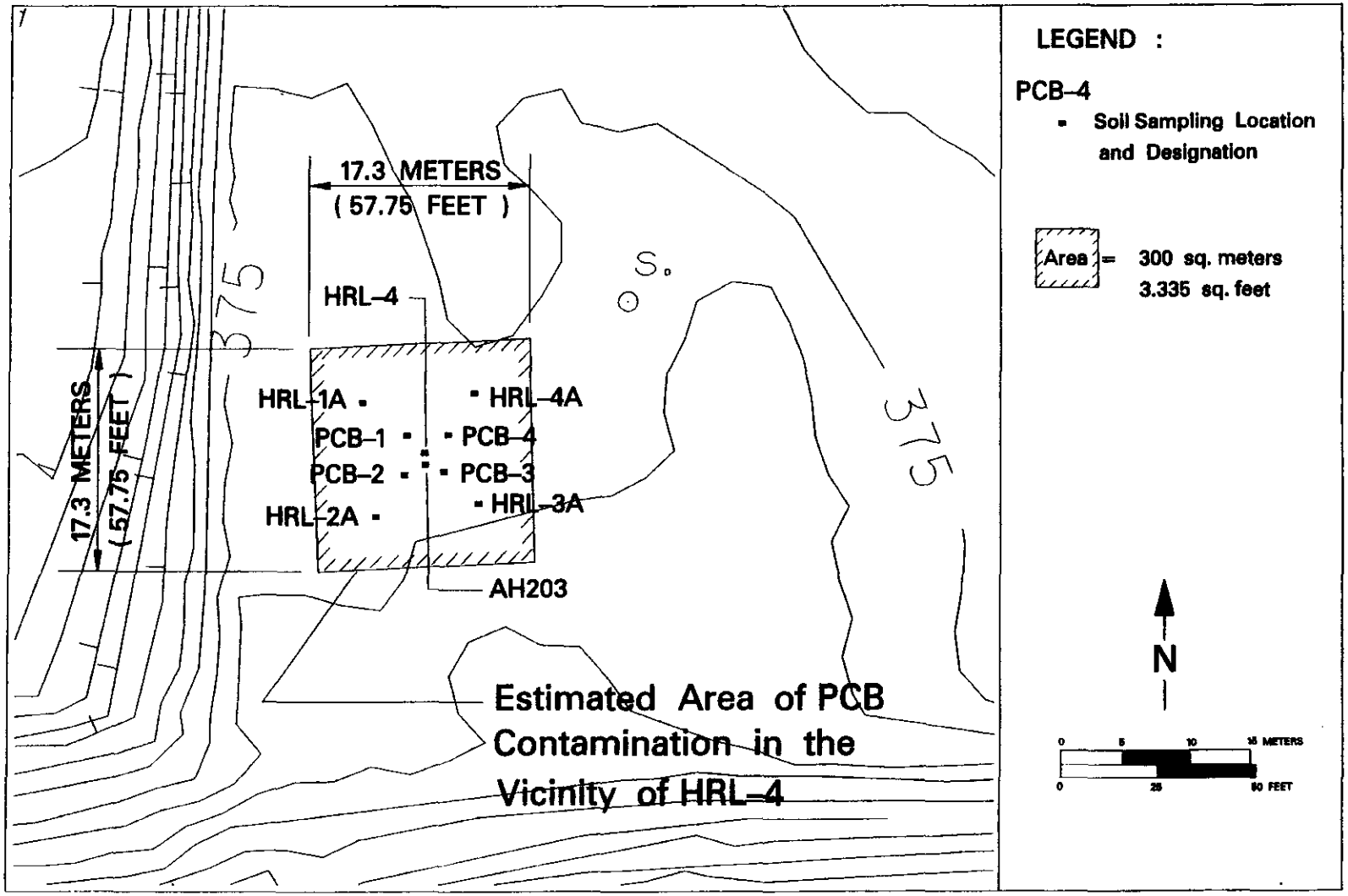



Figure 7-2. Estimated Area of PCBs Concentration at the Ephemeral Pool Operable Subunit.




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

Figure 7-3.




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

Figure 7-4.

### 7.2.3 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 7.1. 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 Discolored Soil Site, the Ephemeral Pool, HRL, and the groundwater beneath the HRL, and are discussed in paragraphs 7.2.3.1 through 7.2.3.6.

**7.2.3.1 No Action.** This alternative is required by the NCP and has been retained for baseline 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 and L).

**7.2.3.2 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.

**7.2.3.3 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.

**7.2.3.4 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.

**7.2.3.5 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.

**7.2.3.6 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.

## 7.3 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 is used as a basis for screening. This information includes contaminant types, concentrations, and volumes, and site soil and hydrogeological characteristics.

The Phase I and II FS's (DOE/RL-90-32) initially developed alternatives for remedial actions at the Discolored Soil Site and the HRL. Contamination at the Ephemeral Pool and of groundwater beneath the HRL was not addressed. For the Discolored Soil Site, alternatives that were retained included no action, institutional controls, excavation and treatment by incineration, and in-situ biological treatment. For the HRL, no action, institutional controls, excavation and treatment by incineration, dechlorination, or stabilization, and excavation and offsite disposal were the alternatives retained. The process options that comprise these alternatives are reevaluated in this report.

Technology types and process options are selected within each general response action to satisfy the remedial action objectives for the site. Appropriate 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).

### 7.3.1 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.

### 7.3.2 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.

## 7.4 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.

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



| 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 for all subunits. |
| | | Deed Restrictions | Change of ownership deeds would require limitations on future land uses. | Potentially feasible for all subunits. |
| | | Excavation Restrictions | Existing and future landowners would be restricted in new subsurface construction or excavation. | Potentially feasible for all subunits. |
| | | Fences | Access to contaminated soil sites would be restricted by use of fence. | Potentially feasible for all subunits. |
| | Monitoring | Groundwater Monitoring | Sample and test groundwater on a regular basis. | Potentially feasible for all subunits. |

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



| 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 for all subunits. |
| | | MSWLF Cap | Cap complying to the Washington Administrative Code (WAC) for closure of municipal solid waste landfills (MSWLF) in arid regions. | Potentially feasible for all subunits. |
| | | Asbestos Cap | Cap complying to the code of Federal regulation for closure of landfills containing asbestos. | Potentially feasible for HRL. |
| | 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 at HRL. Not feasible due to small volumes of material at the Discolored Soil Site and Ephemeral Pool. |
| | Vertical Barriers | 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 at HRL. Not feasible due to small volumes of material at the Discolored Soil Site and Ephemeral Pool. |

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



| 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 at all subunits. |
| | Thermal Treatment | Rotary Kiln Incinerator | Slightly inclined, refractory-lined cylinder used for the controlled combustion of organic waste. | Potentially feasible for PCB's and BEHP contaminated soils. |
| | | 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 PCB's and BEHP contaminated soils. |
| | | 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 PCB's and BEHP contaminated soils. |
| | | 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 for all subunits. |

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



| 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. Effectiveness on PCB's and BEHP contaminated soils 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 contaminated soils. 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 contaminated soils. |
| | | Supercritical $CO_2$ Extraction | Organics are extracted from contaminated soils by mass transfer to supercritical $CO_2$. | Potentially feasible for PCB's and BEHP contaminated soils. |
| | | Soil Washing | Mechanical processes are used to separate particles that contain contaminants. | Potentially feasible for PCB's and BEHP contaminated soils. |

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



| 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 contaminated soils. |
| | | Anaerobic | Cosubstrate is introduced to stimulate anaerobic bacteria to degrade contaminants. | Potentially feasible for PCB's and BEHP contaminated soils. |
| | Disposal | Onsite | Treated soils exhibiting no hazardous characteristics redeposited onsite. | Potentially feasible for all subunits. |
| | | Offsite | Treated soils meeting RCRA BDAT criteria deposited in hazardous waste landfill. | Potentially feasible for all subunits. |
| 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 PCB's and BEHP. |
| | | In Situ Vitrification | Electrodes are placed in contaminated soils and resistive heating melts soil and forms stable glass. | Not feasible for nonhomogenous landfill soils at HRL or shallow contaminated soils at the Discolored Soil Site and Ephemeral Pool. |

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



| 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 for all subunits. |
| | | Surfactant Enhanced Soil Washing | Surfactant solution is percolated through soil column to expedite removal of contaminants. | Not feasible due to areal extent of contamination at HRL and small volumes of material at the Discolored Soil Site and the Ephemeral Pool. |
| | 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 contaminated soils. |
| | | Anaerobic | Cosubstrate and nutrients are introduced to subsurface and anaerobic bacteria are stimulated to degrade chlorinated organics. | Potentially feasible for PCB's and BEHP contaminated soils. |

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<br>Deed Restrictions<br>Excavation Restrictions<br>Fences |
| | Monitoring | Groundwater Monitoring |
| Containment | Capping | RCRA Cap<br>MSWLF Cap<br>Asbestos Cap (HRL only) |
| Excavation/Treatment/Disposal | Excavation | Earth-Moving Equipment |
| | Thermal Treatment | Rotary Kiln Incinerator<br>Infrared Incinerator<br>Circulating Fluid Bed Incinerator<br>Vitrification |
| | Chemical Treatment | Dechlorination (PCB's contaminated soils only)<br>Fixation/Stabilization |
| | Physical Treatment | Solvent Extraction<br>Supercritical $CO_2$ Extraction<br>Soil Washing |
| | Biological Treatment | Aerobic<br>Anaerobic |
| | Disposal | Onsite<br>Offsite |
| In Situ Treatment | Chemical Treatment | Fixation/Stabilization |
| | Biological Treatment | Aerobic<br>Anaerobic |

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



| 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. |

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



| 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. |

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



| 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. |

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. |

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. |

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.) | 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. |
| | | Supercritical Fluid Extraction | Supercritical fluid 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. |

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.) | 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 for TCE. |

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.) | 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. |

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. | Not feasible. Diluted wastewater could potentially upset offsite sewage treatment system. |
| | | 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. |

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



| 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. | Not applicable due to low concentration of TCE. |
| | | 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. |

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<br>Ion Exchange (nitrates only)<br>Reverse Osmosis<br>Ozonation (TCE only)<br>Ultraviolet Radiation (TCE only)<br>Electrodialysis (nitrates only) |
| | Access Restrictions | Administrative Controls<br>Deed Restrictions |
| | Monitoring | Monitoring Wells |
| Containment | None Remaining After Screening | Not Applicable |
| Extraction/Treatment/ Discharge | Extraction | Deep Wells<br>Ejector Wells<br>Enhanced Extraction |
| | Physical Treatment | Adsorption (TCE only)<br>Air Stripping (TCE only)<br>Steam Stripping (TCE only)<br>Reverse Osmosis<br>Electrodialysis (nitrates only) |
| | Chemical Treatment | Chemical Oxidation (TCE only)<br>Ultraviolet Radiation/Photolysis (TCE only)<br>Irradiation (TCE only)<br>Ion Exchange (nitrates only) |
| | Biological Treatment | Aerobic<br>Anaerobic<br>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<br>Reuse/Recycle<br>Recharge |
| In Situ Treatment | Physical | Aeration (TCE only)<br>Heating (TCE only) |
| | Biological | Aerobic<br>Anaerobic<br>Aerobic/Anaerobic |

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.

A detailed narrative evaluation of each of the process options is provided in the following paragraphs.

## 7.5 SOIL PROCESS OPTIONS EVALUATION

Remaining process options for the remediation of contaminated soils are evaluated in the following paragraphs.

### 7.5.1 No Action

This alternative is required under the National Contingency Plan and is retained for comparison with other alternatives. Under this alternative, the site soils will not be disturbed and groundwater monitoring of existing wells in the Horn Rapids Landfill (HRL) would be continued to determine if potential downward percolation of soil contaminants is affecting groundwater quality. Groundwater monitoring is considered an "institutional control."

This alternative would not be effective in reducing the short- and long-term risks to human health and the environment. Risks would remain the same as those identified in the baseline risk assessments. Implementation of the plan would be difficult because applicable or relevant and appropriate requirements would not be achieved. The cost of this alternative would be low.

### 7.5.2 Institutional Controls

Institutional controls are actions which protect human health and the environment and assure continued effectiveness of a response action. These actions would prevent exposure to contaminated soils for onsite workers and would ensure that the contaminants are not migrating offsite. Access restrictions and long-term monitoring are the institutional controls considered.

**7.5.2.1 Access Restrictions.** Access controls are measures that would restrict the access to or activity in the contaminated areas. Administrative controls such as land use zoning could be utilized to restrict the use of the land. Currently, the 1100-EM-1 Operable Unit is zoned for industrial use and this land use is anticipated to continue for at least the next 20 years (appendix J). Administrative controls are retained as an option for at least the near-term future.

Restrictions limiting land use could be attached to deeds if and when the Department of Energy (DOE) relinquished ownership of parts or all of the sites. Similarly, excavation restrictions would prevent future land owners from engaging in construction activities that would disturb the sites. These restrictions are usually not effective because they are difficult to enforce. Also, they are not implementable because it is the policy of the Federal government to dispose of only those properties which have unrestricted use. Therefore, each operable subunit must be fully remediated before it can be disposed of and the need for deed restrictions would be eliminated. For this reason, deed and excavation restrictions are not considered further.

Perimeter fencing at the sites would be effective in restricting public access and reducing the potential for exposure. Fencing is readily implementable with moderate capital and low operation and maintenance (O&M) costs. Fencing is a viable process option which may be used in combination with other alternatives and is retained for consideration.

**7.5.2.2 Monitoring.** Monitoring of groundwater may be required whether or not remedial actions are taken. This option is used in combination with all remedial alternatives for which contaminants remain onsite and is carried forward to be evaluated in the alternative selection process.

### 7.5.3 Containment

Capping is the only containment option which is retained after initial screening. Because of the limited areal extent and volume of the contaminated material at the Discolored Soil Site and the Ephemeral Pool subunits, containment options at these sites were not considered. Capping is only considered as an option at the HRL subunit. A final capping system would prevent direct contact with soils and emissions of fugitive dust and/or to minimize any long-term potential for migration of liquids (leaching potential) through the contaminated soil site

The Resource Conservation and Recovery Act (RCRA) cap requirement (EPA, 1989d) is a multi-layered system consisting of:

- A top layer of at least 60 cm (2 ft) of soil, either vegetated or armored at the surface;
- A granular or geosynthetic drainage layer with a hydraulic transmissivity of no less than 3E-05 $cm^2$/sec (0.0209 ft/day); and,
- A two-component low-permeability layer comprised of 1) a flexible membrane liner installed directly on 2) a compacted soil component with an hydraulic conductivity no greater than 1E-07 cm/sec (0.003 ft/day).

The Washington Administrative Code (WAC) allows a municipal solid waste landfill (MSWLF) cap of reduced design for installations in arid regions such as Hanford [< 18 cm (7 inches) rainfall per year]. This cap would consist of:

- A top layer of at least 15 cm (6 inches) of soil;
- An impermeable layer consisting of a 50 mil thick geomembrane.

Installation of either cap would be effective in minimizing infiltration. The RCRA cap also provides a means for collecting water that is able to penetrate the cap. The potential for leaching of contaminants to the groundwater would be minimal for either option. However, the contaminants of concern at the Discolored Soil Site (BEHP), Ephemeral Pool (PCB's), and the HRL (PCB's) are generally insoluble and are tightly bound to the soil. As stated in paragraph 7.1.2.1, the existing potential for vadose zone contaminant migration to the aquifer is considered minimal. Caps designed to limit infiltration are not a remedial action objective. Of these two caps, only the MSWLF cap is retained for further evaluation in the alternative selection process to provide a conservative containment option that addresses uncertainty.

An alternate landfill closure option has been used at many sites that contain wide areas of contaminated soils at low concentrations, such as found at the HRL. For these closures, cover requirements are less stringent because the wastes being contained do not pose a threat to groundwater. Direct contact and fugitive dust threats can be adequately addressed with a soil cover. Long term management at these sites would include site and cover maintenance, access controls, land use restrictions, and long term monitoring. At sites where RCRA requirements for closure are "relevant and appropriate", these hybrid closure requirements can be used (53 FR 51446 and EPA, 1988b).

One such option that would meet these hybrid closure requirements is a cap designed to prevent the emission of fugitive dust containing asbestos from the HRL. For inactive disposal sites containing asbestos, minimum cap requirements are either (40 CFR 61):

(1) A compacted 15 cm (6-inch), non-asbestos-containing soil cover with an established and maintained vegetative cover; or

(2) A compacted 60 cm (2-foot), non-asbestos-containing soil cover maintained to prevent exposure to asbestos-containing soil; or

(3) A compacted 15 cm (6-inch), non-asbestos-containing soil cover with an additional 3-inch layer of non-asbestos-containing crushed rock to prevent erosion.

All the above options would be effective in minimizing fugitive dust emission. Option (1) would not be implementable because of the desert environment. Options (2) and (3) are both implementable with the cost of each being comparable and moderate. To simplify future alternative evaluations, option (2) will be carried forward.

### 7.5.4 Excavation/Treatment/Disposal

The excavation/treatment/disposal general response action encompasses all process options to remediate the contaminated soil sites ex situ. These are discussed in the following sections.

**7.5.4.1 Excavation.** Excavation of soils for processing will be done using conventional earthmoving equipment (backhoes, front-end loaders, dump trucks). This method is effective and implementable. A key consideration will be the control of fugitive dust during these operations to prevent short-term risks to onsite remediation workers. Safety precautions, such as the use of respirators, protective clothing and the misting of soil for dust control, may be required. The cost of the operations may increase substantially based on the level of protection determined to be protective of human health. This option is retained for further consideration.

**7.5.4.2 Thermal Treatment.** Thermal treatment processes use high temperatures to thermally destroy organic contaminants. Four thermal process, three of which are incinerators, were retained after initial screening and are discussed further in the following paragraphs.

7.5.4.2.1 Incineration--Rotary kiln incinerators are slightly inclined, refractory-lined cylinders used for the controlled combustion of organic waste under net oxidizing conditions (EPA, 1991b, and EPA, 1991c). Wastes and auxiliary fuel are fed into the high end of the kiln and passed through the combustion zone by gravity. Turbulence is created by the rotation of the combustion chamber and improves burnout of the solids. Organics which may volatilize and reside in the gases are destroyed in a secondary combustion chamber. Residuals from this process include ash, flue gases, and brine solution from the ash quench, and wet scrubber.

Infrared processing systems use electrical resistance heating elements or indirect fuel-fired radiant U-tubes to generate thermal radiation beyond the red end of the visible spectrum

(EPA, 1991b and EPA, 1991c). Waste is fed into the combustion chamber by conveyor belt and exposed to the radiant heat. Exhaust gases are passed through a secondary combustion chamber. Residuals are the same as those for the rotary kiln incinerator.

Circulating fluidized bed incinerators use high air velocities to suspend and circulate fuel/waste particles in a refractory-lined combustion vessel (EPA, 1991b and EPA, 1991c). Fluidized beds can be operated at lower temperatures than other incinerators because the increased turbulence aids combustion. Flue gas is separated from heavier particles in a solids separation cyclone. Limestone is used to capture acid gases, thus eliminating wet scrubbers and one of the residual process waste streams.

The effectiveness of each of these incinerators in destroying organic contaminants is demonstrated by removal efficiencies of greater than 99.9 percent (EPA, 1991). Based on the 95 percent upper tolerance limit concentrations of 18,000 mg/kg BEHP at the Discolored Soil Site, 15 mg/kg PCB's at the Ephemeral Pool, and 38 mg/kg PCB's at the HRL, residual concentrations in incinerator ash would be 18, < 0.1, and < 0.1 mg/kg, respectively, for each operable subunit. These concentrations are well below the remedial action objectives.

Rotary kiln incineration is readily implementable. Soil feed size up to 12 inches in diameter can readily be handled (EPA, 1991). Size reduction would be required for both the fluidized bed and infrared units as they require waste feed material to be less than 2 inches in diameter (EPA, 1991). Soils at the operable subunits typically contain gravels greater than 2 inches in diameter. All processes being equally effective, only the rotary kiln incinerator is retained because it does not require special handling of feed soils. Because of the small volume of contaminated material onsite, a small mobile incineration unit is required. Units which process five tons per day are available at moderate mobilization and O&M costs.

Additional costs may be required for permitting, compliance monitoring and for the disposal of residuals. Also, the public reaction to onsite incineration has not always been favorable at other sites and the public may not accept this process option. The process is carried forward to be incorporated into alternatives, however, because it is proven effective in destroying the organic contaminants of concern.

7.5.4.2.2 Vitrification--A Joule heated ceramic melter is used to vitrify soils at temperatures up to 1500° C (2700° F). Organic contaminants present in the feed stream are destroyed by pyrolysis and/or combustion at these high operating temperatures (PNL, 1988). Final system design can assure effective destruction of BEHP and PCB's in the soil. Any inorganic contaminants in soils from the HRL would be incorporated into the glass matrix of the final product and isolated from the environment upon final disposal.

Waste materials and glass frit are fed into a high-temperature furnace where the organics decompose and any residual oxides and ash material melt to form a glass product. The glass frit typically consists of silica, soda ash, and lime. Contaminated soils are fed either on top of or below the molten glass surface of the melter. Waste particles undergo pyrolysis and organics are thermally degraded. Off gases are readily burned in the plenum space or in a secondary combustion chamber. The molten mixture is discharged into

disposal containers or quenched in water to produce a granular product for bulk disposal (PNL, 1988).

The process is not readily implementable because the technology is not yet mobile. Pacific Northwest Laboratories (PNL) had planned to construct a mobile unit that could process five tons of contaminated soils per day but the project was suspended (PNL, 1992). An engineering scale vitrification plant is planned in the 300 Area, which will process 250 kg/day. This system will be permitted to process up to 1,000 kg of waste from any source. This facility could possibly be used to process a small quantity of these contaminated soils as a demonstration of the effectiveness of the technology.

If a fixed vitrification plant were operating and readily available, the cost of treatment would be moderate. However, because the technology is not yet on-line, this process option is not considered further. Vitrification should be revisited in the design phase if the DOE decides to proceed with a site-wide vitrification plant for the treatment of hazardous waste.

**7.5.4.3 Chemical Treatment**--Dechlorination and stabilization/solidification were the chemical treatment processes retained after initial screening and are evaluated further here.

7.5.4.3.1 Dechlorination--Chemical dechlorination is the process by which hazardous chlorinated wastes are destroyed or detoxified by substitution of the contaminant chlorine atoms with other atoms (predominantly hydrogen). This process is potentially effective for the treatment of PCB's. Contaminated soils are heated and mixed with an alkali metal hydroxide-based polyethylene glycol reagent in a mobile batch reactor (EPA, 1991).

Soils are first processed by screening to remove the large rocks and debris in order to avoid jamming of the reactor mixer blades. Reagent is then mixed well with the soil in the reactor to obtain efficient treatment. The mixture is heated to between 100° and 180° C and reactions are carried out for 1 to 5 hours depending on the type, quantity, and concentration of the contaminants. The treated mixture is then processed in a separator where the reagent is removed and recycled (EPA, 1991c).

Vaporized water resulting from the reaction is condensed and collected for further treatment or recycled through the washing process. Carbon filters are used to capture volatile organics that are not condensed. The treated soil is washed and neutralized by the addition of acid, dewatered, and then disposed of onsite if regulatory requirements are met.

A key process residual that may effect the overall cost of the treatment is the waste washwater. Typically, this residual contains only trace amounts of contaminants and reagents, and is expected to meet discharge standards that would allow it to be discharged to a publicly-owned treatment works. If the washwater does require treatment, typical methods are carbon adsorption, chemical oxidation, biodegradation and/or precipitation.

Field performance data suggests that dechlorination is effective in reducing PCB concentrations to below 2 parts per million (ppm) in treated soil (EPA, 1991b and EPA, 1990c). Initial soil concentrations cited were much higher than the PCB concentrations at the

1100-EM-1 Operable Unit. It is expected that by adjusting batch mixing time, temperature, and reagent ratio, soils can be treated to below the 1 ppm level.

The process is readily implementable with a number of vendors able to provide treatment units. Costs are moderate in comparison to other technologies which treat PCB's (*i.e.*, incineration). However, information from one vendor suggests that these systems are cost effective only when at least 10,000 tons of soil are processed (Galson, 1992). Because of the limited amount of material to be processed at the site, dechlorination as an innovative and cost-effective technology is not carried forward in the evaluation process.

7.5.4.3.2 Stabilization/Solidification--Stabilization and solidification processes achieve one or more of the following results (EPA, 1986):

- Improve the handling and physical characteristics of the waste;
- Decrease the surface area of the waste mass across which transfer or loss of contaminants can occur; and/or,
- Limit the solubility of any hazardous constituents of the waste such as by pH adjustment or sorption phenomena.

Stabilization limits the solubility or mobility of the contaminants without necessarily changing the physical characteristic of the waste. The process usually involves the addition of a reagent that maintains the hazardous contaminant in its least mobile or toxic form.

Solidification produces a solid block of waste material with high structural integrity. The contaminants are mechanically locked in the solidified matrix. Migration of the contaminant is limited by the reduction of surface area exposed to the environment and/or by isolating the contaminants by microencapsulation.

Typically, portland cement and pozzolan materials (*e.g.*, fly ash) are blended with contaminated soils to produce a stronger waste/concrete composite. Contaminants are contained in the concrete matrix by microencapsulation. Other reagents are also used; however, most reagents have been found to be ineffective in immobilizing organic constituents (EPA, 1990b). A 1988 evaluation of a proprietary reagent gave inconclusive evidence on its ability to immobilize PCB's (EPA, 1990b).

While this process option is readily implementable at a moderate cost, its effectiveness in stabilizing the organic soil contaminants is questionable. The process is proven to be effective in immobilizing metals. Because leaching of contaminants to the groundwater aquifer at the HRL is not a pathway of concern at this site, stabilization/ solidification methods are not pursued further.

**7.5.4.4 Physical Treatment.** Physical treatment processes involve the separation of the contaminant from the soil. Three process options were retained after initial screening and each is evaluated further here.

7.5.4.4.1 Solvent Extraction--In this process, hazardous contaminants are extracted from soils using an organic solvent. A solvent, which preferentially removes organic contaminants, is mixed with contaminated media, and transfer of the contaminants from the media to the solvent phase occurs. A change in temperature or pressure is then used to separate the contaminant from the solvent. This process is one of waste reduction; contaminants are not destroyed but are concentrated in their liquid forms. This concentrate will require further treatment. Processed soils can be redeposited onsite if they meet regulatory criteria.

The process has demonstrated effectiveness in removing PCB's from sediments at an efficiency rate of between 84 to 98 percent (EPA, 1991). It should be noted that removal efficiencies increased with the increase in number of passes made through the reactor. It is reasonable to expect that 99 percent removal efficiencies can be achieved; however, the costs associated with this level of treatment will be comparatively high. The effectiveness of the process on BEHP removal is not proven, but the process is demonstrated to be effective on nonhalogenated semivolatile compounds.

The process is readily implementable with a number of vendors who are able to provide treatment units. Special material handling is required because units can only process materials 1/8 to 1 inch in diameter.

Because of the many passes required to increase removal efficiencies, the material handling considerations, and the requirement for post treatment of the extract, the cost of solvent extraction relative to other treatments for the small amount of contaminated soil is high. For these reasons, solvent extraction is not considered further.

7.5.4.4.2 Supercritical CO2 Extraction--This extraction process uses supercritical carbon dioxide as the solvent to extract organic constituents from soils. The process operates at the critical temperature and pressure of carbon dioxide. At these conditions, carbon dioxide is at its critical density. The process is extractive and further treatment of the extract is required to destroy hazardous contaminants.

Near the critical point, the density of a supercritical fluid is typically $10^2$ to $10^3$ times greater than that of the gas at ambient temperatures. By increasing the density, the solvent strength of the supercritical fluid increases. Because carbon dioxide has a low critical temperature (31.1°C), extractions are performed at thermally mild conditions and the soil structure is not destroyed. Also, because carbon dioxide is a gas at room temperature, concentration of the extract is simplified.

Supercritical fluids have higher solute diffusivities than solvents used in conventional extraction techniques. Thus, removal efficiency is increased. This eliminates the multiple passes required in conventional systems.

The Westinghouse Hanford Corporation (WHC) has recently completed initial bench scale studies evaluating this process (WHC, 1992b). In these studies, contaminated soils from the UN-1100-6 and from the HRL were used. Preliminary results indicate that BEHP can be extracted from the UN-1100-6 soil at efficiencies of about 97 percent. While this is

not sufficient to remediate soils to meet Model Toxics Control Act levels, these results are encouraging. Further bench scale studies that alter either the pressure or temperature under which the reactions are carried out will be conducted to determine optimal removal efficiencies. Removal efficiencies for the HRL soils containing PCB's were greater than 99 percent.

Although this technology is not yet available on a full scale for soil remediation, it is carried forward to the next step in the process because it is an innovative technology.

7.5.4.4.3 Soil Washing--Soil washing is a volume reduction process used for pretreatment. The process is applicable to contaminants that are concentrated in the fine fraction of the soil (silt, clay, and soil organic matter) and to contaminants associated with the coarse soil fraction (sand and gravel), which are surficial. The goal of this separation process is to concentrate the contaminants in a smaller volume of material separate from a washed soil product. The washed product will meet cleanup standards and can be redeposited at the cleanup site.

Many of the unit processes are common to that of the mineral processing industry. Soils are first screened to remove the large debris (> 2 inches). Process steps can include mixing trommels, pug mills, vibrating screens, froth flotation cells, attrition scrubbing machines, hydrocyclones, screw classifiers, and various dewatering operations (Biotrol, 1992). The soils are mixed with washwaters to remove contaminants from the soil. Sometimes, organic solvents, chelating compounds, surfactants, acids, or bases are used to enhance the extraction of the contaminant from the soil. The soil and washwater are then separated, and the soil is rinsed with clean water resulting in a clean soil as a product. Suspended soil particles in the washwater are recovered as a sludge by discrete settling using gravity or by flocculation through the use of a polymer. This sludge consists of the fine fraction of the original soil and should contain most of the contaminants. The sludge is dewatered and then sent on for further treatment to destroy the contaminants. Processed washwater is usually recycled after biological or physical treatment.

The soil washing process has proven to be effective in reducing the volume of soils contaminated with PCB's. Although not directly cited in literature, its effectiveness for BEHP removal should be similar. Destruction of these contaminants would require additional treatment.

Soil washing would be readily implementable for the soils at the 1100-EM-1 sites. The technology is available from various vendors, and the process has been seen as favorable by the public at other sites.

For sites with a small volume of contaminated soil, the costs of soil washing are high. One vendor reports that for sites with less than 10,000 tons of contaminated soils, the process is not cost effective (Biotrol, 1992). These high costs are only associated with volume reduction of the soils and do not take into account added costs for treatment and destruction of the contaminant. For these reasons, soil washing is deemed not to be cost effective at this site and is not carried forward for further consideration.

**7.5.4.5 Disposal.** Both onsite and offsite disposal options were retained after initial screening and are evaluated further in the following sections.

7.5.4.5.1 Onsite Disposal--Onsite disposal is considered for all soils treated by onsite process options. These soils will be subject to the RCRA Land Disposal Restrictions that require treatment of wastes to the best demonstrated available technology (BDAT) levels prior to land disposal. The ability to meet these requirements is dependent on the treatment process option chosen. In some instances, as in the use of innovative technologies, alternative treatment levels may be selected if a treatability variance establishing these levels is obtained.

The site remediation goal would be to meet BDAT levels and redeposit treated soils at the respective subunits. The treated soils would then be capped with 2 feet of random fill material and regraded. This process is effective in handling treated soils and should not increase risks to human health or the environment. It is easily implementable, has a relatively low cost, and will be considered for inclusion in the remedial action alternatives.

7.5.4.5.2 Offsite Disposal--Soils contaminated with BEHP are land banned under the third-third RCRA Land Disposal Restrictions. Offsite disposal of these soils cannot be considered unless the soils are treated to BDAT levels. The use of a Toxic Substance Control Act (TSCA)-approved disposal facility is considered for disposal of untreated PCB soils. Under TSCA, PCB-contaminated soils with concentrations up to 500 ppm may be disposed of in a licensed hazardous waste landfill.

This method is not effective in destroying the contaminant. PCB's are immobilized by containerization and the containers are deposited in the landfill. The landfill is built to specific requirements that prevent future migration of the contaminant. This disposal method is implementable with an approved facility within 180 miles of the site. The cost of this disposal option is moderate. This process option will be used in the development of alternatives.

### 7.5.5 In-Situ Treatment

Stabilization/Solidification is the only in-situ process option retained after initial screening. This process is similar to the ex-situ process except that soil cutting and mixing blades are used to blend soils in situ while stabilizing agents are being injected. Soils to depths of 9 m (30 ft) can easily be stabilized. The process is proven for the immobilization of metal soil contaminants; its effectiveness on organic contaminants is not well documented and treatability studies would be required to determine its ability to immobilize PCB's and BEHP.

Deep soil mixing augers and pressurized slurry-injection systems specifically built for this type of work are readily available. This equipment is most effective where there are sandy, relatively dry soils. Buried debris and concrete rubble, as might be encountered at the HRL, significantly hamper the process and may make the use of this technology infeasible for this site. The cost of the process is moderate.

This process is not carried on for further consideration because it may not easily be implemented at the HRL and its effectiveness on organic contaminants is uncertain. Additionally, contaminant migration from the vadose zone to the groundwater has been dismissed as an operative pathway making further immobilization of the contaminants unwarranted.

### 7.5.6 Biological Treatment

Biological treatment refers to the use of microorganisms to decompose contaminants. This occurs under both aerobic conditions (in the presence of oxygen) and anaerobic conditions (devoid of oxygen), depending on the nature of the microbes. Sometimes decomposition is direct (the microbe consumes the contaminant as a source of carbon or other nutrient needed for growth) or the microbe may produce enzymes that catalyze a chemical change in the contaminant (cometabolism). The presence of existing microbes in the soil, suited to the decomposition of the contaminant, is beneficial. Otherwise, the microbes that are needed can be genetically derived or isolated in the laboratory. Regardless of the microbial origin, treatability studies are conducted to be sure that the desired decomposition of the contaminant can be achieved without the production of hazardous byproducts.

In order to stimulate the growth of the decomposing organisms, air and nutrients (aerobic biodegradation) or methane and nutrients (anaerobic biodegradation), must be supplied. The quantities of these inducers are determined stoichiometrically.

Contaminated soil can be treated in place or excavated and treated at a remote location. In-situ treatment of contaminated soil promotes and accelerates the natural biodegradation process in the undisturbed soil. Generally, it consists of a water recirculation system with above-groundwater treatment and conditioning of the infiltration water with nutrients and an oxygen source. The system is usually designed to allow uncontaminated groundwater to enter the zone of contamination, but prevents groundwater from leaving the contaminated zone (EPA, October 1991). For small sites containing contaminated soils at shallow depths, in-situ treatment is not economical. Therefore, in-situ bioremediation of soils is not carried forward for further consideration.

Ex-situ biological treatment of contaminated soil includes three general technologies: 1) slurry phase, 2) land treatment, and 3) contained land solid phase. In the slurry phase, the soil is excavated, mixed with water, and slurried to the bioreactor where the biological conversion takes place. Once treated, the soil is dewatered and disposed.

Land treatment is also called land farming. Using this method, the soil is excavated and placed in a prepared, lined treatment bed. Using standard farm equipment, a large area can be treated.

Contained solid phase generally refers to above-ground composting of the soil with appropriate soil amendments to stimulate microbial decomposition of the contaminant.

There is some evidence that bioremediation of BEHP may be possible. Waste Stream Technology (WST) has reported that they have isolated a microbe that can obtain energy for growth from BEHP (WST, 1992). WST has also reported that BEHP was among several contaminants biotreated in situ at the Pittsburgh Airport in Allegheny County, Pennsylvania. During construction of the Pittsburgh Airport expansion project, an abandoned garbage dump was discovered. BEHP was among the contaminants of concern at the site. The concentrations of BEHP were on the order of 1,000 to 2,000 mg/kg. After biotreatment, the concentrations of BEHP were below the target levels.

The potential effectiveness of biotreatment on the BEHP at this Pennsylvania site is unclear. There is reason to suggest that dilution by mixing, rather than biotreatment may explain the reduced concentrations in post treatment samples. The dump area was excavated and placed in a temporary stockpile where it was biologically treated. Since only isolated samples taken at the dump site contained concentrations of BEHP, it is possible that the BEHP was diluted during excavation, transport, and placement in the stockpile.

The fact that microbes have been isolated that utilize BEHP as their energy source is encouraging. A treatability study would be required to confirm that in-situ biotreatment of BEHP is feasible at the UN-1100-6 site. Bioremediation of BEHP through landfarming practices is carried forward as an innovative technology.

Biodegradation of PCB's in both aerobic and anaerobic realms has been investigated. Positive results have been achieved in bench scale testing of the biotreatability of PCB's. In a series of studies (Unterman *et al.*, 1988), soil from New York State contaminated with Aroclor 1242 (similar to Aroclor 1248) was sampled for biodegradation testing. Resting cell studies using the contaminated soil have shown substantial PCB biodegradation (Unterman *et al.*, 1988). These studies also included work on genetically engineered bacteria designed specifically for biodegradation of Aroclor 1242-contaminated soil. Additionally, PCB-degrading bacteria were isolated.

Dechlorination of Aroclor 1242 under anaerobic conditions has been attempted. At a project on the upper Hudson River, New York, PCB- (Aroclor 1242) contaminated sediments were dechlorinated by microorganisms under anaerobic conditions in a bench scale test (ATTIC-RM00468, 1992). Dechlorination occurred primarily from the para and meta positions; congeners that were substituted only in the ortho positions were accumulated (ATTIC-RM00468, 1992). These dechlorination products are both less toxic and more readily degraded by aerobic bacteria (ATTIC-RM00468, 1992). Again, treatability studies would be required to confirm biodegradation of PCB's at the 1100 sites is possible.

Successful PCB degradation in field studies has not been documented in the literature surveyed. To date, degradation has only been demonstrated in bench scale studies where input variables were closely controlled. Although bioremediation of PCB's in the field is an emerging technology, it has not been demonstrated and its use is not considered further here.

## 7.6 GROUNDWATER PROCESS OPTIONS

Groundwater process options remaining after initial screening are evaluated further in the following paragraphs.

### 7.6.1 No Action

Under this scenario, no remedial action would be taken on the HRL groundwater and contaminant levels would be naturally attenuated by dispersion, diffusion, and dilution. This alternative is required under the NCP to establish a baseline condition to compare to other alternatives and will be considered in the development of alternatives.

Currently, there is no use of this groundwater as a drinking water source. Domestic water is supplied through the city of Richland distribution network. Therefore, there is no current risk to human health or the environment. This alternative still may not be acceptable to regulators or the public because contaminants are left in place and are not actively remediated.

### 7.6.2 Institutional Controls

Institutional controls are actions that reduce the exposure of receptors to contaminated groundwater and that monitor the spread and level of contamination. Process options were retained after initial screening in the four technology types and are evaluated here.

**7.6.2.1 Alternate Water Supplies and Point of Entry/Point of Use Treatment.** For domestic consumption, alternate water supplies would be provided through Richland's distribution network or by commercially supplied (bottled) water. Richland's distribution network already serves the current industrial user in the area and can be readily accessed at low cost. It is the only alternate water supply that will be carried forward.

Point of entry/point of use treatment would be used by domestic consumers to purify water prior to ingestion. These systems would require maintenance and monitoring to ensure their effectiveness. Again, since Richland's distribution network is available, these types of process options are not considered further.

**7.6.2.2 Access Restrictions.** Access restrictions are actions that would prevent consumption of the contaminated water until it is remediated. Administrative controls would consist of regulations that would require owners to abandon wells or prevent the use of these wells. These controls are usually difficult to implement. There are currently no domestic consumers downgradient of the contaminated plume and the need for these restrictions is nonexistent. Deed restrictions could be imposed that would prohibit development of wells by new owners, upon disposal of the land by DOE. If this land would come under private ownership, deed restrictions could be difficult to implement. Deed restrictions are not pursued further.

Future use and the development of new wells can be controlled by both DOE, who owns the land, and Ecology, through which water well permits must be attained. These administrative controls are easily implementable and should be used until the groundwater is remediated. The cost of this option is low.

**7.6.2.3 Monitoring.** Monitoring wells are valuable in identifying the extent, spread, and concentration of contaminants. Additionally, they are used to evaluate the effectiveness of the remedial activity. Installation of wells involves standard practices. Initial capital costs, O&M costs, and sampling and analytical costs are high when compared to other institutional controls. Monitoring is carried forward to the development of alternatives.

### 7.6.3 Extraction/Treatment/Discharge

This is the group of active remediation scenarios that would withdraw and treat contaminants prior to discharge. Extraction is by the use of a variety of wells and well configurations. Treatment includes physical, chemical, and biological processes. Also several discharge scenarios are evaluated.

**7.6.3.1 Extraction.** Deep well pumps have their impellers close enough to the water surface to avoid cavitation. The motor may be at ground level with a long shaft connecting it to the impellers, or it may be at the bottom of the well, below and directly adjacent to the impellers. These pumps efficiently move large volumes of water and are effective in aquifers with high hydraulic conductivities. Ejector well pumps are primarily used in aquifers with low hydraulic conductivity. They are designed to be operated intermittently and generally have lower efficiencies than deep well pumps. The HRL aquifer has a high hydraulic conductivity and the use of deep well pumps is most appropriate. This extraction method will be used for the development of alternatives.

Installation of well casing and pumps is readily implementable. Initial capital costs and O&M costs for a deep well pumping system are relatively low.

Enhanced extraction is the process where water is discharged to the aquifer in order to increase its hydraulic gradient and, thus, increase its capacity to flush contaminants. This procedure is most appropriately used where there is a known source area. The contaminants at HRL are widely dispersed and the benefits of this method would be minimal. Its use is not considered further.

**7.6.3.2 Physical Treatment.** Physical processes involve the separation of the contaminant from the groundwater. These processes exploit various physicochemical phenomena to remove the undesirable constituents. Five physical processes were retained following initial screening. Each is described and evaluated here. Viable physical processes for the removal of TCE are compared against each other in paragraph 7.6.3.2.6.

7.6.3.2.1 <u>Adsorption</u>--Organics that are refractory and that are difficult to remove by conventional biological treatment processes are frequently removed by adsorption onto an

active solid surface. Activated carbon is the most widely used adsorbent in these processes (Eckenfelder, 1989).

The underlying principle of adsorption is the mass transfer of an organic molecule from a liquid onto a solid surface. Adsorption occurs because there are forces that attract the organics to the solid surface from solution. In the case of activated carbon, the porous structure of the carbon attracts and holds (adsorbs) the organic contaminant. The contaminants are attracted either because: 1) they have a low solubility in the water; 2) they have a greater affinity for the carbon than for the water; or 3) a combination of the two (GII, 1991).

The carbon adsorption process usually consists of a series of columns that are packed with carbon. The contaminated water is passed through the vertical beds with either an upward or downward flow. The contaminants are most rapidly and effectively adsorbed by the carbon closest to the inlet of the bed. This carbon is in contact with the highest concentrations of the contaminated water. As treatment progresses, these carbon sites lose their adsorptive capacity and the adsorption zone progresses up or down the column. As this zone approaches the end of the carbon bed, effluent concentration approaches that of the influent. This is termed breakthrough. At this point the carbon bed is spent and no additional removal of the contaminant occurs. The carbon bed is then taken off line and the carbon is regenerated by thermal methods or replaced.

Carbon adsorption is demonstrated to reduce trichloroethene (TCE) concentrations in contaminated waters to below 1 $\mu$g/L. Systems to handle the range of flows anticipated for this site are available from several vendors. Initial capital costs and annual O&M costs are typically high for these systems when compared to other physical processes.

7.6.3.2.2 Air Stripping--Air stripping is the physical process of transferring a volatile organic contaminant (VOC) from water into the air. This is normally done by passing water through a packed column countercurrent to a flow of air. The packing is usually an open structured, chemically inert material (plastic) that is selected to provide high surface areas that facilitate mass transfer of the contaminant from the water to the gas phase. This process is affected by the contact area, the solubility of the contaminant, the diffusivity of the contaminant in air and water, and the temperature (Eckenfelder, 1989). Besides the diffusivity and temperature, these parameters are dependent on the air- and water-flow rates and the packing media selected. The efficiency of the process in removing a contaminant is directly related to the Henry's Law constant of the organic compound and the mass transfer coefficient of the packing.

TCE has a Henry's Law constant of 0.01 atm·m$^3$/gmole. Air stripping is usually applicable to contaminants with Henry's Law constants greater than 0.003 atm·m$^3$/gmole. Generally the greater the Henry's Law constant, the easier the contaminant is removed from the liquid phase.

Typically a process unit consists of a cylindrical tower containing packing which disrupts the flow of the liquid thus renewing the air and water interface. Water is pumped to the top of the unit and flows countercurrent to a forced draft provided by a blower.



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The system is characterized by high interfacial area compared to the volume of water in the column. Principal design parameters are the volumetric air flow ratio, the packing type, size and depth, column diameter, water and air loading rates, and the gas pressure drop.

One consideration with stripping towers is the emission of the stripped VOC's to the atmosphere. VOC's are designated air pollutants whose emissions are controlled. However, because of the low concentration of TCE at the site, attaining air quality standards is not anticipated to be a problem.

Air stripping technology is readily available from multiple vendors. The process has been proven to remove TCE to below maximum contaminant levels (MCL's). The capital and O&M costs of a stripping system are moderate compared to other physical processes.

7.6.3.2.3 Steam Stripping--Steam stripping is generally used to increase the efficiency of a stripping process. Heating of the contaminated water raises the Henry's Law constant of the contaminant thus making it more strippable. TCE is readily stripped at temperatures of 20° C. Steam stripping is an energy intensive process that would not be of great benefit for use at this site. This process is not considered further.

7.6.3.2.4 Reverse Osmosis--Reverse osmosis (RO) is a membrane process in which hydrostatic pressure is used to drive the feedwater through a semipermeable membrane while a major portion of the contaminant remains behind and is discharged as waste (reject). The process has shown some promise in removing VOC's, however, removal efficiencies for TCE were found to be between 30 and 69 percent (Clark *et al.*, 1984). New membranes are being developed that may increase these removal efficiencies.

RO is also applicable to the removal of nitrates. The development of tin filmed composite spiral wound membranes have made this process cost effective. Additionally, the reject can be flash evaporated leaving behind a solid residual that can easily be handled and disposed. This has advantages over other nitrate removal processes that have treatment residuals that are costly to treat (Culligan, 1992). RO is retained for further consideration for these reasons.

7.6.3.2.5 Electrodialysis--Electrodialysis (ED) is a membrane process that is used to transfer ions from the contaminated water through the membrane, leaving behind a purified water. Use of ED for removal of organics is not documented in the literature; there is little documentation on its use solely for nitrate removal. ED processes remove nitrate-nitrogen at efficiencies of less than 50 percent (Sorg, 1978). Costs for ED processes are typically high compared to other nitrate removal options. ED is not considered further.

7.6.3.2.6 Comparison of Physical Processes for TCE Removal--The remaining physical processes are carbon adsorption and air stripping. Both processes have demonstrated high removal efficiencies from 90 to 99 percent. For the removal of TCE only, air stripping has proven to be far more economical over a wide range of influent concentrations and treatment flows (Clark *et al.*, 1984). As treatment flows increase, the difference in capital costs between the two processes gets larger because the carbon-adsorption system must operate under high pressures that require special pressure vessels for the carbon beds (Westates

Carbon, 1992). While these systems provide equivalent treatment, air stripping is carried forward because of the economics.

**7.6.3.3 Chemical Treatment.** Four chemical treatment processes for the treatment of TCE or nitrates in groundwater were retained after initial screening and are evaluated in greater detail here.

7.6.3.3.1 Chemical Oxidation and Ultraviolet (UV) Radiation--In this process oxidants are added to contaminated groundwater to oxidize pollutants to terminal end products or to intermediate products that are more readily biodegradable or more readily removed by adsorption. Common oxidants used are chlorine, ozone, hydrogen peroxide, and potassium permanganate. Of these, only ozone and hydrogen peroxide are reported to oxidize refractory organic compounds. However, under normal conditions, complete degradation of these compounds does not occur; and, research has shown that using an additional energy source in conjunction with these oxidants (*i.e.*, UV radiation) readily decomposes these refractory compounds (Eckenfelder, 1989). It is believed that the UV activates the oxidant molecule and that it may also activate the organic substrate. The processes described below use UV in conjunction with either ozone or hydrogen peroxide or both.

Ozone is usually generated onsite from dry air or oxygen by a high-voltage electric discharge. Oxygen usually yields twice the ozone concentration (0.5 to 10 wt percent) as air. Ozone oxidation systems typically mix ozone with the contaminated water in a reaction chamber. At the same time, the mixture is exposed to UV radiation. Ozone off gases are treated in a catalytic ozone decomposer and released to the air. The terminal end products of this reaction are $CO_2$ and $H_2O$. Similarly, hydrogen peroxide is mixed with the contaminated water in a reactor and irradiated with UV light.

In a third oxidation process, ozone and hydrogen peroxide are added to the contaminated water in a reactor and the water is subjected to UV light. This process was demonstrated in the field in 1989 as part of the Superfund Innovative Technology Evaluation (SITE) program. Results from this demonstration showed that the process removed 98 to 99 percent of the TCE present in the influent groundwater (EPA, 1990d). Some of the TCE removal was due to stripping (10 percent).

Of the three oxidation processes, the ozone, hydrogen peroxide and UV system will be considered further. The system is available at moderate capital cost. O&M for the system is high.

7.6.3.3.2 Irradiation--Irradiation as a means of chemically decomposing organic compounds has been found to require longer reaction times and by itself, has not been demonstrated with high efficiencies. Irradiation is not considered further.

7.6.3.3.3 Ion Exchange--Ion exchange systems are commonly used in municipal water treatment systems for the removal of nitrates. In this process, negatively charged nitrate anions are removed by an insoluble, strong base resin, which exchanges other like charged anions into the solution. This exchange occurs with no structural changes in the resin. The nitrates in solution rapidly diffuse into the network of the resin where exchange occurs.

The exchanged ions proceed by the same path into solution. At some point an ion exchange equilibrium is reached and the resin must be regenerated (Benefield *et al.*, 1982).

Various operational modes of ion exchange systems exist. The fixed-bed system is the most common of these. The operating cycle for a fixed-bed system consists of four steps: service, backwash, regeneration, and rinse.

Fixed-bed systems for nitrate removal by strong base resins are operated in the upflow or downflow mode for service, and vice versa for regeneration. This is known as countercurrent operation. Typically for these systems the resin has a high affinity for the exchanged ion and requires a considerable excess of regenerant to regenerate the resin bed. The column typically experiences leakage at the start of the next service run (Benefield *et al.*, 1982).

Ion exchange systems are readily available from a number of water treatment equipment vendors and are an effective treatment method for nitrate removal. The operational requirements for handling the strong base regenerant (NaOH), and the column rinsate are great, which make the O&M costs for these systems high. Based on a comparative study for treatment of site groundwater for nitrate, reverse osmosis was determined to be the more economical method (Culligan, 1992). While both methods are equal in effectiveness, ion exchange is dropped from further consideration because of its higher cost.

**7.6.3.5 Discharge.** Three discharge alternatives were retained and are evaluated below.

7.6.3.5.1 Surface Water--Discharge to the Columbia River would entail the construction of a 1.61 km (1 mile) pipeline. Installation of a gravity-driven system would require extensive excavation. A pumped system would reduce excavation, but increase O&M costs. This system would have high initial capital costs when compared to other discharge systems and is not considered further.

7.6.3.5.2 Reuse/Recycle--After treatment, the water will meet MCL's and would be available for reuse or recycle. However, there currently is no demand for water and there is no expected future demand. Therefore, this discharge option is not pursued.

7.6.3.5.3 Recharge--Subsurface drains consist of perforated distribution pipes placed in a trench and surrounded by clean sand. Treated groundwater would be gravity fed or pumped to the pipes and the system would be sized to ensure that the flow out of each orifice would be equal to assure even distribution of the discharge. After being discharged, the effluent would percolate through site gravels and eventually would return to the aquifer. This system is readily implementable and very effective in homogenous aquifers with high permeability such as found at the site. The cost of this system is low compared to other discharge systems and is retained for consideration.

### 7.6.4 In-Situ Treatment

Two physical in-situ treatments were retained after initial screening and are discussed below. In-situ biological methods are discussed in paragraph 3.5.

**7.6.4.1 Aeration.** In-situ aeration involves the pumping of air into the aquifer to induce the mass transfer of volatile organics to the gas phase. Typically this is done in vertical wells that are used as air strippers. Horizontal wells have been used to strip groundwater in situ along a leaking pipeline. These systems can only treat limited areas of the plume (source or hot spots) efficiently. As the areal extent of the plume gets larger and the contaminant more dispersed, the number of wells required to effectively treat the area would be cost prohibitive. For these reasons this process option is not considered further.

**7.6.4.2 Heating.** In-situ heating would involve the injection of steam and air into the aquifer, again to induce the mass transfer of the organic contaminant into the gas phase. The principal here is that the contaminant is more readily strippable at higher temperatures. TCE is readily strippable without heating. This process option is dropped from consideration for the same reason as was in-situ aeration, which is that the areal extent of the plume is too great to economically employ this process.

### 7.6.5 Biological Treatment

Biological treatment refers to the use of microorganisms to decompose contaminants. This occurs both under aerobic conditions (in the presence of oxygen) and anaerobic or anoxic conditions (devoid of oxygen), depending on the nature of the microbes. Sometimes decomposition is direct, in that the microbe consumes the contaminant as a source of carbon, or other nutrient needed for growth. Or the microbe may produce enzymes that catalyze a chemical change in the contaminant (cometabolism). It is beneficial if the microbes needed for decomposition already exist in the aquifer (indigenous). Otherwise the microbes that are needed can be genetically derived or isolated in the laboratory. Regardless of the microbial origin, treatability studies are almost always conducted to be sure that the desired decomposition of the contaminant can be achieved without the production of hazardous byproducts.

In order to stimulate the growth of the decomposing organisms, air and nutrients (aerobic) or methane and nutrients (anaerobic), must be supplied. The quantities of these inducers are determined stoichiometrically. When biological treatment is conducted in situ, these materials are injected into the aquifer. A dilemma that is almost always faced in in-situ treatment is the potential for fouling the injection well. The microorganisms tend to flourish at the injection point resulting in clogged injectors and/or aquifer pores. Another problem encountered is that the contaminant is forced away from the injection point, as the aquifer makes room for the injected materials.

Ex-situ treatment requires that the aquifer be pumped, treated and then re-injected. Ex-situ biological treatment is performed in a bioreactor. Similar to in-situ treatment, the inducers are injected into the reactor, which provides adequate mixing and detention time for



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decomposition of the contaminant to occur. Sludge is produced in the process. Consequently sludge handling facilities must be considered in the ex-situ scenario.

In-situ biological treatment of TCE under aerobic conditions shows some promise. Research has determined that TCE can be completely mineralized to carbon dioxide, water, and chlorine in an aerobic environment. Aerobic processes require the presence of an inducing compound (an aromatic compound such as toluene or phenol), which may not be present. TCE is epoxidated by the enzyme methane monooxygenase, emitted by methylotrophic bacteria as they consume methane for energy (Russell *et al.*, 1992). Epoxidated TCE is very unstable, so hydrolization to various by-products is rapid (half life = 12 seconds in phosphate buffer with pH 7.7) (Miller and Guengerich, 1982).

One concern in an aerobic in-situ scenario is that the methane needed to stimulate the methylotrophs may be inhibitory to the TCE epoxidation (Russell *et al.*, 1992). Potentially, only a portion of the TCE would be epoxidated before being transported away in a flow situation.

Decomposition of TCE under anaerobic conditions is described as reductive dehalogenation. Under anaerobic conditions, TCE can function as an electron sink and is readily reduced by electrons (or reducing equivalents) formed as a result of the metabolism (oxidation) of the organic electron donors by members of the methanogenic consortia (Russell *et al.*, 1990/91). By introducing electron donors into the contaminated environment, TCE can be reduced. However, in the absence of adequate oxidizable organic compounds (*e.g.*, toluene), there is the potential to produce dichloroethylene and vinyl chloride (Bouwer and McCarty, 1983, and Bouwer *et al.*, 1981). Dichloroethylene is a suspected carcinogen and vinyl chloride is a known carcinogen. Therefore, if in-situ biological treatment in the anaerobic realm was selected, careful monitoring would be required to ensure that these compounds, particularly vinyl chloride are not produced.

Based on the discussion above, biologically treating TCE is not recommended at this time. Although evidence indicates that TCE can be biologically destroyed (cometabolized in an aerobic environment; reduced in an anaerobic environment), the practicality of providing the needed nutrients and inducers necessary for biological treatment in an in-situ environment is uncertain. Further, the inducers necessary for biological treatment, such as toluene or phenol in an aerobic environment, and toluene or acetone in an anaerobic environment, are themselves toxic. These organic contaminants are not present in the groundwater at this site, and injecting them for removal of TCE is not recommended. Also, in the anaerobic environment, there is potential to produce dichloroethylene and vinyl chloride as by-products (Russell *et al.*, 1990/91; Bouwer and McCarty, 1983; Bouwer *et al.*, 1981). As noted above, dichloroethylene is a suspected carcinogen and vinyl chloride is a known carcinogen.

Nitrate is reduced by a process known as denitrification. Denitrification is accomplished by facultative anaerobic microorganisms in an anoxic environment (Metcalf and Eddy, 1991). Denitrification is a two step process: 1) the conversion of nitrate to nitrite, and 2) production of nitric oxide, nitrous oxide and nitrogen gas. The last three compounds are gaseous compounds that can be released to the atmosphere.

An ex-situ demonstration project at Hanford was performed to investigate denitrification of nitrates (Brouns *et al.*, 1991). Both a continuous stirred-tank bioreactor and a fluidized bed bioreactor were used in the pilot scale test. Results of the study indicate that microorganisms native to the Hanford site are capable of reducing nitrates to below the drinking water standard when supplied with an electron donor such as acetate (Broun, *et al.*, 1991). In-situ denitrification is being investigated. A pilot scale study has been initiated at Hanford but no results have been reported to date.

The use of biological treatment for in-situ treatment of nitrates is still experimental. An organic inducer would be required to stimulate denitrification. Ex-situ treatment has been investigated with positive results. Should the aquifer be treated ex situ, bioremediation of nitrate may be possible. A pilot test has been completed at Hanford using both continuous stirred tank and fluidized bed reactors (Broun *et al.*, 1991). Both reactors were able to reduce the influent nitrate concentration to below the drinking water standard (10 mg/L), with the fluidized bed reactor showing the best results. However, biological denitrification has several undesirable features. First, the process requires careful control to prevent bacterial and organic inducer breakthrough. Commonly the inducer itself is a hazardous chemical and even though low concentrations would be needed, system failure could result in the discharge of this substance to the environment. Secondly, the biological mass takes considerable time to develop and stabilize; system upsets in which this mass is lost would cause extended shutdowns of the system. For these reasons, biological nitrate removal is not considered further.

## 7.7 SUMMARY

Summaries of the evaluations of soil and groundwater process options are provided in tables 7-7 and 7-9. 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 for all subunits. |
| 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 for all subunits. |
| | | 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 for all subunits. |

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 | 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 at HRL only. |
| | | Asbestos Cap | Does not prevent infiltration. Effective in prevention of fugitive dust. | Easily implemented. | Moderate capital. Low O&M. | Yes at HRL only. |
| 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 for all subunits. |

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 for PCBs and BEHP contaminated soils. |
| | | 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 |

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 for PCB's and BEHP contaminated soils. |

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 |
| | Biological Treatment | 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 for BEHP contaminated soils only. |
| | | 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 for treated soils from all subunits. |
| | | 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 for disposal of untreated PCB's contaminated soils. |

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 is 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. Ability to maintain favorable conditions for microorganisms is difficult. | Low capital. Moderate O&M. | No |
| | | 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 |

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



| General Response Action | Remedial Technology Types | Process Options |
|---|---|---|
| No Action | None | Not Applicable |
| Institutional Controls | Access Restrictions | Administrative Controls<br>Fences |
| | Monitoring | Groundwater Monitoring |
| Containment | Capping | WAC Cap (HRL only)<br>Asbestos Cap (HRL only) |
| 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 (for Discolored Soil Site) |
| | Disposal | Onsite (for treated soils)<br>Offsite (for untreated soils) |
| In Situ Treatment | Chemical Treatment | None Remaining |

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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 |

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? |
|---|---|---|---|---|---|---|
| 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 |

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 for TCE only. |
| | | 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 |

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.) | 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 for nitrates only. |
| | | 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 $H_2O$. | Equipment readily available. | High capital. High O&M. | Yes for TCE only. |
| | | 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 for TCE only. |
| | | Irradiation | Not effective by itself in treating organic contaminants. | Requires long reaction times. | Moderate capital. High O&M. | No |

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 |

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 |

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? |
|---|---|---|---|---|---|---|
| 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



| 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 (TCE only) |
| | Chemical Treatment | Chemical Oxidation (TCE only)<br>Ultraviolet Radiation/Photolysis (TCE only)<br>Ion Exchange (nitrates only) |
| | Biological Treatment | None |
| | Discharge | Recharge |
| In Situ Treatment | Physical | None |
| | Biological | None |

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# 8.0 DEVELOPMENT AND SCREENING OF ALTERNATIVES

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.

## 8.1 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, 1988a):

- 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



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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 N 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 5 percent used over the lifetime of the alternative.

There are several factors which may contribute to the uncertainty of the costs presented. In the case of soils, uncertainty in volume estimates due to limited sampling data could greatly influence costs. Quantity estimates in this report were based on conservative parameters. For groundwater, there are substantial annual O&M costs associated with the treatment of nitrates. Because nitrate is transported through the aquifer at rates much faster than TCE, nitrate levels in groundwater will probably fall below MCL's much sooner than levels for TCE. Substantial savings could be realized by turning off those components of the treatment system that specifically address nitrate removal. However, for the costs presented in this report, the entire treatment train was assumed to operate throughout the remedial action. Therefore, life-cycle costs may be overstated.

## 8.2 SOIL REMEDIAL ACTION ALTERNATIVES

Section 7.0 identified the viable process options for the specific contaminants in the contaminated media. Due to the small volume of contaminated soil at each subunit, the alternatives presented here address all contaminated soil rather than that of each subunit. Since treatment by one technology means one set of mobilization and set up costs, the net result is a reduction in cost per unit of treated soil. The mobilization and set up costs for two or three separate technologies would greatly increase these unit costs. Thus, economies of scale will dictate the actions taken at this operable unit and alternatives have been developed accordingly.

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.

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### 8.2.1 Common Components.

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

**8.2.1.1 Institutional Controls.** Institutional controls would 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 would be both technically and administratively implementable. The cost of these controls would vary according to the cleanup level achieved and would be evaluated with respect to each alternative. For purposes of alternative comparison, it is assumed that the no action alternative would require continued monitoring of all presently monitored wells over the next 30 years. Using historical costs of $52,150 per monitoring round, this has an estimated life-cycle present worth of $802,000. 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 would be for the HRL. Pro-rated costs for this reduced monitoring effort are estimated at $40,500 per annual sampling event. This has an estimated life-cycle present worth of $623,000 over 30 years.

**8.2.1.2 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 would 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. 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.

## TABLE 8-1. SOIL REMEDIAL ACTION ALTERNATIVES

| PROCESS OPTION | 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 5A | S 5B | S 5C | S 5D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No Action | ● | | | | | | | | | | | | | | | | | | | | |
| Institutional Controls | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Bioremediation of BEHP | | ● | ● | ● | ● | | | | | | | | | | | | | | | | |
| Onsite Incineration /Disposal | | | | | | | | | | | | | | | | | | | | | |
| • All Sites | | | | | | ● | | ● | | | | | | | | | | | | | |
| • UN-1100-6 and Ephemeral Pool | | | | | | | ● | | ● | | | | | | | | | | | | |
| Offsite Incineration /Disposal | | | | | | | | | | | | | | | | | | | | | |
| • All Sites | | | | | | | | | | ● | | ● | | | | | | | | | |
| • UN-1100-6 and Ephemeral Pool | | | | | | | | | | | ● | | ● | | | | | | | | |
| • UN-1100-6 | | | | | | | | | | | | | | | | | | ● | ● | ● | ● |
| Offsite Disposal | | | | | | | | | | | | | | | | | | | | | |
| • HRL and Ephemeral Pool | | ● | | ● | | | | | | | | | | | | | | ● | | ● | |
| • Ephemeral Pool | | | ● | | ● | | | | | | | | | | | | | | ● | | ● |
| Supercritical $CO_2$ Extraction | | | | | | | | | | | | | | | | | | | | | |
| • All Sites | | | | | | | | | | | | | | ● | | ● | | | | | |
| • UN-1100-6 and Ephemeral Pool | | | | | | | | | | | | | | | ● | | ● | | | | |
| Containment at HRL | | | | | | | | | | | | | | | | | | | | | |
| • MSWLF Cap | | | | ● | ● | | | ● | ● | | | ● | ● | | | ● | ● | | | ● | ● |
| • Asbestos Cap | | ● | ● | | | ● | ● | | | ● | ● | | | ● | ● | | | ● | ● | | |

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 $m^3$ (600 $yd^3$) of contaminated soil at HRL either by onsite or offsite incineration, or through disposal in a TSCA facility are $1,514,000; $2,679,000; and $448,000, 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.

**8.2.1.3 Containment at the HRL.** Of the remaining 11 alternatives, 10 include some sort of capping option at HRL. The first would be a cap option designed in accordance with WAC 173-304 for the closure of municipal and solid waste landfills (MSWLF cap) in arid regions. As described in section 7.0, this would be an impermeable cap which exceeds the remedial action objectives for the subunit. This capping option was retained for evaluation to establish a baseline containment action that addresses uncertainty at the subunit. The second containment option would be a cap designed for the closure of inactive asbestos disposal sites under 40 CFR 61. Each is described and evaluated below.

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

The construction of the cap would require approximately 86,500 $m^3$ (113,000 $yd^3$) of random fill material to be used in preparing an adequately sloped subgrade. Placement of the first 15 cm (6 in) of material would require special construction practices to prevent the exposure of remedial workers to possible asbestos-containing fugitive dust. A 15 cm (6 in) geomembrane bedding layer consisting of 2.54 cm (1 in) minus material would be placed on top of the random fill. Next, 87,900 $m^2$ (105,000 $yd^3$) of geomembrane would be placed and covered with 15 cm (6 in) of topsoil. The capped area would be reseeded to establish a vegetative cover and 1.83 km (6000 ft) of perimeter fence would be constructed to restrict access to the site. Appropriate warning signs would 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 would be obtained from offsite sources within a 16 km (10 mi) radius of HRL.

8.2.1.3.2 Evaluation of the MSWLF Cap--The MSWLF cap would be effective in preventing surface water intrusion into the landfill area and in preventing the migration of fugitive dust. Fencing around the landfill area would restrict access and would limit the potential of exposure to receptors. Contaminant volume and toxicity would not be reduced under this option; mobility of contaminated fugitive dust would be eliminated and the low



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potential for contaminant migration from the vadose zone to the groundwater would be reduced further. It should be noted that this action goes substantially beyond the RAO's for HRL, which are to prevent the ingestion of and dermal contact with PCB-contaminated soils, and to prevent the migration of fugitive dust containing asbestos. Short-term risks associated with the construction of the cap would be minimal and the long-term risks are substantially reduced. The long-term effectiveness of the cap would be dependent on the chemical and weather resistant properties of the geomembrane and would need to be periodically evaluated. The impact to the environment would be minimal as potential animal habitat would be disturbed during construction but would be enhanced by the placement of topsoil and a vegetative cover at the completion of cap placement.

This option would be easily implemented. Construction of the cap would involve 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 would have to be followed to protect workers from asbestos hazards until the initial cover layer was placed over the site.

The estimated initial capital cost for this option is $5,445,000. 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.

8.2.1.3.3 Description of the Asbestos Cap--The asbestos cap would be constructed by placing 37,100 $m^3$ (48,500 $yd^3$) 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 would require the use of special construction practices to limit the exposure of remedial workers to fugitive dust. The random fill material would be placed uniformly over the site following existing contours; no effort would be made to direct surface runoff off of the cap area. A 15 cm (6 in) topsoil layer would then be placed and seeded to dryland grasses. Access to the landfill area would be restricted by constructing 1.83 km (6,000 ft) of perimeter fence. Appropriate warning signs would be placed to notify the public that the area was used as a landfill and that it contains asbestos.

8.2.1.3.4 Evaluation of the Asbestos Cap--Placement of the cap would meet the RAO of preventing the migration of fugitive dust from the landfill. Construction of a perimeter fence would restrict site access and, therefore, the potential exposure to receptors would be reduced. Contaminant volume and toxicity would remain unchanged. Site risks would be reduced because there would be 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 would be employed during initial placement of the fill, short-term risks to remedial workers would be minimal. As discussed in section 7.0, this cap conforms to the "hybrid" closure requirements allowed by EPA at landfill sites with low levels of contamination.

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

An initial construction capital cost of $2,131,000 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.

**8.2.1.4 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 $m^3$ (340 $yd^3$) of contaminated soil would be removed and disposed of. Front end loaders would be used for excavation and hauling would be by Department of Transportation (DOT) approved hazardous waste haulers. The contaminated material would be hauled in bulk in approximately 28 ton truckloads. Removal of material would 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 was not achieved, or if any PCB's remain onsite (< 1 mg/kg) after the removal of 250 $m^3$ of material, institutional controls would be implemented (access restrictions and annual downgradient groundwater sampling). If cleanup to background levels was achieved, the site would be closed without restrictions. At the completion of the removal action the site would be regraded and covered with 15 cm (6 in) of clean random fill material.

This option would reduce the mobility of PCB contaminated material at the site through removal actions; the volume and toxicity would not be reduced. Placement in a permitted offsite facility would ensure that controls are in place to prevent releases to the environment. The remedial action would be 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 would be minimal as precautions would be taken to preclude worker exposure to contaminated material. If any PCB's remain onsite, access restrictions would prevent long-term exposure to onsite workers thus reducing risks.

The costs for this option are based on the assumption that the site would be remediated to background levels by removing a maximum of 250 $m^3$ of material. The estimated initial capital cost of this action is $356,000. There would be no O&M costs associated with clean closure.

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### 8.2.2 Alternative S-0 (No Action)

**8.2.2.1 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.

**8.2.2.2 Evaluation of Alternative.** This alternative would 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 5E-5 and hazard index of 0.3 for an onsite worker, as determined in appendix K 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 L, 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 8.2.1.1.

### 8.2.3 Alternative S-1B and S-1D

**8.2.3.1 Description of Alternatives.** These alternatives consider the use of bioremediation for the BEHP contaminated soil at the Discolored Soil Site, 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 would be through the method of landfarming. A diked treatment area approximately 30.5 m by 36.6 m (100 ft by 120 ft) would be constructed onsite and lined with an impervious geomembrane. The contaminated soil, estimated to be a maximum of 340 $m^3$ (440 $yd^3$), would be excavated and placed into the treatment area. A sprinkler system would 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 would be tilled after each application of this mixture to provide additional mixing and aeration. Excess water would be collected and recycled. A bioreactor would be required onsite to culture the microorganisms. It was assumed that bioremediation would 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 was assumed to take 2 years. However, this is a crude estimate and the actual time would be better estimated after treatability testing. After remediation, the soils would be placed back at the Discolored Soil Site and the area would 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 was not met, a land disposal treatability variance would be petitioned for.

**8.2.3.2 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 would better define the actual treatment levels that may be achieved. Therefore, it is difficult to predict the levels to which toxicity would be reduced. Unless the soils are remediated to background levels, which is unlikely, there would be no reduction in volume or mobility.

Landfarming would be an easily implemented treatment method. Initial construction of the facility would be simple. O&M would be somewhat difficult due to the sensitivity of the bacterial colonies, however, this would be overcome by initial operator training. The facility would 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 estimated at $4,107,000 for alternative S-1B and at $7,421,000 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.

### 8.2.4 Alternatives S-2B and S-2D

**8.2.4.1 Description of Alternative.** These alternatives would 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 would use a cap designed for asbestos containment while, alternative S-2D would use a MSWLF cap at the HRL.

Onsite incineration would 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 would be approximately 1,100 metric tons (1,210 tons) of contaminated soils to be processed. Rotary kiln technology would be used to process materials as big as 5 cm (2 in) in diameter. Electricity would be used to power the combustion source. Combustion off gases would be treated to meet air quality standards for emissions through use of a secondary combustion chamber and wet scrubbers. Ashes would be quenched with water and the quench water would be recirculated. After incineration, the ash would be placed back at the operable subunit and the area would be regraded and covered with 15 cm (6 in) of topsoil.

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

**8.2.4.2 Evaluation of Alternatives.** Incineration has been proven to be effective with 99.9 percent destruction efficiencies for PCB's and BEHP (EPA, 1991b). This option would 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 would significantly reduce the toxicity of the soils. The volume of soils would be slightly reduced, while the mobility of the contaminants that remain after incineration would stay the same. Soils redeposited after processing are likely to have some residual contaminants, however, these would be minimal and should not prohibit the delisting of the sites.

Mobile incinerator technology would be 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 $5,636,000 and $8,950,000 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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### 8.2.5 Alternatives S-3B and S-3D

**8.2.5.1 Description of Alternatives.** In these alternatives, offsite incineration to destroy contaminants in subunit soils would be 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 would be excavated and shipped to an offsite incinerator. DOT licensed hazardous waste haulers would 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 would be disposed of in this facility's ash disposal landfill. Post action sampling and analyses of remaining subunit soils would be required to confirm the level of cleanup. These alternatives would require either an asbestos cap (alternative S-3B) or a MSWLF cap (alternative S-3D) as the containment option at HRL.

**8.2.5.2 Evaluation of Alternatives.** The capping components of these alternatives were described previously. The efficiency of this option would be 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 would be slightly reduced in the incineration process.

There is both adequate incineration and transportation capacity to easily implement this alternative. Also, the public would be 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 $6,099,000. A cost of $9,413,000, 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.

### 8.2.6 Alternatives S-4B and S-4D

**8.2.6.1 Description of Alternatives.** Treatment for the Discolored Soil Site and Ephemeral Pool soils are accomplished through the use of supercritical $CO_2$ 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 section 7.0. Conceptually, contaminated soils would be fed into a reactor in which it would be subjected to a constant flow of supercritical $CO_2$ 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 $CO_2$ 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.

**8.2.6.2 Evaluation of Alternatives.** Bench scale studies recently performed (WHC, 1992) on contaminated soils from both the Discolored Soil 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 would not be 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.

### 8.2.7 Alternatives S-5B and S-5D

**8.2.7.1 Description of Alternatives.** These alternatives would treat 619 metric tons (682 tons) of contaminated Discolored Soil Site soils using offsite incineration, dispose of 250 $m^3$ (340 $yd^3$) 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.

**8.2.7.2 Evaluation of Alternatives.** As previously discussed, offsite incineration for the treatment of BEHP soils would 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 would be controlled through containment measures instituted by the facility. These options would reduce long-term exposure to onsite workers by removing contaminated materials. As indicated, these options would be easily implemented. The estimated initial capital cost of alternative S-5B is $5,241,000. Alternative S-5D is estimated to have an initial capital cost of $8,555,000. There are no O&M costs associated with this alternative. The yearly groundwater sampling and analyses cost and the life-cycle present worth cost, assuming clean closure of the Discolored Soil Site and Ephemeral Pool sites, would be as described in paragraph 8.3.1.1 for the 30 year period.

### 8.2.8 Summary of Remedial Alternative Costs

A summary of the retained remedial action alternative costs is provided in table 8-2. The detailed evaluation of these alternatives will be performed in section 9.0.

## 8.3 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.

### 8.3.1 Proposed Point of Compliance and Indicator Contaminant.

An integral part of any groundwater remedial action is the establishment of a point of compliance (POC) at which the contaminants of concern must meet ARAR's. For groundwater at HRL, the George Washington Way diagonal, as described in section 6.0 (see figure 6-25) is proposed as the POC. The reasons for this proposal are: the diagonal is a conveniently oriented construct that is easily identified and is within DOE property boundaries; from modeling results, the outer edge of the TCE plume which is above MCL's is approximately 600 m (2,000 ft) upgradient of the proposed POC; and the 300 Area is approximately 300 m (1,000 ft) downgradient of the POC at its nearest point providing a buffer zone between the two areas.

The risks from groundwater at this site are a result of TCE contamination when calculated using the uncertain residential land use scenario. Even under this conservative scenario, nitrate contamination does not pose a significant risk. As discussed in section 7.0, the presence of nitrate alone in the groundwater at the reported levels would not trigger remedial actions. Therefore, TCE is proposed as the indicator contaminant and the site would be out of compliance when TCE levels above MCL's are detected at the POC.



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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 | $3,484,000 | $6,798,000 | $5,013,000 | $8,327,000 | $5,476,000 | $8,790,000 | $4,618,000 | $7,932,000 |
| 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] | $802,000 | $623,000 | $623,000 | $623,000 | $623,000 | $623,000 | $623,000 | $623,000 | $623,000 |
| Total Present Worth Costs | $802,000 | $4,107,000 | $7,421,000 | $5,636,000 | $8,950,000 | $6,099,000 | $9,413,000 | $5,241,000 | $8,555,000 |

[1] 30 year life.

| 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 Contingency Plan | | ● | | | | | | |
| Extraction-Infiltration | | | | | | | | |
| • Scenario 1 | | | ● | ● | | | | |
| • Scenario 2 | | | | | ● | ● | | |
| • Scenario 3 | | | | | | | ● | ● |
| TCE Treatment | | | | | | | | |
| • Air Stripping | | | ● | | ● | | ● | |
| • Chemical/UV Oxidation | | | | ● | | ● | | ● |
| Nitrate Treatment | | | | | | | | |
| • Reverse Osmosis | | | ● | ● | ● | ● | ● | ● |

As noted in section 6.0, nitrate has greater dispersion than TCE, which accounts for the bigger nitrate plume. It is not unreasonable to assume that nitrates (possibly above MCL's) would be detected at the proposed POC well in advance of TCE.

### 8.3.2 Common Components

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

**8.3.2.1 Institutional Controls.** Institutional controls would 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 would be both technically and administratively implementable. The costs of these controls would be minimal. Additionally, yearly groundwater sampling and analysis would 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 estimated at $40,500, which corresponds to a life-cycle present worth of $623,000. 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.

**8.3.2.2 Extraction-Infiltration Scenario 1.** Under this scenario groundwater would be pumped at a rate of 0.38 $m^3$/min (100 gpm) through one extraction well. The extracted water would be treated and then would be distributed to an infiltration system consisting of 61 m (200 ft) of 31 cm (12 in) diameter perforated pipe from which the treated water would be recharged into the ground. The extraction well would be approximately 18.3 m (60 ft) deep. The bottom 6.1 m (20 ft) would be screened. A 5 horsepower(hp)-pump would be 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 would be 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 would be remediated to below the 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.

**8.3.2.3 Extraction-Infiltration Scenario 2.** Three wells each being pumped at a rate of 0.38 $m^3$/min (100 gpm) each, for a combined total of 1.14 $m^3$/min (300 gpm), are the basis of this extraction scheme. Each well would be 18.3 m (60 ft) deep and would be screened over the bottom 6.1 m (20 ft). The water would be 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 required. After treatment, the effluent would be collected in a sump and a 3 hp pump would be used to discharge the effluent to a 183 m (600 ft) long infiltration



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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 would 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.

**8.3.2.4 Extraction-Infiltration Scenario 3.** This scenario represents the most aggressive pumping scenario considered. Ten wells, each extracting at a rate of 0.38 $m^3$/min (100 gpm), for a total of 3.79 $m^3$/min (1,000 gpm), would be installed. Each well would be equipped with a 7.5 hp pump. The water would be 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 would be required. After treatment, the effluent would be 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 would be 305 m long by 6.1 m wide (1,000 ft by 20 ft).

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 would be captured and treated. Preliminary estimates indicate that 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 $m^3$/min (100 and 300 gpm). For these reasons, alternatives GW-4A and GW-4B are dropped from further consideration.

**8.3.2.5 Additional Monitoring Wells.** In all alternatives (except GW-0, the no-action alternative), six additional wells would be installed in order that the contaminant plume can be more effectively monitored. Three wells would be installed just west of and parallel to the proposed POC. Three other wells would be installed at locations to be determined downgradient of HRL. The depth of these wells would 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 estimated at $685,000. Annual sampling and analyses costs for these additional wells would be $24,300. Life-cycle present worth costs would vary according to the estimated life of the project.

### 8.3.3 Alternative GW-0.

**8.3.3.1 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.

**8.3.3.2 Evaluation of Alternative.** It is estimated that the groundwater contaminants in the plume would naturally attenuate to below MCL's by the year 2017 and that no TCE above MCL's would cross the George Washington Way diagonal . 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 would be reduced through dispersion and dilution. Technically, this alternative would be 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 capital costs associated with this alternative.

### 8.3.4 Alternative GW-1.

**8.3.4.1 Description of Alternative.** This alternative would be similar to Alternative GW-0 in that no active remedial action would be taken initially. Instead, a point of compliance would be established along a line just west and parallel to George Washington Way. The three new monitoring wells installed along this line would provide information on contaminant migration. In addition, a contingency plan would be developed in the event that TCE at levels above MCL's were detected at these wells.

**8.3.4.2 Evaluation of Alternative.** Under the most conservative groundwater modeling scenario, TCE at levels above MCL's do not migrate past The George Washington Way diagonal and naturally attenuate by the year 2017. Establishing the diagonal as a POC within the DOE site boundary, provides some insurance if the actual conditions differ from those modelled. If TCE above MCL's is detected at any of the three new wells along the diagonal,a contingency plan can be initiated. 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 would be easy to implement technically and, administratively, may be better accepted because a contingency plan would be in place to trigger an appropriate response 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 are estimated at $1,059,000. This assumes that no remedial action would be necessary in the future based on modeling results.

### 8.3.5 Alternatives GW-2A Through GW-3B

**8.3.5.1 Description of Alternatives.** These alternatives would treat various flow rates of extracted groundwater using two separate treatment trains. Alternatives GW-2A and GW-3A treat 0.38 and 1.14 $m^3$/min (100 and 300 gpm) flows, respectively, using air stripping for treatment of TCE and reverse osmosis for the treatment of nitrates. Alternatives GW-2B and GW-3B use an ultraviolet (UV)/oxidation system to treat TCE and reverse osmosis for the treatment of nitrates at these same respective flows.



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8.3.5.1.1 Pretreatment Units--At the head end of each process train, high flow multi-media filters would remove sediments from the groundwater. This would prevent fouling of the air stripping media and of the osmotic membrane. Filters or a combination of filters are available to meet the proposed design flows (Culligan, 1992). Filters have been sized for flow rates of 0.28 $m^3/min\text{-}m^2$ (7 $gpm/ft^2$). Sedimentation ponds would be constructed onsite to facilitate settling of sediments from backwash water. Overflow from settling ponds would be discharged to a drain field.

8.3.5.1.2 Air Strippers--Air strippers are commonly used for the removal of TCE from groundwater. As described in section 7.0, stripping makes use of TCE's favorable Henry's Law Constant. Air would be passed countercurrent to water flow and the volatile organic contaminant would be transferred from the liquid phase to the gas phase. Air stripping units for the various flow rates would have the following design parameters (Hydro Group, 1992). Strippers are used in Alternatives GW-3A, GW-4A, and GW-5A.

| Parameter | 0.38 $m^3/min$ | 1.14 $m^3/min$ |
|---|---|---|
| Height | 7.63 m (25 ft) | 7.63 m (25 ft) |
| Diameter | 0.61 m (2 ft) | 1.22 m (4 ft) |
| Packing Height | 4.57 m (15 ft) | 4.57 m (15 ft) |
| Blower Size | 1 hp | 3 hp |

All units would be constructed of structural aluminum and would be free standing.

8.3.5.1.3 UV/Oxidation Units--The UV/oxidation process is described in section 7.0 and applies to the treatment of TCE (alternatives GW-2B and GW-3B). Typical processes would mix the contaminated water with ozone and hydrogen peroxide in a reaction chamber. This mixture would then be irradiated with UV light. Off gases would be 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 (ULTROX, 1992). System components would 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 and 45.4 kilograms (kg) [28 and 100 pounds (lbs)] of ozone would need to be generated per day.

8.3.5.1.4 Reverse Osmosis--Reverse osmosis is chosen as the process option to remove nitrates to below MCL's. As described in section 7.0, hydrostatic pressure would be used to drive feedwater through a semipermeable membrane while a major portion of the contaminant content would remain behind and would be discharged as waste. This waste discharge would then be flash evaporated, leaving behind residue, which could easily be disposed of. Units, or a combination of units, are available to treat the range of flows proposed (Culligan, 1992). Standard systems would feature 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.

**8.3.5.2 Evaluation of Alternatives.** Each of these alternatives would be effective in reducing the contaminant levels in the groundwater to below MCL's. Air stripping would transfer the TCE to the gas phase and would not reduce the overall volume or toxicity of the TCE. Mobility would be 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 and 157.7 grams/day (0.12 and 0.35 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 would also degrade in the atmosphere after several days. The process would be 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.

The UV/oxidation system would destroy the TCE and convert it to $CO_2$ and water. The system would effectively reduce TCE concentrations to below MCL's. Volume, mobility, and toxicity of the contaminant would all be 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 should not be a concern.

Reverse osmosis has proven effective in removing nitrates to below MCL's. Residuals from this process are easily disposed of. Volume would not be reduced, but toxicity and mobility are reduced as nitrate would remain as a constituent of a solid residue. This technology is readily available and would be 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. Vendor quotes for all equipment were obtained. O&M costs are based on pumping, chemical, and energy requirements. Where possible, costs were obtained from the vendor, otherwise costs 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.

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TABLE 8-4. GROUNDWATER REMEDIAL ALTERNATIVE COSTS[1]

| Alternative | GW-0[2] | GW-1[2] | GW-2A[3] | GW-2B[3] | GW-3A[4] | GW-3B[4] |
|---|---|---|---|---|---|---|
| Capital Cost | $0 | $685,000 | $1,536,000 | $2,072,000 | $3,557,000 | $4,228,000 |
| Annual O&M Cost | $0 | $0 | $232,000 | $238,000 | $481,000 | $514,000 |
| Annual Monitoring for Six Additional Wells | $0 | $24,300 | $24,300 | $24,300 | $24,300 | $24,300 |
| Lifecycle Present Worth Cost of Annual Costs | $0 | $374,000 | $2,890,000 | $2,957,000 | $4,747,000 | $5,057,000 |
| Total Present Worth Costs | $0 | $1,059,000 | $5,111,000 | $5,714,000 | $8,989,000 | $9,970,000 |

[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] 13-year life.

# 9.0 DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

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.

## 9.1 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. The first two are considered "threshold criteria" and relate to statutory requirements. The next five are considered "balancing criteria" and consider a number of subcriteria to allow a more thorough analysis and evaluation. State and community acceptance are appropriately reviewed during the receipt of public comment and 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.

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### 9.1.1 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.

### 9.1.2 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.

### 9.1.3 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.

### 9.1.4 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.

### 9.1.5 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), as well as the speed with which risks posed by the site are addressed. 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.

### 9.1.6 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.

### 9.1.7 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 EPA 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



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discounting all future costs and annual costs to a common base year. For this report a discount rate of 5 percent was used to determine present worth costs. Detailed costs are presented in section 8.0 with backup provided in appendix N.

### 9.1.8 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-EA report and the proposed plan are received.

### 9.1.9 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-EA report and proposed plan are received.

## 9.2 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.

### 9.2.1 Alternative S-0 (No Action)

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

**9.2.1.1 Criterion 1--Overall Protection of Human Health and the Environment.** 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 would both be within acceptable ranges set forth in the NCP.

**9.2.1.2 Criterion 2--Compliance with ARAR's.** MTCA cleanup levels would not be achieved by this alternative.

**9.2.1.3 Criterion 3--Long-Term Effectiveness and Permanence.** 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.

**9.2.1.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** There would be no reduction in the toxicity, mobility, or volume of the contaminants under this alternative.

**9.2.1.5 Criterion 5--Short-Term Effectiveness.** Because no active remedial actions would be undertaken there would be no short-term risks to remedial workers or the public. There would be no impacts to the environment due to construction or operation.

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

**9.2.1.7 Criterion 7--Cost.** The present worth cost of this alternative is estimated at $802,000.

### 9.2.2 Alternative S-1B

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

**9.2.2.1 Criterion 1--Overall Protection of Human Health and the Environment.** 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.

**9.2.2.2 Criterion 2--Compliance with ARAR's.** Achievement of MTCA cleanup levels may not be possible for the bioremediation of BEHP at the Discolored Soil Site. 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 would be significantly reduced. The asbestos cap would comply with the requirement for capping inactive landfills containing asbestos. Installation of a soil cap would be consistent with the EPA policy for closure of landfills containing contaminants at low concentrations. Warning signs would alert the public to the potential hazards of the landfill as required.



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**9.2.2.3 Criterion 3--Long-Term Effectiveness and Permanence.** Cleanup to the MTCA levels at the Discolored Soil Site and Ephemeral Pool subunits would reduce residual risks at those sites to the E-6 range and below. Because the PCB's at HRL would not be 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 would be adequate and reliable controls which would significantly reduce the potential for exposure. Continued yearly downgradient monitoring would determine if contaminants are migrating offsite and if additional remedial measures would be necessary.

**9.2.2.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** The toxicity of the bioremediated Discolored Soil Site soil would be 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 would not reduce either the toxicity, mobility, or volume of PCB-contaminated soil at HRL. The mobility of fugitive dust containing asbestos would be reduced.

**9.2.2.5 Criterion 5--Short-Term Effectiveness.** 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 would be required to wear protective coveralls to protect against dermal exposure. At HRL, special construction practices including dust suppression would be utilized to prevent worker exposure to asbestos.

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

Bioremediation of the Discolored Soil Site 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 would be required to complete the capping and installation of the fence at HRL.

**9.2.2.6 Implementability.** Bioremediation is a commonly used technology that requires no special equipment. Initial operator training would be required to establish procedures for culturing the microorganisms and for supplementing and aerating the soil. Confirmatory testing would be required to determine when cleanup levels are achieved. If this treatment

cannot achieve cleanup objectives, other methods described in this report can be readily instituted.

Removal of PCB's to an offsite facility would also be easy to implement. Excavation of material would be by using conventional earthmoving equipment. Confirmatory testing would 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 would require only conventional earthwork practices. Earth materials for fill are available within a 16.1-km (10-mile) radius of the site. No special permits would be required.

**9.2.2.7 Cost.** The total present worth cost of this alternative is estimated at $4,107,000.

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### 9.2.3 Alternative S-1D

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

**9.2.3.1 Criterion 1--Overall Protection of Human Health and the Environment.** The use of a WAC cap in this alternative would satisfy the remedial action objectives. Potential receptor exposure to contaminants would be significantly reduced through the capping of the site and the imposition of access restrictions.

**9.2.3.2 Criterion 2--Compliance with ARAR's.** Again, MTCA cleanup levels for PCB's would not be achieved at HRL, however, exposure to the contaminant would be significantly reduced. The WAC cap conforms to state requirements for capping of landfills in arid climates. Warning signs would alert the public to the potential hazards of the landfill as required.

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

**9.2.3.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** The cap would not reduce the volume or toxicity of the PCB's. The cap would be impermeable thus infiltration would be reduced. This should further reduce the already limited mobility of the PCB's. The mobility of fugitive dust containing asbestos would be reduced.

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

**9.2.3.6 Criterion 6--Implementability.** The cap would be constructed using conventional practices and should be easily implemented. Geomembranes would be 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 would be required for construction.

**9.2.3.7 Criterion 7--Cost.** The total present worth cost of this alternative is estimated at $7,421,000.

### 9.2.4 Alternative S-2B

This alternative considers the use of onsite incineration for the destruction of contaminants at the Discolored Soil Site 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 would be employed to evaluate remedial actions.

**9.2.4.1 Criterion 1--Overall Protection of Human Health and the Environment.** Remedial action objectives would be met through this alternative. Residual risks would be reduced to less than E-6 if cleanup levels are obtained; no residual risks from these contaminants would remain if clean closure is obtained.

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

**9.2.4.3 Criterion 3--Long-Term Effectiveness and Permanence.** There should be little or no residual risks associated with remediation of this site as indicated above. If contaminants above background remain, annual monitoring would provide reliable controls to establish if subsequent releases occur.

**9.2.4.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** Toxicity of the contaminants would be significantly reduced as these processes typically have 99.9 percent destruction removal efficiencies. Incineration of soils would not reduce volume substantially. Mobility of the remaining residuals would remain the same.

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

**9.2.4.6 Criterion 6--Implementability.** Vendors are available to supply onsite incineration facilities that have proven effectiveness in remediating soils with similar contaminants. Operation of the incinerator would typically be 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.

**9.2.4.7 Criterion 7--Cost.** The present worth total cost of this alternative is estimated at $5,636,000.

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### 9.2.5 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 estimated at $8,950,000.

### 9.2.6 Alternative S-3B

This remedial alternative utilizes incineration at an offsite facility for the remediation of the Discolored Soil Site 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 would be conducted annually to monitor the effectiveness of the remedial actions.

**9.2.6.1 Criterion 1--Overall Protection of Human Health and the Environment.** This alternative would meet the site-wide remedial action objectives. Risks to human health from these specific contaminants would be reduced to below 1E-06 if MTCA cleanup levels are obtained and eliminated if the site attains clean closure.

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

**9.2.6.3 Criterion 3--Long-Term Effectiveness and Permanence.** Long-term risks, as indicated above, would be significantly reduced through this action. If contaminant residuals

do remain, monitoring of groundwater would provide adequate controls to measure the effectiveness of the action.

**9.2.6.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** Contaminant toxicity would be reduced due to the high destruction removal efficiencies associated with this process option. If residuals remain, their mobility would be unaffected. Volume would be only slightly reduced through the incineration of soils.

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

**9.2.6.6 Criterion 6--Implementability.** This alternative would be 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 would be 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 would be used to determine when cleanup levels are achieved.

**9.2.6.7 Criterion 7--Cost.** The total present worth cost of this alternative is $6,099,000.

### 9.2.7 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 estimated at $9,413,000.

### 9.2.8 Alternative S-5B

This alternative is a hybrid alternative that utilizes offsite incineration for the Discolored Soil Site soils contaminated with BEHP and, offsite disposal for the PCB's contaminated soils of the Ephemeral Pool. A cap for asbestos containment would be 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 estimated at $5,241,000.

### 9.2.9 Alternative S-5D

Like Alternative S-5B, offsite incineration for Discolored Soil Site soils and offsite disposal for Ephemeral Pool soils would be 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 estimated at $8,555,000.

### 9.2.10 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.

**9.2.10.1 Criterion 1--Overall Protection of Human Health and the Environment.** All the alternatives would meet the remedial action objectives established at the site with the exception of alternative S-0. Protection of human health would be 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 would be through one of two capping options.

**9.2.10.2 Criterion 2--Compliance with ARAR's.** All actions except alternative S-0 have the potential of meeting ARAR's. For alternative S-0, MTCA cleanup levels would not be 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 would need to be determined in order to evaluate if MTCA cleanup levels can be met. Capping options at HRL would not address MTCA cleanup levels, however, capping of landfills containing contaminants at low concentrations is consistent with EPA policy.

**9.2.10.3 Criterion 3--Long-Term Effectiveness and Permanence.** 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 Discolored Soil Site and Ephemeral Pool subunits. For Alternatives S-3B and S-3D, soils containing residuals would be disposed of onsite. Alternatives S-5B and S-5D also have high degrees of long-term permanence because contaminants would be either destroyed or removed offsite to a controlled facility. Alternatives S-1B and S-1D have the potential for long-term permanence if contaminants could be degraded to below cleanup levels. No long-term maintenance would 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 would be 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 would ensure that releases

from HRL would not be occurring and would be 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.

**9.2.10.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** Toxicity would be 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 Discolored Soil Site only.

Onsite mobility would be 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 would not reduce the toxicity, mobility, or volume of contaminated soils.

**9.2.10.5 Criterion 5--Short-Term Effectiveness.** All alternatives present relatively low risks to the community during implementation. Some fugitive dust emissions from cap construction activities would be anticipated although precautions would be taken to reduce these to protect both remedial workers and the community. Risks to remedial workers for all other alternatives would 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 would be accomplished within 3 months of initiating field activities. The capping options in each of the alternatives would be constructed within 6 months of initiating field activities.

**9.2.10.6 Criterion 6--Implementability.** All alternatives would be 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 would be 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 would be able to transport these materials.

**9.2.10.7 Criterion 7--Cost.** 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 would be the same because total cleanup of the Discolored Soil Site and Ephemeral Pool subunits is assumed and the only costs would be associated with the yearly monitoring of wells downgradient of HRL. Options that use the asbestos cap at HRL would be 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 would be less costly than alternatives that utilize either onsite or offsite incineration. A summary of estimated costs is presented in table 8-2.

**9.2.10.8 Summary of Soil Remedial Alternatives Evaluation.** Table 9-1 is a summary of the evaluation of groundwater alternatives versus the seven criteria against which they were evaluated.

## 9.3 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.

### 9.3.1 Alternative GW-0

No active remedial measures would be undertaken under this alternative. Annual groundwater monitoring would be implemented to evaluate the migration of contaminants over time. Exiting 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.

**9.3.1.1 Criterion 1--Overall Protection of Human Health and the Environment.** This alternative would meet the remedial action objectives of the site. Overall risks to human health would be minimal because there are no current receptors. Continued use of the institutional controls would 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 would groundwater with TCE above MCL's cross the George Washington Way diagonal.

**9.3.1.2 Criterion 2--Compliance with ARAR's.** This alternative would attain SDWA MCL's by the year 2017 through natural attenuation as estimated by groundwater modeling. No other ARAR's apply to this alternative.

**9.3.1.3 Criterion 3--Long-Term Effectiveness and Permanence.** After natural attenuation to below MCL's is complete, the long term residual incremental cancer risk would be reduced to 1E-6 for TCE and the hazard quotient for nitrates would be 0.17. Groundwater monitoring would be a reliable control to determine the rate and concentration of plume migration.



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**TABLE 9-1. EVALUATION OF SOIL REMEDIAL ALTERNATIVES**

| CERCLA CRITERIA | S-0 No Action | S-1B | S-1D | S-2B | S-2D | S-3B | S-3D | S-5B | S-5D |
|---|---|---|---|---|---|---|---|---|---|
| Overall Protection | M | H | H | H | H | H | H | H | H |
| Compliance with ARAR's | L | M/H | M/H | H | H | H | H | H | H |
| Long-Term Effectiveness and Permanence | M | H | H | H | H | H | H | H | H |
| Reduction of Toxicity, Mobility, Volume | L | M/H | M/H | M/H | M/H | M/H | M/H | M/H | M/H |
| Short-Term Effectiveness | M/L | M/H | M/H | M/H | M/H | H | H | H | H |
| Implementability | H | H | H | M/H | M/H | H | H | H | H |
| Cost (Present Worth) Thousands of Dollars | $802K | $4,107K | $7,421K | $5,636K | $8,950K | $6,099K | $9,413K | $5,241K | $8,555K |

L = Low--Does not meet all elements of the Criterion adequately
M = Medium--Does meet all elements of the Criterion adequately
H = High--Meets all of the elements of the Criterion to a high degree

**9.3.1.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** The toxicity of contaminants would be reduced through the effects of diffusion, dispersion, and dilution. Mobility and volume would remain the same.

**9.3.1.5 Criterion 5--Short-Term Effectiveness.** There would be 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 would be complete in 22 years.

**9.3.1.6 Criterion 6--Implementability.** This alternative would be easily implemented. The annual groundwater monitoring would be conducted under procedures already established for this site.

**9.3.1.7 Criterion 7--Cost.** There would be no costs associated with this alternative.

### 9.3.2 Alternative GW-1

This alternative would be similar to the no action alternative except that points of compliance would be established on a line just west and parallel to George Washington Way. Three monitoring wells would be installed along this line to monitor the plume migration. A contingency plan would be implemented if TCE above MCL's is detected at any of these wells.

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

**9.3.2.2 Criterion 2--Compliance with ARAR's.** This alternative would comply with SDWA MCL's when attenuation is complete.

**9.3.2.3 Criterion 3--Long-Term Effectiveness and Permanence.** The residual incremental cancer risk associated with attenuation to MCL's would be 1E-6 and the hazard quotient would be 0.17. Groundwater monitoring would be a reliable control to determine if attenuation is complete.

**9.3.2.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** There would be no reduction in contaminant volume or mobility under this alternative. Contaminant toxicity would be reduced through dispersion, diffusion, and dilution.

**9.3.2.5 Criterion 5--Short-Term Effectiveness.** Because there would be no downgradient users of this aquifer, and because contaminants would not be extracted, the risks to the community during remediation would be minimal. Risks associated with monitoring well installation would also be low. There is no transfer of contaminants from one media to

another. There is no transport of contaminants or disposal at another site. Natural attenuation to MCL's would be expected to be complete in 22 years under the most conservative modeling estimate.

**9.3.2.6 Criterion 6--Implementability.** This alternative would be technically easy to implement with the only new construction consisting of well development. Obtaining regulatory approval for setting the points of compliance and leaving contaminants in place would be required. Annual groundwater monitoring would reliably evaluate the effects of natural attenuation throughout the remediation timeframe. If TCE above the MCL is detected at the points of compliance, a contingency plan would be implemented to assure an appropriate response.

**9.3.2.7 Criterion 7--Cost.** The total present worth cost of this alternative is estimated at $1,059,000, which assumes that natural attenuation would occur as modelled and that no additional remedial action would be necessary. This cost includes the capital cost of well construction and annual monitoring cost over a 30-year period.

### 9.3.3 Alternative GW-2A

Groundwater would be actively remediated under this scenario. An extraction rate of 0.38 $m^3$/min (100 gpm) would be used. Groundwater would be 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 would be recharged through an infiltration trench. Current institutional controls would remain in place and six additional monitoring wells would be installed.

**9.3.3.1 Criterion 1--Overall Protection of Human Health and the Environment.** This alternative meets the remedial action objectives for the site. Risks to human health would be minimal because there are no current or potential consumptive users of the groundwater. Remediation to below MCL's would be expected by the year 2012.

**9.3.3.2 Criterion 2--Compliance with ARAR's.** The groundwater would be remediated to SDWA MCL's. TCE emissions from the air stripper would not be expected to be above levels that require treatment.

**9.3.3.3 Criterion 3--Long-Term Effectiveness and Permanence.** Remediation to MCL's reduces the site incremental cancer risk to below 1E-6 and the hazard quotient to 0.17. However, it should be noted that while case studies have shown pump and treat options to be effective in controlling contaminant migration, it is less effective in cleaning up an aquifer to MCL's. Groundwater monitoring would 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.

**9.3.3.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** This extraction scenario would only capture 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 would be increased. However, TCE would degrade naturally in the atmosphere after a number of days.

Likewise, only a portion of the nitrate plume would be captured and the remainder would be allowed to attenuate naturally. There would be no reduction of nitrate volume. However, toxicity and mobility would be reduced because nitrate would be contained in the solid residue remaining after treatment.

**9.3.3.5 Criterion 5--Short-Term Effectiveness.** There would be no downgradient users of the aquifer so the risks to the community from ingestion would be minimal. The risks associated with TCE emissions would also be 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 would be low.

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

**9.3.3.6 Criterion 6--Implementability.** This alternative would be implemented easily. The required equipment, materials, and construction techniques are common to industry. The treatment units should reliably meet remediation goals.

**9.3.3.7 Criterion 7--Cost.** The total present worth cost for this alternative, including additional monitoring wells and yearly sampling, is $5,111,000.

### 9.3.4 Alternative GW-2B

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

**9.3.4.1 Criterion 1--Overall Protection of Human Health and the Environment.** This alternative meets the remedial action objectives for the site. Risks to human health would be minimal because there are no current or potential consumptive users of the groundwater. Remediation to below MCL's would be expected by the year 2012.

**9.3.4.2 Criterion 2--Compliance with ARAR's** SDWA MCL's would be met under this alternative. No other ARAR's were identified.

**9.3.4.3 Criterion 3--Long-Term Effectiveness and Permanence.** Remediation to MCL's reduces the site incremental cancer risk to below 1E-6 and the hazard quotient to 0.17. However, it should be noted that while case studies have shown pump and treat options to be effective in controlling contaminant migration, it is less effective in cleaning up an aquifer to MCL's. Groundwater monitoring would 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.



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**9.3.4.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** This treatment scheme would destroy TCE and thus would reduce its volume. Again, only the portion of the plume above 35 ppb would be captured using this extraction scenario. The remainder of the plume would be allowed to naturally attenuate.

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

**9.3.4.5 Criterion 5--Short-Term Effectiveness.** There would be minimal risks to the community and remedial workers during the implementation of this alternative. The environment would be slightly impacted by construction activities. It is estimated that the plume would be remediated to below MCL's in 17 years.

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

**9.3.4.7 Criterion 7--Cost.** The total present worth cost of this alternative is $5,714,000. The costs of institutional controls are included.

### 9.3.5 Alternative GW-3A

Under this alternative, groundwater would be extracted at a rate of 1.14 $m^3$/min (300 gpm) through three extraction wells. The water would be treated through a treatment train similar to that of alternative GW-2A, except that it would be sized for the larger flow. Six additional monitoring wells would be installed and existing institutional controls remain in place.

**9.3.5.1 Criterion 1--Overall Protection of Human Health and the Environment.** This alternative meets the remedial action objectives for the site. Risks to human health would be minimal because there are no current or potential consumptive users of the groundwater. Remediation to below MCL's would be expected by the year 2008.

**9.3.5.2 Criterion 2--Compliance with ARAR's.** The groundwater would be remediated to SDWA MCL's. TCE emissions from the air stripper would not be expected to be above levels that require treatment.

**9.3.5.3 Criterion 3--Long-Term Effectiveness and Permanence.** Remediation to MCL's reduces the site incremental cancer risk to below 1E-6 and the hazard quotient to 0.17. However, it should be noted that while case studies have shown pump and treat options to be effective in controlling contaminant migration, it is less effective in cleaning up an aquifer to MCL's. Groundwater monitoring would 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.

**9.3.5.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** This extraction scheme captures the portion of the TCE plume that would be above the 5 ppb MCL. The remaining contaminants would be allowed to migrate and attenuate naturally. TCE mobility would be increased when it is stripped and transferred to the gas phase. However, TCE would degrade in the atmosphere after only a few days.

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

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

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

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

**9.3.5.7 Criterion 7--Cost.** The total present worth cost of this alternative is estimated at $8,989,000. This cost includes the cost of institutional controls.

### 9.3.6 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.

**9.3.6.1 Criterion 1--Overall Protection of Human Health and the Environment.** Risks to human health would be minimal because there would be no current or potential consumptive users of the groundwater. Remediation to below MCL's would be expected by the year 2008. Therefore, this alternative meets site remedial action objectives.

**9.3.6.2 Criterion 2--Compliance with ARAR's.** SDWA MCL's would be met under this treatment alternative. No other ARAR's were identified.

**9.3.6.3 Criterion 3--Long-Term Effectiveness and Permanence.** Site incremental cancer risks would be reduced to 1E-6 and the hazard quotient would be reduced to 0.17 when MCL's are attained. However, it should be noted that while case studies have shown pump and treat options to be effective in controlling contaminant migration, it is less effective in cleaning up an aquifer to MCL's. Maintenance would be required for pumps and treatment

units to ensure their proper operation. Groundwater monitoring would provide reliable controls to assess the effectiveness of the remedial action.

**9.3.6.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** This treatment scheme destroys TCE and thus reduces its volume. Again, only the portion of the plume above 5 ppb would be captured using this extraction scenario. The remainder of the plume would be allowed to attenuate naturally.

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

**9.3.6.5 Criterion 5--Short-Term Effectiveness.** There would be minimal risk to the community and remedial workers during the implementation of this alternative. The environment would be slightly impacted by construction activities. It is estimated that the plume would be remediated to below MCL's in 13 years.

**9.3.6.6 Criterion 6--Implementability.** This alternative would be easily implemented. The treatment system would attain the MCL goals. Equipment, material, and skilled labor would all be readily available.

**9.3.6.7 Criterion 7--Cost.** The total present worth cost of this alternative, including institutional controls, is estimated at $9,970,000.

### 9.3.7 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.

**9.3.7.1 Criterion 1--Overall Protection of Human Health and the Environment.** All alternatives protect human health and the environment by attaining the site RAO's for groundwater. There would be no current users of the groundwater and the continued use of institutional controls would ensure that consumptive use of the aquifer would not occur until remediation to below MCL's would be complete.

**9.3.7.2 Criterion 2--Compliance with ARAR's.** All alternatives attain the SDWA MCL's of 5 $\mu$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 would produce TCE air emissions, however, these quantities of TCE released would be small and do not require regulation.

**9.3.7.3 Criterion 3--Long-Term Effectiveness and Permanence.** 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 1E-06 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 would be 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 would be no users of the groundwater.

**9.3.7.4 Criterion 4--Reduction of Toxicity, Mobility, or Volume Through Treatment.** 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 would be 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 would not be reduced under any alternative. In fact, TCE mobility would be increased by transfer to the gas phase under alternatives GW-2A and GW-3A. Nitrate mobility would be reduced under all options that utilize treatment trains because it would be incorporated in a solid residue after treatment.

**9.3.7.5 Criterion 5--Short-Term Effectiveness.** All alternatives present low remedial risks to the community and to onsite remedial workers with GW-0 and GW-1 presenting the lowest risk because contaminants are not extracted and, therefore, there is no potential for exposure. Emissions from the air strippers of alternatives GW-2A and GW-3A would be relatively low. The site would be distant from the community, therefore, posing minimal risk of exposure to emissions.

Alternatives GW-0 and GW-1 would remediate the site in 22 years. Alternatives GW-2A and GW-2B would remediate the site in 17 years. It would take an estimated 13 years to remediate the site under alternatives GW-3A and GW-3B.

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

**9.3.7.7 Criterion 7--Cost.** Alternative GW-0 is the least costly. It is assumed that alternative GW-1 would not require additional remedial action in the future and it is estimated to be less costly than alternatives which actively treat the groundwater. Alternatives that treat 0.38 $m^3$/min (100 gpm) would be less costly than those that treat 1.14 $m^3$/min (300 gpm). For alternatives treating the same flows, those that use air stripping

for TCE removal would be less costly than those utilizing UV/Oxidation for the destruction of TCE. A summary of these costs is presented in table 8-4.

**9.3.7.8 Summary of Groundwater Remedial Alternatives Evaluation.** Table 9-2 is a summary of the evaluation of groundwater alternatives versus the seven criteria against which they were evaluated.

## 9.4 SUMMARY

The next step in the RI/FS process is to assemble a comprehensive site remediation plan that addresses all the contaminated soil at each operable subunit and the groundwater at the HRL. This plan would combine a soil remedial alternative with a groundwater remedial alternative. Any number of comprehensive plans could be formed. From this group of comprehensive plans, one will be selected as the preferred alternative and will be put forth as the proposed plan.

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**TABLE 9-2. EVALUATION OF GROUNDWATER REMEDIAL ALTERNATIVES**

| CERCLA CRITERIA | W-0 No Action | GW-1 Monitor | GW-2A Airstrip 100 GPM | GW-2B UV/Ox 100 GPM | GW-3A Airstrip 300 GPM | GW-3B UV/Ox 300 GPM |
|---|---|---|---|---|---|---|
| Overall Protection | M | M | M | M | M | M |
| Compliance with ARAR's | M/H | H | H | H | H | H |
| Long-Term Effectiveness and Permanence | M | M | M | M | M | M |
| Short-Term Effectiveness | M | M | M | M | M | M |
| Reduction of Toxicity, Mobility, Volume | M | M | M | M | M | M |
| Implementability | H | H | M | M | M | M |
| Cost (Present Worth) Thousands of Dollars | $0 | $1,059K | $5,111K | $5,714K | $8,989K | $9,970K |

L= Low--Does not meet all elements of the Criterion adequately
M = Medium--Does meet all elements of the Criterion adequately
H = High--Meets all of the elements of the Criterion to a high degree

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