UCRL-AR-113861

Final Feasibility Study for the Pit 6 Operable Unit Lawrence Livermore National Laboratory Site 300

R. Devany*
R. Landgraf
T. Berry*

Authors
D. Carpenter
G. Caviness*
L. Green-Horner*
L. Hall
V. Madrid*
B. McDowell
T. McClish*

K. Rauhut
D. Scott*
M. Shin*
S. Vonder Haar*

Technical Contributors
P. Ottesen

T. Carlsen
R. Ferry*
A. Lamarre
D. MacQueen
A. Martorana*
B. Mukhopadhyay
P. Webster-Scholten

December 1994

*Weiss Associates, Emeryville, California

Environmental Protection Department
Environmental Restoration Division

Work performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Certification

I certify that the work presented in this report was performed under my supervision. To the best of my knowledge, the data contained herein are true and accurate, and the work was performed in accordance with professional standards.

ALBERT L. LAMARRE
No. 4133

Albert L Lamarre 10/24/94

Albert L. Lamarre Date
California Registered Geologist
No. 4133
License expires: June 30, 1998

Acknowledgments

A number of dedicated individuals have contributed to the Feasibility Study for the Pit 6 operable unit. The Environmental Restoration Division would like to thank the following individuals for the dedication, expertise, and hard work that made the project successful.

R. Anderson
S. Bookless*
R. Depue*
S. Emmons*
T. Finnigan
S. Haera
S. Hunter
C. Justin
H. Kennedy*
S. Markow
M. Meamber*
J. Orloff
B. Simonds
J. Sprinkle
B. Staley*
J. Tanaka*
K. Walter*

* Contract employee

Contents

List of Figures

List of Tables

Appendices

Executive Summary

This Feasibility Study (FS) was prepared at the request of the Department of Energy (DOE) by Lawrence Livermore National Laboratory (LLNL) for the Pit 6 operable unit of the LLNL Site 300 Experimental Test Site near Tracy, California. It is prepared in accordance with the terms outlined in the Site 300 Federal Facility Agreement (FFA) negotiated between DOE, U.S. Environmental Protection Agency (EPA), California Department of Toxic Substances Control (DTSC), and the California Regional Water Quality Control Board (RWQCB). This FS is prepared in compliance with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). This FS also complies with DOE Order 5400.4 by including an assessment of general environmental considerations/impacts posed by future remedial action as required by the National Environmental Policy Act (NEPA). Together with the recently completed Final Site-Wide Remedial Investigation (SWRI) report (Webster-Scholten, 1994), which characterizes the site, the FS forms the basis for evaluating and selecting remedies for the Pit 6 operable unit.

The Pit 6 operable unit is a subarea of the SWRI Pit 6 Area study area and consists of about 43 acres containing the former waste disposal area (pit 6) and its related ground water contaminant plume. The Pit 6 operable unit is located in the southwest quadrant of Site 300 about 2 miles west of the Site 300 entrance on Corral Hollow Road. Historical information indicates that about 1,911 yd^3 of solid waste were disposed in several shallow burial trenches at pit 6 between July 1963 and February 1973. As was typical for disposal areas of that era, no preconstruction geologic, engineering, or hydrologic studies were conducted. Also, no efforts were made to contain the waste in the subsurface (i.e., clay or synthetic liner systems). A site logbook and other records indicate that waste in pit 6 consists of miscellaneous solids, including shop and laboratory materials contaminated with residues of uranium and beryllium, capacitors, empty drums and tanks, compressed gas cylinders, pallets, and mercury-filled lamps and ignition tubes. About 8% (149 yd^3) of the waste is animal carcasses and waste from biomedical experiments conducted by LLNL and Lawrence Radiation Laboratory, Berkeley. At the time of burial, some of the biomedical waste contained milli- and micro-curie quantities of short-lived radionuclides.

Since 1982, ground water monitoring, surface and subsurface soil sampling, soil vapor surveys, radiation surveys, and air monitoring have been conducted at the Pit 6 operable unit. Resulting data indicate that the only environmental release from pit 6 consists of trichloroethylene (TCE), and to a lesser degree, other volatile organic compounds (VOCs), which have migrated from the southern-most trench through about 20 ft of unsaturated alluvium to shallow ground water. The highest historic total VOC concentration detected in ground water was 250 µg/L (parts per billion [ppb]) TCE in November 1989. Since then, VOC concentrations in nearly all monitor wells have shown a distinct declining trend. Currently, total VOC concentrations do not exceed 20 ppb in any monitor wells within the Pit 6 operable unit. Available data suggest that VOC mass is naturally declining, due to source depletion and evaporation from the shallow plume. As a result, drinking water maximum contaminant levels

(MCLs) currently are exceeded in only 2 monitor wells. Because of this decline, we expect concentrations in these wells to decrease to or below MCLs in a few years.

VOCs are migrating eastward in Quaternary alluvial deposits and, to a lesser extent, in permeable portions of the near-vertical dipping Neroly and Cierbo Formations. The VOC plume extends about 600 ft east of its source at pit 6 and has not migrated beyond the Site 300 southern or eastern boundaries. The closest water-supply wells (CARNRW2 and CARNRW3) are at the Carnegie State Vehicular Recreation Area (SVRA) residence area and lie about 600 ft east of the downgradient leading edge of the VOC plume.

Trichloroethylene has been the most frequently detected contaminant in soil, soil vapor, ground water, and surface water within the Pit 6 operable unit, and has been identified as the primary contaminant of concern. Other chemicals associated with the TCE release include 1,1-dichloroethylene, 1,2-dichloroethylene, 1,1,1-trichloroethane, acetone, chloroform, freon compounds, methylene chloride, tetrachloroethylene, toluene, and xylene.

A risk assessment was performed as part of the SWRI to evaluate the potential risk and hazard to adults and animals that may be exposed to contaminants detected in soil and ground water. This analysis included the potential ingestion of contaminated ground water from CARNRW2, inhalation of VOCs that volatilize from the surface of the residence pond at the Carnegie SVRA, inhalation of VOCs that volatilize from soil in the vicinity of pit 6 and nearby spring 7, inhalation of VOCs that volatilize from spring 7 surface water, inhalation of particulates, and ingestion of and dermal exposure to surface soil contaminants. Of these scenarios, inhalation of VOCs at pit 6, spring 7, and near the residence pond exhibit potentially unacceptable levels of risk and/or hazard. However, these estimates are conservative by design and are only slightly elevated above the EPA's threshold unacceptable excess cancer level of 1×10^{-6} and hazard index of 1. For example, the highest risk is at spring 7 where the risk assessment indicates a hazard index of 1.5 and an excess cancer risk of 4×10^{-5} for a health-conservative scenario of adults working outdoors at spring 7 for their entire career (25 y). The estimates for inhalation risks at pit 6 and the residence pond indicate much lower risks (hazard index less than 1 and excess cancer risks of 5×10^{-6} and 3×10^{-6}, respectively). Available data and the conceptual hydrologic/contaminant transport model indicate that it is unlikely that VOC concentrations above drinking water MCLs will reach off-site receptors at the Carnegie SVRA. This is supported by contaminant fate and transport modeling, which suggests that the maximum TCE concentration to be expected at the Carnegie SVRA wells is 1 µg/L (ppb) after a period of 60 years.

As part of the FS process, we identified the federal, state, and local chemical-, location-, and action-specific Applicable or Relevant and Appropriate Requirements (ARARs), as well as other criteria to be considered (TBC). The identification of ARARs and TBCs, combined with site conditions and potential exposure routes and receptors, resulted in the development of the following remedial action objectives (RAOs) for the Pit 6 operable unit:

- Prevent the off-site ingestion of ground water that contains VOC concentrations above the state and federal drinking water MCLs.
- Reduce the likelihood of any future releases of hazardous materials from pit 6.
- Mitigate the potential for worker inhalation exposure to VOCs that may volatilize from spring 7 to levels below 10^{-4} to 10^{-6} excess cancer risk and a hazard index less than 1.

- Mitigate potential residential inhalation exposure to VOCs that may volatilize from the SVRA residence pond to levels below 10^{-4} to 10^{-6} excess cancer risk.
- Mitigate potential worker inhalation exposure to VOCs that may volatilize from subsurface soil at the rifle range at pit 6 to levels below 10^{-4} to 10^{-6} excess cancer risk.

General Response Actions capable of achieving these RAOs at the Pit 6 operable unit include containment, extraction, source removal, treatment, disposal, and administrative controls. Screening on the basis of effectiveness, implementability, and cost indicates that source removal is the only one of these actions that is not implementable at the Pit 6 operable unit. The staggering cost (potentially exceeding $68 million) and likely negative impacts to human health and the environment due to releases during excavation, treatment, transportation, and disposal of the waste make it nonimplementable. For the remaining General Response Actions, technology and process options were explored and assembled into four alternatives.

The key features of these alternatives and present-worth costs are summarized in Table EX-1. Alternative 1, the required no-action baseline alternative, includes only ground water monitoring. Alternative 2 includes a pit cover, contingency fencing at spring 7 to mitigate potential worker exposure, contingency point-of-use ground water treatment, and additional ground water monitoring. Alternative 3 includes all elements of Alternative 2 and adds ground water extraction and treatment, if necessary. Alternative 4 includes all elements of Alternative 3 plus subsurface permeability reduction barriers.

These alternatives were compared using the first seven of the following nine EPA evaluation criteria:

1. Overall protection of human health and the environment.
2. Compliance with ARARs.
3. Long-term effectiveness and permanence.
4. Reduction of toxicity, mobility, and volume.
5. Short-term effectiveness.
6. Implementability.
7. Cost.
8. State acceptance.
9. Community acceptance.

The results of the comparative analysis of the remedial alternatives are presented in Table EX-2. State and community acceptance will be addressed in the Record of Decision report following comments on the FS report and the proposed plan.

As part of DOE NEPA/CERCLA integration requirements, we also evaluate the potential impacts that implementation of the remedial alternatives would have on the environment on site and off site.

Table EX-1. Pit 6 operable unit remedial alternatives.

	Alternative 1 No action	Alternative 2 Risk mitigation and natural attenuation	Alternative 3 Risk mitigation with enhanced mass removal	Alternative 4 Release mitigation with enhanced mass removal
Key features	No remedial action	All elements of Alternative 1 plus:	All elements of Alternative 2 plus:	All elements of Alternative 3 plus:
	Ground water monitoring	Pit cover	Contingency ground water extraction and treatment	Subsurface permeability reduction barriers around each pit 6 burial trench/pit
	Possible natural attenuation of VOCs to levels below MCLs	Administrative controls (contingency fencing around spring 7, restricted site access)		
		Contingency point-of-use treatment		
Present-worth cost (1994 dollars)[a]	$1.97M	$5.05M	$11.25M	$18.87M

[a] Estimated costs are based on 30 years of post-construction monitoring. Alternatives 3 and 4 costs also include 25 years of ground water extraction and treatment system operation and maintenance.

Table EX-2. Comparative evaluation of remedial alternatives for the Pit 6 operable unit.

Alternative	Overall protection of:		Compliance with ARARs[a]	Long-term effectiveness and permanance		Reduction in toxicity, mobility, and volume (TMV)						Short-term effectiveness	Implement-ability	Cost[d]	State acceptance	Community acceptance
	Human health	Environ-ment		Ground water[b]	Trenches	Ground water[b]			Trenches							
						T	M	V	T	M[c]	V					
Alternative 1	◑	◑	●	◑	○	◑	◑	◑	○	○	○	Not applicable	●	1.97M	TBD	TBD
Alternative 2	●	◑	●	◑	●	◑	◑	◑	○	●	○	●	●	5.05M	TBD	TBD
Alternative 3	●	●	●	●	●	●	●	●	○	●	○	●	●	11.25M	TBD	TBD
Alternative 4	●	●	●	●	●	●	●	●	○	●	○	●	●	18.87M	TBD	TBD

○ = Does not meet criteria

◑ = May meet criteria

● = Meets criteria

TBD = To be determined

a = Alternatives may not meet all requirements of SWRCB Resolutions 68-16 and 92-49.

b = VOCs in ground water are naturally attenuating, thus TMV may also be reduced by Alternatives 1 and 2.

c = In Alternatives 2, 3, and 4, mobility is reduced by the installation of a pit cover. In Alternative 4, mobility is further reduced by installing subsurface permeability reduction barriers.

d = Total present worth.

1. Introduction

This Feasibility Study (FS) was prepared by Lawrence Livermore National Laboratory (LLNL) for the Pit 6 operable unit of the LLNL Site 300 Experimental Test Site near Tracy, California. It is prepared in accordance with the terms outlined in the Site 300 Federal Facility Agreement (FFA). The FFA was negotiated between the Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), California Department of Toxic Substances Control (DTSC), and California Regional Water Quality Control Board (RWQCB). The FFA provides the framework for the conduct of the site cleanup and preparation of necessary regulatory documents. This FS is prepared in compliance with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). This FS, along with the previously conducted Site-Wide Remedial Investigation (SWRI) (Webster-Scholten, 1994), forms the basis for evaluating and selecting alternative technologies for remediation of health and environmental effects that may arise as a result of the presence of potentially hazardous materials in the Pit 6 operable unit. The FS process involves:

- Identifying remedial action objectives based on site conditions and Applicable or Relevant and Appropriate Requirements (ARARs).
- Identifying general response actions.
- Identifying potential treatment and containment technologies and the associated process options.
- Screening various technologies and process options based on their effectiveness, implementability, and cost.
- Assembling the selected technologies into alternatives for remediation of the contaminated media within the Pit 6 operable unit.

1.1. Purpose

The purpose of this FS is to develop and evaluate alternatives for remedial action within the Pit 6 operable unit, in accordance with CERCLA/SARA and the National Environmental Policy Act (NEPA). The FS process will result in the selection and subsequent implementation of cost-effective remedial alternatives to provide adequate protection of human health and the environment.

This FS is based on the remedial investigation of the Pit 6 Area study area presented in Chapter 12 of the SWRI report (Webster-Scholten, 1994). The remedial investigation identified former disposal pit 6 as the only release source within that study area that potentially could affect human health and the environment. As a result of these findings and negotiations between the U.S. EPA, DTSC, RWQCB, DOE, and LLNL in November and December 1993, the area in the immediate vicinity of former disposal pit 6 and its associated ground water volatile organic compound (VOC) plume have been defined as the Pit 6 operable unit for the purpose of this FS. Thus, this report focuses on remedial action for contaminant releases from former disposal pit 6 only. The remainder of the Pit 6 Area study area will be incorporated into a site-wide monitoring operable unit, which will be discussed in the forthcoming sitewide Record of Decision (ROD) report.

1.2. Background

LLNL Site 300 is a Department of Energy (DOE) test facility operated by the University of California. The facility is located in the eastern Altamont Hills about 13 mi southeast of the main Laboratory in Livermore and 8.5 mi southwest of Tracy (Fig. 1-1). Site 300 is primarily a high explosives (HE) test facility that supports the LLNL Weapons Program in research, development, and testing associated with weapon components. This work includes explosives processing; preparation of new explosives; and pressing, machining, and assembly of explosives components. Site 300 activities also include hydrodynamic testing for verifying computer simulation results, obtaining equation-of-state data for weapons materials, evaluating material behavior at assembly joints and welds, evaluating the quality and uniformity of implosion, and performance evaluation of postnuclear-test design modifications (LLNL, 1991a). Occasionally, experiments performed at Site 300 do not involve HE. These experiments may require more space or isolation, or may have other requirements that cannot be met at the Livermore Main Site (U.S. DOE, 1982). Access to Site 300 is restricted.

Prior to August 1990, investigations of potential chemical contamination at Site 300 were conducted under the oversight of the California RWQCB—Central Valley Region. In August 1990, Site 300 was placed on the National Priorities List (NPL). Since then, all investigations, including the preparation of the SWRI report, have been conducted in accordance with CERCLA under the oversight of the three supervising regulatory agencies: the EPA, the RWQCB, and the DTSC.

The Pit 6 operable unit encompasses a portion of the Pit 6 Area study area described in the SWRI. Located in the southwestern portion of Site 300 (Fig. 1-2), the operable unit consists of the area immediately surrounding closed disposal pit 6. The active Small Firearms Training Facility (SFTF) is located within the operable unit, as are portions of the Carnegie historic site and several old mining prospects and adits. The Carnegie State Vehicular Recreation Area (SVRA) is located mainly to the south across Corral Hollow Road. However, a residence area for the SVRA ranger and some staff members is located north of Corral Hollow Road and is largely surrounded by the operable unit. Locations of Pit 6 operable unit facilities and adjacent features are shown in Figure 1-3.

As a result of waste buried in pit 6, volatile organic compounds (VOCs) have been inadvertently released to the subsurface. Analytical data presented in the SWRI report indicate that VOCs and aromatic compounds are present in soil/rock, soil vapor, surface water, and ground water. These data also indicate that no significant concentrations of metals, HE compounds, radionuclides, PCBs, or other chemical compounds have been released to the environment at the Pit 6 operable unit.

Trichloroethylene (TCE) has been the most frequently detected VOC in soil and soil vapor, as well as in surface and ground water, within the Pit 6 operable unit. TCE has been identified as the primary chemical of concern; other chemicals associated with the TCE releases in the study area include 1,1,1-trichloroethane (TCA), acetone, chloroform, 1,2-dichloroethylene (DCE), freon compounds, methylene chloride, tetrachloroethylene (PCE) toluene, and xylene.

From 1964 to 1973, waste was buried in nine separate trenches within pit 6; these include three solid waste trenches and six smaller animal pits. The present volume of the waste is approximately 1,911 yd^3. The nine trenches comprise only about 6% of the total area within the pit 6 former fence line (Fig. 1-3). The three solid waste disposal trenches contain approximately 1,762 yd^3 of solid waste that includes empty drums, glove boxes, lumber, filters, ducting, and capacitors. Records indicate that some of this material may have contained residues of uranium and beryllium. The six animal pits contain approximately 149 yd^3 of animal carcasses and animal wastes containing short-lived radionuclides. There are no known reports of bulk dumping, liquid disposal, or the burning of waste material at pit 6. No firing table gravel or shot debris are buried in any of the pits or trenches.

1.2.1. Description of Site 300

Site 300 is located in the southeastern Altamont Hills of the Diablo Range, about 30 mi east of San Francisco Bay. Site 300 is situated about 17 mi east-southeast of Livermore and 8.5 mi southwest of Tracy, California, and covers 10.4 mi^2, most of which is in San Joaquin County (Figs. 1-1 and 1-2). The western one-sixth of the site is located in Alameda County.

The topography of Site 300 consists of a series of steep hills and canyons generally oriented northwest to southeast. Elevation ranges from about 500 ft in the southeast corner to about 1,750 ft in the northwestern area. Grassland cover grows seasonally. The climate of Site 300 is semiarid and windy. The average annual rainfall for the 27-y period from 1965 through 1991 was 10.03 in. The wind is predominantly from the west-southwest; the temperature extremes in 1991 ranged from 102 degrees in July to 27 degrees in December. The estimated potential evapotranspiration (defined by the U.S. Department of Agriculture [USDA] as the amount of moisture a plant could use if it had all the moisture it needed) at Site 300 is about 30.6 in. (USDA, 1966).

The seven major plant habitats occurring at Site 300, four upland habitats and three less extensive wetland habitats, consist of 14 plant communities containing 343 plant taxa. The upland habitats include introduced grassland, native grassland, coastal sage scrub, and oak woodland. The rare wetland habitats consist of northern riparian woodland, vernal pool, and the most frequently-encountered, herbaceous wetlands. Fauna observed at Site 300 include 20 species of reptiles and amphibians, 70 species of birds, and 25 species of mammals. Mammals include mice, hares, squirrels, skunks, foxes, and black-tailed deer. Detailed ecological information including assessment of endangered species at Site 300 is included in the SWRI report.

Site 300 has been divided into several operable units based on the nature and extent of contaminants at the site. The Pit 6 operable unit is in the southwestern portion of the site (Fig. 1-2).

Off-site land use in close proximity to the Site 300 boundary (Fig. 1-4) includes:

- The Gallo ranch to the south, the Connolly ranch to the south and east, and other private ranchlands to the west and north—primarily used for cattle grazing.
- California Department of Fish and Game ecological preserve to the east.

- Carnegie SVRA to the southwest—an outdoor recreational facility for off-road motorcycle riding, testing, and racing.
- Physics International, Inc. to the east—a privately owned HE testing facility.

1.2.2. Site 300 History

LLNL, operated by the University of California for the DOE, began weapons research operations at the Livermore Main Site in 1952. At that time, LLNL was a separate part of what was then the University of California Radiation Laboratory (UCRL). In July 1953, UCRL proposed the location for a HE test site along Corral Hollow Road between Livermore and Tracy, and experiments with HE began at the site in 1955. The original site was approximately 3 mi^2, and was enlarged to 10.4 mi^2 in 1957 (U.S. DOE, 1982). Prior to acquisition by UCRL, land use in the area of Site 300 was limited to sheep and cattle grazing.

1.2.3. Corrective Actions and Facility Upgrades

Concurrent with the remedial investigation of Site 300, we have conducted several corrective actions and facility upgrades. The locations of these activities are shown in Figure 1-5. Each project is briefly described below.

1.2.3.1. Pit 6 Protection Measures

After pit 6 was closed in February 1973, a 1- to 3-ft-thick native soil cap was placed over the area. In 1981–82, a drainage ditch was constructed north of pit 6 to divert sheet flow away from the landfill area (Taffet, 1990).

1.2.3.2. HE Rinsewater Lagoon Closures

In 1985, we removed nine HE rinsewater lagoons from service and replaced them with two double-lined surface impoundments. Soils beneath the lagoons were investigated, and the lagoons were capped under RWQCB guidance in 1989 (Carpenter et al., 1988).

1.2.3.3. HE Open Burn Treatment Facility Closure

In July 1993, we submitted a closure plan for the Building 829 High-Explosives Open Burn Treatment Facility (HE-OBTF), located in the northwestern part of the HE Process Area (Fig. 1-5). The HE-OBTF is used to thermally treat explosives-process waste generated by operations at Site 300 and explosives research at LLNL. The DTSC currently is reviewing the closure plan report (Lamarre et al., 1993).

1.2.3.4. Well Sealing and Abandonment

From 1988 to 1991, we sealed and abandoned eight inactive water-supply wells at Site 300. Four of these wells were located in the East Firing Area and West Firing Area (EFA/WFA), two in the HE Process Area, and two in the General Services Area (GSA). The wells were sealed to prevent contaminants from migrating into other aquifers beneath the site. This topic is described in Lamarre et al. (1988), Taffet et al. (1989), Crow and Toney (1991), McIlvride et al. (1990), and Webster-Scholten (1994).

1.2.3.5. Removal/Replacement of Firing Table Gravels

In 1988, we removed gravel containing low activities of tritium and low concentrations of metals and uranium beneath six HE firing tables in the EFA/WFA. At the three active firing tables, the gravels were replaced by fresh materials. This topic is described in Lamarre and Taffet (1989), Taffet et al. (1990), and Webster-Scholten (1994).

1.2.3.6. EFA/WFA Tritium Evaporator

We have pilot tested a treatment system involving a 20-ft-high atomizing tower that was shown to evaporate tritium-bearing ground water from well 8 spring at a maximum rate of 40 gph (Taffet and Oberdorfer, 1991). The evaporator was permitted for operation; however, treatment was discontinued to avoid transferring tritium to the atmosphere.

1.2.3.7. Underground Fuel Storage Tank Removal

Three underground tanks located near Buildings 801 and 850 in the EFA/WFA and Building 874 in the GSA were determined to have caused releases of diesel and/or kerosene to the surrounding soil. The contaminated soil was excavated, treated using enhanced soil bioremediation (ESB), and the sites were closed in accordance with environmental regulations.

1.2.3.8. Enhanced Soil Bioremediation (ESB)

We are using ESB to reduce concentrations of diesel fuel in soil excavated during underground storage tank (UST) closure activities in the GSA. During the summer of 1990, we conducted an ESB pilot study with about 1 yd^3 of soil that was contaminated with diesel fuel. During the summer and fall of 1991, we used the findings of the 1990 ESB pilot study to design and operate a full-scale ESB for 100 yd^3 of soil with average concentrations of 83 mg/kg total-extractable-petroleum-hydrocarbons (TEPH) diesel. The contaminated soil was spread out on a gravel pad, tilled, watered, and fertilized on a regular schedule. After four months, the average TEPH-diesel concentrations had declined to 40 mg/kg. The full-scale ESB is still in operation.

1.2.3.9. Building 834 Complex Remediation

We have remediated some of the VOCs in the subsurface beneath the Building 834 Complex by soil excavation and aeration, soil venting, and ground water extraction and treatment (Bryn et al., 1990; Landgraf and Miner, 1994). In addition, this facility has been used as a test bed for several innovative technology projects, including an EPA Superfund Innovative Technology Evaluation (SITE) test of a PURUS pulsed ultraviolet soil-vapor treatment system, an electrical soil-heating pilot test, and a demonstration of an electron accelerator to treat soil vapor (Matthews et al., 1992). In May 1994, ground water extraction and treatment were restarted at the core of the Building 834 Complex as part of a CERCLA Removal Action. Ground water treatment involves batch air sparging and granular activated carbon (GAC) vapor treatment.

1.2.3.10. Central GSA CERCLA Removal Action

We are currently designing and installing a ground water and soil vapor extraction and treatment system to remove VOCs released from two dry wells (sumps) in the central GSA. Ground water is being extracted from seven extraction wells and treated by air stripping or sparging, and the VOCs released as a result are processed through GAC canisters. Soil vapor will be extracted and treated using GAC. An EPA Superfund Innovative Technology Evaluation (SITE) of a Peroxidation Systems, Inc., UV/H_2O_2 ground water treatment system was performed in 1992.

1.2.3.11. Eastern GSA CERCLA Removal Action

In June 1991, we installed a CERCLA Removal Action ground water treatment system (GWTS) to remediate VOCs, primarily PCE and TCE, emanating from one or more debris burial trenches in the eastern GSA. Ground water is extracted from one to three extraction wells, treated with an air sparger, and discharged to the Corral Hollow creekbed. As of February 28, 1994, about 33 million gallons of ground water have been treated (Rueth, 1994).

1.2.3.12. RCRA Capping of Landfill Pits 1 and 7

We installed 8-ft-thick RCRA caps consisting of several engineered layers of natural earth materials, including 2 ft of low-permeability clay, on these two inactive landfills in the EFA/WFA study area. The RCRA caps are designed to prevent infiltration of precipitation that might cause the landfill contents to leach into ground water. We currently are monitoring the effectiveness of these landfill caps.

1.2.3.13. Endangered Species Reintroduction

In 1992, we reintroduced a rare endangered plant species, the large-flowered fiddleneck (*Amsinckia grandiflora*), into the Site 300 ecosystem. Site 300 contains two of the three known natural extant populations of this plant. We hope to create a third sustainable population of *Amsinckia grandiflora* at Site 300.

1.2.4. Site 300 Geology

This section contains general descriptions of the principal geologic features of Site 300. Regional geologic maps and stratigraphic columns based on studies prior to 1981 have been modified by recent investigations conducted by LLNL during the preparation of RI/FS documents. Detailed geologic logs have been prepared for most boreholes and monitor wells at Site 300. A detailed discussion of Site 300 geology is presented in Chapter 3 of Webster-Scholten (1994).

1.2.4.1. Stratigraphy

Bedrock strata exposed within Site 300 have been correlated with five mappable geologic units (Webster-Scholten, 1994). These units are the late Cretaceous Great Valley sequence (Kgv), the late Paleocene to mid-Eocene Tesla Formation (Tts), the mid-Miocene Cierbo Formation (Tmss), the late Miocene Neroly Formation (Tn), and the Pliocene nonmarine unit (Tps) of Dibblee (1980). These bedrock units are locally overlain by mid- to late Pleistocene terrace deposits and late Pleistocene to Holocene floodplain, ravine fill, landslide, and colluvial deposits (Carpenter et al., 1991; Dibblee, 1980) (Table 1-1). A schematic stratigraphic column for Site 300 is presented in Figure 1-6. Summary lithologic descriptions of these geologic units are provided in Table 1-1. Distributions of the various units are shown on the Site 300 geologic map (Fig. 1-7).

1.2.4.2. Structure

Site 300 is located in an area of historical seismicity and Quaternary folding (Eaton, 1986; Namson and Davis, 1988; Wentworth and Zoback, 1989). Structural features within Site 300 are shown on Figure 1-7.

1.2.4.2.1. Folds. The bedrock sequence within Site 300 has been slightly deformed into several gentle, low-amplitude folds (Fig. 1-7). These folds include:

- Patterson Anticline—controls bedding attitudes throughout much of Site 300; the southern limb of the structure strikes nearly east-west and dips toward the south at 5 to 25 degrees; the northern limb strikes toward the northwest and dips northeast, typically at 5 to 15 degrees.
- East Firing Area (EFA) Syncline—informally named the EFA syncline, it is a very broad, open, gently northeast-plunging fold with a wide, nearly flat axial trough (Taffet et al., 1990).
- HE Process Area Syncline—a southeast-plunging syncline that underlies the HE Process Area in the southerly portion of Site 300 (Fig. 1-7).

1.2.4.2.2. Faults. Three general types of faults have been identified within Site 300:

- West-northwest trending, high-angle, presumably strike-slip faults;
- Discontinuous, north-northeast trending, normal faults mapped chiefly in the east-central portion of Site 300 (Webster-Scholten, 1994).
- West-northwest trending, high-angle reverse and thrust faults that are mainly present on the south flank of the Patterson Anticline (Webster-Scholten, 1994).

Locations of principal faults within Site 300 are listed below and shown on Figure 1-7.

- Corral Hollow-Carnegie Fault Zone—interpreted as a right lateral strike-slip fault that crosses the southwestern portion of Site 300 and extends southeast and west beyond the limits of the site (Raymond, 1973; Dibblee, 1980). The fault system is regarded as active and is judged capable of generating an earthquake in the range of $M_S = 6.3$ to 7.1 (Carpenter et al., 1992).
- Elk Ravine Fault—a complex structure composed of pre-Holocene strike-slip faults, reverse faults, normal faults, and local folds. Two branches of the Elk Ravine Fault have been mapped as extending across Site 300 from northwest to southeast (Dibblee, 1980) (Fig. 1-7).
- Possible Midway Fault Extension (Dibblee, 1980)—a possible southeasterly extension of the Midway Fault mapped north of Site 300 across the northeastern corner of Site 300

(Fig. 1-7). The fault is classified as potentially active based on geomorphic criteria and possible associated microseismicity (CDWR, 1979).

- Terrace Fault (informal name)—a high-angle reverse fault or fault zone within the southern portion of Site 300 (Fig. 1-7). Farther east, the projection of the Terrace Fault enters the southern HE Process Area.
- Unnamed Fault (informal name)—a well-defined, north-south trending fault. Approximately 50 ft of pre-Holocene normal offset occurs along this near-vertical fault.

1.2.4.2.3. Joint and Fracture Systems. Joint sets are observed most often in the well-indurated rocks within Site 300. These rocks include the Great Valley sequence, Tesla Formation, and Neroly Formation. Joint sets are observed locally in more indurated portions of the Tps unit, but well-defined joints are uncommon in these sediments and in the poorly indurated Cierbo Formation strata.

Rock outcrops at Site 300 are pervasively fractured. Frequently, thin-bedded claystones are intensely fractured. At various locations throughout Site 300, persistent zones of high-angle (often vertical), closely-spaced, healed, and well-cemented fractures form resistant outcrops. These cemented fracture zones are generally 1 to 4 ft wide, cut across regional bedding, strike dominantly north to northeast with a vertical or near-vertical dip, and may extend for over 1 mi in length.

As presented in Chapter 3 of Webster-Scholten (1994), cores from monitor wells and exploratory boreholes often contain fractures. Fracture intensity has been characterized using the rock quality designation (RQD) system of Deere et al. (1969) locally supplemented by downhole video studies. In drill cores, iron and manganese oxide and other weathering products are visible on some fracture and bedding plane surfaces to average depths of about 100 ft. The presence of these minerals suggests circulation of oxygen-bearing ground water to these depths through the fracture network. Fractures below 100 ft are generally closed and may be filled with carbonates, sulfides, opaline silica, and clay minerals (Webster-Scholten, 1994).

1.2.4.3. Seismic Setting

Site 300 is located near the eastern margin of the seismically active San Francisco Bay region and is also within about 4 mi of the seismically active Coast Ranges—Central Valley boundary (Eaton, 1986; Namson and Davis, 1988). Seismic monitoring by LLNL (Hauk, 1990) confirms microseismic activity within the Altamont Hills in the region surrounding Site 300. Table 1-2 lists principal active and potentially active faults in the San Francisco Bay region, the Altamont Hills and the Central Valley margin areas.

Facilities at Site 300 may experience earthquake shaking from three seismic sources. These sources are:

- A major earthquake on a principal Bay Region fault.
- A strong earthquake generated by a local fault within the Altamont Hills.
- A major earthquake on a regional fault along the Coast Ranges—Central Valley boundary or possibly beneath the western portion of the San Joaquin Valley.

1.2.5. Site 300 Hydrogeology

This section describes the general framework of the hydrogeologic model of Site 300, including the occurrence of surface water, ground water, and natural ground water chemistry. Details specific to the Pit 6 operable unit are presented in section 1.3.4.

1.2.5.1. Surface Water

There are no perennial streams at Site 300. Surface water at the site consists of intermittent runoff, springs, and natural and man-made ponds. Surface water drainage basins are shown on Figure 1-8. Surface water sometimes occurs locally as a result of discharge from cooling towers.

1.2.5.1.1. Springs. There are 24 springs at and near Site 300 (Fig. 1-9). Most of the springs have very low flow rates and are recognized only by small marshy areas, pools of water, or vegetation surrounding them. Vegetation surrounding the springs includes cattails, nettles, willows, and grass. Only three of the springs have flow rates greater than 1 gal./min.

1.2.5.1.2. Other Surface Water. Site 300 contains three man-made surface water bodies (Fig. 1-9). A sewage treatment pond is located in the southeast corner of the site in the GSA, and two lined HE rinsewater impoundments are located in the HE Process Area study area. The Carnegie SVRA residence pond is located off site just east of pit 6 at the mouth of Middle Canyon. In addition, there are four small off-site stock watering ponds in the area north of Site 300. As mentioned above, other surface water at Site 300 results from blowdown water from cooling towers.

There is a natural pool in the northwest corner of Site 300, within the EFA/WFA. It is a perennial pool created by ponding of water in a natural depression.

1.2.5.1.3. Drainage. The major drainages at Site 300 are Elk Ravine in the EFA/WFA study area; Draney Canyon, Davis Canyon, Drop Tower Canyon, Firing Range Canyon, Middle Canyon, and Paper Canyon in the Pit 6 Area study area; Long Canyon in the HE Process Area study area; and 832 Canyon, which extends along the western edges of the Building 834 and Building 833 study areas to the central GSA (Fig. 1-8). Water flows in these drainages only after heavy storms. The occasional runoff from these drainages eventually flows into Corral Hollow Creek. This creek is an intermittent stream that flows eastward along the southern boundary of Site 300 toward the San Joaquin Valley.

1.2.5.2. Ground Water

Site 300 is a large and hydrogeologically diverse site. Due to topographic relief, stratigraphic heterogeneity, and structural complexity, the stratigraphic units described in section 1.2.4 and Table 1-1 are discontinuous across the site. Consequently, unique hydrogeologic conditions govern the occurrence and flow of ground water and the fate and transport of contaminants beneath each study area. We have defined individual hydrologic units consisting of one or more stratigraphic intervals that comprise a single hydraulic system within each study area. These hydrologic units and their stratigraphic components are shown in Figure 1-10 and are described in detail in Webster-Scholten (1994). Site-wide stratigraphic relationships are depicted in cross-sections A-A' and B-B' (Fig. 1-11). The hydraulic relationships between the northwest and southeast portion of the site, however, have not yet been clearly established due to sparse well control in the center of the site. Hydrologic relationships between the Pit 6 operable unit and other portions of Site 300 are also uncertain because of long distances between the Pit 6 wells and the nearest wells in the HE Process Area study area. Separate potentiometric surface contour maps for the six major hydrologic units at Site 300 are shown in Figure 1-12. The discontinuous potentiometric surface contours between the northwestern and southeastern parts of the site are due to the lack of well control, as mentioned above.

In the northeast part of Site 300, ground water occurs under unconfined to confined conditions primarily within the $Tnbs_1$ and Tmss stratigraphic units, which are part of the Qal-Tmss hydrologic unit. As shown by the potentiometric surface contours, the general ground water flow direction in the EFA/WFA study area is to the east (Fig. 1-12). This ground water flow direction is controlled primarily by the dip of the bedding planes. Perched water-bearing zones also occur within Quaternary alluvial sands and gravels, and fractured siltstones and claystones of the $Tnbs_1$ and Tmss stratigraphic units. These perched zones are highly discontinuous and variable.

Throughout most of the southeastern part of Site 300, the $Tnbs_1$ hydrologic unit is a continuous, regional water-bearing zone (Fig. 1-12). This aquifer probably extends westward and underlies major portions of the Pit 6 operable unit. Ground water in the $Tnbs_1$ hydrologic unit occurs within sandstones of the $Tnbs_1$ stratigraphic unit under confined to flowing artesian conditions. As shown by the potentiometric surface contours, ground water generally flows to the south and southeast (i.e., in the direction of dip) in the southeastern and southern parts of Site 300 (Fig. 1-12). In the eastern GSA, the $Tnbs_1$ stratigraphic unit occurs as a subcrop beneath Corral Hollow alluvium as part of the Qal-Tmss hydrologic unit, and ground water occurs under semiconfined to unconfined conditions. The ground water flow direction in this unit is controlled primarily by the orientation of the permeable alluvial sediments beneath the Corral Hollow Creek floodplain.

Other water-bearing zones that exist in the southeastern part of the site include the $Tnbs_2$ and Tps hydrologic units. Ground water occurs under unconfined to artesian conditions in the $Tnbs_2$ hydrologic unit beneath the HE Process Area study area. The ground water flow direction in this unit is also dip-controlled and sub-parallels the flow direction in the underlying $Tnbs_1$. Perched ground water occurs primarily in gravel channels within the Tps hydrologic unit beneath the Building 834 and the HE Process Area study areas. The ground water flow direction within these shallow, perched zones is controlled by the channel geometry of the water-bearing unit and the dip direction.

Ground water-supply wells within Site 300 and within 0.5 mi of the site are shown in Figure 1-13. Site 300 ground water concentrations of total dissolved solids (TDS) generally range from 300 to 2,000 mg/L; specific conductivity ranges from 770 to 2,400 µhos/cm; pH generally ranges from 7 to 9. The ground water in this area commonly contains naturally occurring selenium and arsenic above drinking water MCLs.

1.3. Pit 6 Operable Unit Background

The Pit 6 operable unit is located within the Pit 6 Area study area in the southwestern portion of Site 300. The Pit 6 Area study area is primarily unoccupied buffer zone land, but contains pit 6, consisting of three closed shallow disposal trenches and six closed shallow disposal pits, and the active Small Firearms Training Facility (SFTF). As previously discussed, the only significant release of chemicals of concern within the Pit 6 Area study area occurred at the Pit 6 operable unit (Webster-Scholten, 1994).

VOCs, mainly TCE, have been released from the pit 6 burial trenches. The only hazardous materials known to be presently stored in the operable unit are limited quantities of gun cleaning solvents in Building 899A at the SFTF. These gun cleaning solvents are stored and used in accordance with all applicable regulations for hazardous materials control (Webster-Scholten, 1994).

1.3.1. Description of the Pit 6 Operable Unit

The Pit 6 operable unit covers approximately 43 acres located 1.8 mi west of the Site 300 entrance and 200 ft north of the Site 300 southern boundary along Corral Hollow Road (Fig. 1-2). It is situated on an alluvial terrace about 30 ft above the Corral Hollow Creek floodplain. Water generally flows in Corral Hollow Creek for only a few weeks each year after heavy precipitation. Two buildings, 899A and 899B, of the SFTF are located about 400 ft east of the disposal pits. Locations of these facilities are shown in Figure 1-3 and are further described in Table 1-3.

1.3.2. History of the Pit 6 Operable Unit

1.3.2.1. Cultural History

From the 1860s to the 1910s, the Corral Hollow area (including the Pit 6 operable unit) was known for the mining of brick clay, coal, pottery clay, manganese, glass sand, limestone, gravel, and cinnabar (U.S. DOE, 1982; Clark, 1955). From 1904 to 1912, brick and sewer pipe were manufactured in oil-fired kilns using clay from the Tesla mines located 4 mi to the west (Aubury, 1906; Clark, 1955). Approximately 2,500 people once lived in the now abandoned towns of Carnegie, Tesla, and Pottery. The Carnegie Brick and Pottery Company site (California Registered Landmark 740) is located on the Carnegie SVRA southeast of the Pit 6 operable unit. The Carnegie townsite is located within the SWRI Pit 6 Area study area, but none of the industrial areas associated with these former communities extended into Site 300 itself.

Several inactive mining prospects (adits) are located in the vicinity of the Pit 6 operable unit (Fig. 1-3 and Table 1-4). The prospects have not been worked since about 1919 (Dietrich, 1928; Clark, 1955), and none apparently became working mines. Table 1-4 lists the five mining prospects (prospects 1–5) that are located north of Corral Hollow Road near the Pit 6 operable unit. In 1990, an abandoned adit was exposed during the excavation of a bedrock outcrop in the Carnegie SVRA residence area. This adit is located about 950 ft southeast of pit 6. The adit is oriented east-west parallel to the strike of the Tesla Formation and evidently prospected several thin coal seams visible in the exposure. The adit extends westerly about 80 ft. Its opening was blocked in 1990 with several feet of soil to prevent entry. Table 1-4 also lists other off-site adits and tunnels (mine workings). All mine workings are oriented vertically or toward the south away from Site 300 (Anonymous, 1890; Dietrich, 1928; Carter, 1991). None of the mine workings on either side of Corral Hollow Road are known to underlie pit 6. After termination of mining and industrial activities in the early 1900s, the Site 300 area reverted to agricultural (sheep and cattle grazing) uses until 1955, when DOE purchased the property.

1.3.2.2. Construction of Trenches and Pits

As shown in Figures 1-3 and 1-14, the original fenced boundary of pit 6 is pentagonal in shape and encompasses approximately 2.63 acres (114,743 ft^2) (LLNL, 1973a; 1984). Although the fence has been removed, the survey corners are still marked with buried rebar (LLNL, 1984; Gonzalez, 1992). Pit 6 was opened in 1964 and, like most burial facilities of its era, was not equipped with liners; containment structures; or leachate detection, collection, and removal systems. Three trenches and six animal pits were filled with solid waste and covered with soil. Pit 6 was closed in 1973.

Figure 1-14 shows the approximate locations of the disposal trenches and animal pits. To determine their location and dimensions, we evaluated many sources of information:

- LLNL engineering drawings (LLNL, 1964; 1973a; 1984);
- Waste Material Logbook (LLNL, 1973b);
- Numerous reports, memoranda, and personal communications;
- Aerial photographs (1968);
- Terrain conductivity and ground penetrating radar (GPR) survey results (CH2M Hill, 1985);
- Magnetic survey results (Rezowalli, 1988); and
- Previous Solid Waste Assessment Test (SWAT), RI, and FS reports (Taffet and Lamarre, 1988; Taffet, 1990; Taffet et al., 1991).

The engineering drawings show that pit 6 originally was planned to consist of six large disposal trenches (LLNL, 1964). However, waste material was deposited in only three large trenches near the center of the burial pit (trenches 1, 2, and 3) and six smaller pits in the northern part (animal pits 1 through 6). Trenches 1 through 3 received 42 shipments of solid waste, and animal pits 1 through 6 received 13 shipments of animal carcasses and waste. The eastern ends of trench 2 and animal pit 4 were not filled with waste.

Each large trench (trenches 1 through 3) is approximately 165 ft long, with ramps of 25 ft and 40 ft on the east and west ends, respectively (LLNL, 1964). Because the ramps were not used for waste placement, approximately 100 ft of space was actually available for the placement of waste. The floors of the three large trenches were constructed at a depth of about 12 ft. The thickness of waste in each trench is about 10 ft. Sutton (1992) stated that the animal pits 1 through 6 were typically constructed to a depth of about 16 ft. A layer of 2 to 4 ft of animal carcasses and animal waste was placed in each pit and then covered with lime and 12 to 14 ft of soil.

The precise thickness of the soil cover on the large trenches is not known accurately. We estimate that the present soil cover averages 2 ft. Taffet (1990) stated that soil averaging 1 to 3 ft was spread over each filled trench to minimize the infiltration of precipitation. This cover was composed of native adobe-clay loam soil compacted by a series of several bulldozer passes. However, engineering drawings (LLNL, 1984) note that a thickness of 5 ft of soil was placed on top of each trench after being filled. Subsequent construction of the SFTF rifle range has further modified the soil cover.

Occasionally, metallic objects have become visible through small surface crevices. On one occasion in the mid-1980s, a partially collapsed glove box could be seen at a depth of about 2 ft (Henry, 1992). In 1991, two metallic objects were removed from the soil cover after being exposed during a rainfall (Fischer, 1992).

Engineering plans specified that a 1-ft-deep drainage ditch be dug along the northern edge of trench 2 (LLNL, 1964) to divert rainfall sheet flow. In late 1981 or early 1982, more grading was done along the north side of pit 6 to drain the hill slope to the north away from the burial pits (Henry, 1992). However, rainfall occasionally ponds next to the east end of disposal trench 1 during the rainy season. The ditches and the soil cover are inspected periodically and maintained by the LLNL Plant Engineering Department. Repairs are performed whenever structural integrity is breached, as may occur when animals burrow into the soil or a heavy rainfall occurs.

1.3.2.3. Waste in Trenches and Pits (Volume and Contents)

Fifty-five shipments of various types of wastes from the Livermore Main Site and from Lawrence Berkeley Laboratory (LBL) were buried at pit 6 between July 1, 1964 and February 20, 1973. Beginning with the first shipment of waste, LLNL personnel recorded the pit 6 disposal operations in a Site 300 Waste Material logbook (LLNL, 1973b). The logbook documents burial contents and locations for all 55 shipments of waste. A summary of the logbook is presented in the SWRI report, Table B-7, Appendix B (Webster-Scholten, 1994).

Table 1-5 summarizes the dates of usage, contents, surface areas, and volumes of the nine trenches. Table 1-6 presents a summary by Rich (1971) of wastes in trenches 1 through 3. The nine burial trenches and pits occupy a small part, approximately 6.4% (approximately 7,350 ft^2), of the area within the original pit 6 fenced boundary.

Our calculation of 47,800 ft^3 for the original waste volume in trenches 1 through 3 is reasonably close to the 54,000 ft^3 estimate by Rich (1971) of the usable volume in these three trenches. He also estimated that the volume of the uncompacted waste was approximately 64,560 ft^3.

We estimate that the present volume of waste in the three trenches and the six animal pits at pit 6 is approximately 51,585 ft^3 (1,911 yd^3). Approximately 92% (1,762 yd^3) consists of solid waste in trenches 1 through 3. The remaining 8% (149 yd^3) consists of animal carcasses and animal waste in animal pits 1 through 6. In our volume estimates, we have not accounted for any decrease in volume attributable to the decay of the animal carcasses.

The majority of drums, retention tanks, and carboys are believed to have been empty before being shipped to pit 6 for disposal. Although the logbook (LLNL, 1973b) provides information about the general types and crude sizes of buried wastes at pit 6, chemical information such as the specific identifications, quantities, volumes, and physical states of the wastes was not listed. There are no known reports of bulk dumping, liquid disposal, or the burning of waste material at pit 6, and waste material was restricted to dry waste (LLNL, 1968). No firing table gravels are known to have been buried in pit 6.

Other references do provide additional information about some disposed wastes, such as the 1,000 ft^3 of ventilation equipment and ducting that was disposed of in pit 6. This equipment and ducting contained residues of beryllium and uranium (Kvam, 1971). More than 2,000 capacitors, which may have contained polychlorinated biphenyl (PCB) dielectric fluids, also were placed in pit 6. Anecdotal information (Kvam, 1985) suggests that large volume PCB containers were drained prior to shipment to Site 300. Compressed gas cylinders (gas bottles) were also disposed of in trenches 1 through 3. Some hazardous cylinders were discharged at Site 300 firing tables before being disposed of at pit 6. The original contents of the gas cylinders are not known. Because heavy equipment was used to fill in the trenches and compact the soil cover, it is reasonable to assume that the gas cylinders were emptied first to prevent a safety hazard (Van Dyke, 1985). Items listed in Appendix B of the SWRI report with the annotation "technically contaminated" are inferred from Rich (1971) to refer to items that had detectable, but very low (i.e., microcurie), quantities of radionuclides.

The only known instance of the burial of radioactive material other than residues in the pit 6 trenches and animal pits involved three shipments (numbers 49, 51, and 53) of drummed or boxed depleted uranium (D-38) chips. LLNL management had the D-38 material excavated from trench 2 in 1971 to address potential public concerns about the burial of radioactive waste at Site 300 (Rich, 1971). Fifty-six 30-gal. drums of D-38 and one drum containing mercury waste were exhumed, packed in secondary containers, and shipped offsite on June 14 and 15, 1971 (Decker, 1971). Based on the original inventory of drums and boxes of D-38 listed in the Waste Material Logbook, we believe that two "drums" exhumed by Decker were actually the two boxes of D-38 described in shipment 49. Shipment 49 had been buried the longest, approximately 23 months.

During the 1971 exhumation operation, releases from two drums were reported. One drum leaked about 0.5 gal. of packing oil onto the asphalt road; the asphalt was removed and placed into a secondary containment drum. The containment integrity of another drum was lost completely; the spilled D-38 chips and surrounding soil were also placed into a secondary containment drum for off-site disposal. Two radiation surveys were conducted after the exhumation operation, and no residual radioactivity was detected (Decker, 1971).

As mentioned above, animal carcasses from biomedical research experiments were disposed of in animal pits 1 through 6. These carcasses included 17 cows, 2 rams, and numerous rats, dogs, and rabbits. Carcasses of large animals, such as cows, were covered with process lime (quick lime) before being covered with soil (Lawrence Radiation Laboratory, 1971). Before being buried, some small animal carcasses were placed in primary containers such as polyethylene bags or ice cream cartons; these containers were then placed in sealed, 55-gal. steel drums (Hairr, 1965). Animal wastes consisting of feces, urine, milk, and blood were also placed in containers and disposed of in animal pits 1 through 6.

Some carcasses retained very small quantities (microcuries) of radionuclides at the time of burial. At least 35 different, mostly short-lived, radionuclides had been used in the biomedical experiments (Hairr, 1965; Johnsen, 1965; Potter, 1965; Kloepping, 1971; and Slaughter, 1973). A list of these radionuclides and their respective half-lives is presented in the SWRI report, Table B-8, Appendix B. The half-lives range from 24 s for ^{110}Ag to 30 y for ^{137}Cs.

1.3.3. Pit 6 Operable Unit Geology

This section summarizes the geology of the Pit 6 operable unit originally detailed in Chapter 3 and section 12.3 of the SWRI report (Webster-Scholten, 1994). Bedrock structure and stratigraphy exert important influences on ground water flow, and therefore also influence the movements of VOCs. Hydrogeology is discussed in section 1.3.4. General geology is shown in

Figure 1-7. A more detailed geologic map of the vicinity of pit 6 is shown in Figures 1-15a and b.

1.3.3.1. Stratigraphy

Stratigraphic units in the Pit 6 operable unit include Quaternary deposits (Qal and Qt units), Pliocene nonmarine deposits (Tps), the Miocene Neroly Formation, the middle Miocene Cierbo (Tmss) Formation, and the Eocene Tesla (Tts) Formation. Regional geologic cross-section A-A', (Fig. 1-16) extends northward from the Pit 6 operable unit into the EFA/WFA study area. Regional structural and stratigraphic correlations are discussed in detail in Chapter 3 of Webster-Scholten (1994).

Geology of the immediate vicinity of the Pit 6 operable unit is shown in Figure 1-15a. Borehole and monitor well locations are also shown on this figure. Hydrogeologic cross sections were constructed in both dip (Fig. 1-17) and strike directions (Fig. 1-18) across the operable unit, using all available surface geologic and subsurface lithologic, hydrologic, and geophysical data. Table 1-7 contains detailed descriptions of the stratigraphic units encountered during drilling operations. The Quaternary (Qal and Qt units) sequence consists of unconsolidated clay, silt, sand, and gravel beds. The Tps unit is exposed southwest of pit 6 and consists mainly of poorly lithified claystone and sandstone with minor conglomerate. The underlying late Miocene Neroly (primarily $Tnbs_1$) bedrock sequence consists of claystone, siltstone, sandstone, and minor conglomerate beds. Beneath the Neroly Formation are the claystone, siltstone, and sandstone of the middle Miocene Cierbo Formation and the Eocene Tesla Formation.

Disposal trenches for pit 6 were constructed in flat-lying Quaternary terrace deposits (Qt). The maximum thickness of Quaternary deposits, including both fine and coarse-grained sediments, is about 55 ft at monitor well K6-04 near the northwest corner of pit 6. Figure 1-19 is an isopach map of the Qt unit gravel, which comprises up to one-half of the total thickness of the Quaternary deposits at pit 6. Of all the strata encountered during drilling, the gravel appeared to have the highest relative permeability. The east-west-trending gravel unit is not continuous across the operable unit, and it reaches a maximum thickness of about 20 ft beneath the northwest corner of pit 6. Past geologic studies have shown that the gravel crops out along the face of the Corral Hollow terrace and is exposed in the steep ravines to the east and west of pit 6.

Surface soils in the immediate vicinity of the operable unit consist of the Carbona clay loam and the Zacharias gravelly clay loam (USDA, 1990). Engineering and hydrologic characteristics of these soils are given in Table 1-8. Although a few landslides are present (Fig. 1-15a), they do not pose hazards to any of the operating facilities or burial pits and trenches.

1.3.3.2. Structure

The primary structural features are the northwest-southeast-trending Corral Hollow-Carnegie fault zone and the southern limb of the Patterson Anticline (Fig. 1-7). These features are shown on north-south geologic cross-section A-A' (Fig. 1-16). Details are presented in Webster-Scholten (1994).

Pit 6 is located on a southward sloping elevated terrace that overlies the northern limit of the Corral Hollow-Carnegie fault zone (Fig. 1-15a). As shown in Figures 1-16 and 1-17, the fault beneath pit 6 represents a major bedrock structural discontinuity. North of the fault, beds dip southward 10 to 30 degrees. South of the fault, the bedrock is highly fractured and sheared; beds dip near vertical to overturned by up to 30 degrees. Evidence for Holocene activity has been observed along a fault strand of the Corral Hollow-Carnegie fault zone located south of pit 6 (Carpenter et al., 1992). The Holocene fault strand is located along the edge of the elevated terrace approximately 160 ft south of disposal trench 3.

An elevation contour map (Fig. 1-20) of the angular unconformity between Quaternary deposits and Tertiary bedrock was prepared to evaluate the potential influence of this surface on the migration of TCE-contaminated ground water discussed in section 1.3.6.4. The map shows that north of pit 6, the unconformity surface dips to the south subparallel to bedrock dips on the southern limb of the Patterson Anticline. However, within the Corral Hollow-Carnegie fault zone south of pit 6, the unconformity surface displays a trough that extends parallel to the fault zone from the southeast corner of pit 6. This trough is coincident with a trend of increased Qt gravel isopach thickness (Fig. 1-19). In the portions where it is saturated, this gravel-filled trough may influence the migration of the TCE ground water plume.

1.3.4. Hydrogeology

This section summarizes the hydrogeology of the Pit 6 operable unit, including the occurrence of surface water and ground water, hydraulic gradients, fracture flow, well yields, and recharge/discharge mechanisms. Figure 1-21 presents the conceptual hydrogeologic model for the Pit 6 operable unit. Figures 1-17 and 1-18 are hydrogeologic cross sections. Geologic structure (primarily faulting and steep dip), stratigraphic heterogeneity and topographic relief are the major factors that control the occurrence and flow of ground water beneath the Pit 6 operable unit. Ground water monitoring since October 1984 indicates low, declining concentrations of TCE and other VOCs in shallow ground water within the uppermost part of the Qt-Tmss hydrologic unit.

1.3.4.1. Surface Water

When present, surface water in the Pit 6 Area study area typically results from either infrequent surface runoff from precipitation or from spring discharge (Fig. 1-21). As a result of the semiarid climate of Site 300 however, surface runoff is rarely observed, and only occurs briefly during severe (>0.3 in./h) or prolonged (>2 h) storms (Bryn et al., 1990). During severe storms, surface water may flow along one of many north-south ravines and into Corral Hollow Creek (Fig. 1-8). A small perennial pond is present within the SVRA residence area. This pond is the only sizable body of surface water in the vicinity of the Pit 6 operable unit (Fig. 1-21).

Figure 1-15a shows the locations of three springs (springs 7, 8, and 15) in the operable unit. Springs 7 and 15, are located southeast and downgradient of pit 6 along the terrace face and have intermittent flow. As water flowed from spring 7 along the edge of the SFTF access road in the 1980s, the maximum depth of visible water was typically about 1 in. Surface area estimates for standing water and moist soil at spring 7 during the 1980s were 150 and 300 ft^2, respectively. Spring 7 stopped flowing in the summer of 1990, after 4 years of drought. A flow rate of about 1 gpm was measured at spring 15 during the fall of 1991, with standing water at a maximum depth of 3 in. Surface area estimates for standing water and moist soil were 10 and 150 ft^2, respectively, and were confined to the north side of Corral Hollow Road. By June 1992, no water, green grass, or moist soil was evident at either spring 7 or 15.

The pond at the Carnegie SVRA residence area is used as stand-by fire-fighting supply. Because of poor quality and lack of supply, no beneficial uses are made of other surface water within the Pit 6 operable unit.

1.3.4.2. Ground Water

Pit 6 is situated on an elevated alluvial terrace composed of silty to clayey soil and silty gravel (Qt unit) unconformably underlain by heterogeneous Tertiary bedrock. Geologic structure and topographic relief control the lateral extent of saturation and the hydraulic gradients of the water-bearing zones. Figure 1-22 presents a local potentiometric surface map of the Pit 6 operable unit. Two hydrologic units have been defined: the Qt-Tmss and the Qal-Tts, which are hydraulically separated by faulting and lithologic discontinuities. Significant quantities of ground water are contained only in the Neroly sandstone $Tnbs_1$ subunit within the Qt-Tmss hydrologic unit. Well completion data are presented in Table 1-9.

As shown on Figure 1-21, the Qt-Tmss hydrologic unit, which consists of the Qt, $Tnbs_1$, and Tmss stratigraphic units, is restricted to the area north of Corral Hollow Road. In general, these units are hydraulically connected because of extensive bedrock fracturing within the Corral Hollow-Carnegie fault zone. In the vicinity of pit 6, the depth to ground water varies from about 25 to 40 ft. Saturation in the Qt unit is laterally discontinuous and consists of at most a few feet of saturated silty gravel overlying an irregular bedrock contact. Some ground water from the Qt unit discharges where it crops out along the exposed terrace face at perennial spring 8 and intermittently at springs 7 and 15. Spring discharges partially limit the rise of ground water in the Qt unit. Water in the Qt unit communicates directly with the $Tnbs_1$ and Tmss bedrock units to a depth of at least 245 ft. Hydraulic conditions range from unconfined to confined.

North of the Corral Hollow-Carnegie fault zone, in the Qt-Tmss hydrologic unit, ground water flows primarily downdip and southward, at an estimated average rate of about 30 ft/yr (Webster-Scholten, 1994). In the fault zone, ground water flows to the southeast as shown on the potentiometric surface map (Fig. 1-22) and as evidenced by the southeast-trending TCE plume emanating from pit 6 (Figs. 1-23 and 1-24). The estimated average flow velocity in the fault zone is about 70 ft/y (Webster-Scholten, 1994). Based on this distinct change in flow regime and the results of cross-fault hydraulic tests, the northern limit of the Corral Hollow-Carnegie fault zone forms a hydraulic barrier to north-south flow of water. This barrier may result from either offset of the beds or low permeability of gouge in a fault plane. Ground water flow in the Qt unit is probably not affected by faulting.

As shown on Figure 1-21, the Qal-Tts hydrologic unit is restricted to the area south of Corral Hollow Road and the southern half of the Carnegie SVRA residence area. The Qal-Tts hydrologic unit consists of Quaternary alluvium and the underlying Tesla Formation. Limited quantities of ground water are present beneath the Corral Hollow Creek floodplain in the Qal-Tts hydrologic unit at elevations typically 25 to 30 ft lower than in the Qt-Tmss hydrologic unit, north of Corral Hollow Road. Shallow ground water is ephemeral and present locally in the Qal unit of the Corral Hollow floodplain; following heavy precipitation, this ground water probably flows eastward. The direction of flow in the underlying Tts unit may also be eastward. As measured in monitor well W-33C-01, the piezometric surface in the Tts unit is about 13 ft; during drilling, ground water was first encountered at 20 ft under confined conditions.

Natural water quality in the Qt-Tmss and Qal-Tts hydrologic units is generally poor due to relatively high TDS concentrations. However, potential beneficial uses includes drinking, agriculture, and industrial water supply.

Horizontal Hydraulic Gradients

North of the Corral Hollow-Carnegie fault zone, ground water in the Qt-Tmss hydrologic unit flows southward at a low, average horizontal gradient of 0.001 ft/ft as measured from wells K6-03 to EP6-08 (Fig. 1-22). The ground water flow direction across the Carnegie Fault changes by about 90 degrees. Within the fault zone, the ground water flows southeastward at a higher gradient that averages 0.014 ft/ft from wells K6-25 to K6-23. The closer spacing of contours along the fault zone suggests lower hydraulic conductivities. Also, the uneven distribution of contours suggests variability (anisotropy) in hydraulic conductivities and ground water velocities within the fault zone.

Vertical Hydraulic Gradients

Water levels from closely-spaced monitor well pairs, completed in relatively short intervals (<28 ft) at depths ranging from 10.5 to 244.5 ft, were used to evaluate potential vertical hydraulic gradients within the Qt-Tmss hydrologic unit. The water level data from well pairs listed in Table 1-10 indicate that both upward and downward vertical gradients may exist within the bedrock units beneath the Pit 6 operable unit. Upward vertical gradients have been found to vary between 0.001 to 0.002 ft/ft, and downward vertical gradients have been found to vary between 0.005 and 0.009 ft/ft.

Hydraulic Tests and Well Yields

Nineteen separate hydraulic tests have been conducted in the Pit 6 operable unit and are presented in Table 1-11. Well yields are highly variable. As shown in Table 1-12, wells completed exclusively in the Tnbs_1 unit have yields that range from 0.5 to 180 gpm. In general, stratigraphic units other than the Tnbs_1 unit have low well yields. Of the 27 monitor wells in the immediate operable unit, 13 are classified as dry-outs due to low recharge during sampling activities.

Summaries of hydraulic conductivity values for near-vertical bedrock and shallow-dipping bedrock are presented in Tables 1-13 and 1-14, respectively. Hydraulic conductivities for wells completed in near-vertical bedrock vary by seven orders of magnitude, from 4.7×10^{-10} to 3.6×10^{-3} cm/sec. Hydraulic conductivities measured in wells completed in shallow-dipping bedrock vary by three orders of magnitude, from 5.0×10^{-5} to 1.8×10^{-2} cm/sec. Hydraulic tests on Carnegie SVRA residence area wells CARNRW2 and CARNRW1 indicate that the near-vertical and shallow-dipping bedrock units are in more direct hydraulic communication in the Carnegie SVRA residence area.

Figure 1-28 shows the locations of three cross-fault hydraulic tests that are listed in Table 1-11. The delayed cross-fault response during one test and a lack of response in the two other tests demonstrates that only limited hydraulic communication exists between near-vertical and shallow-dipping bedrock beneath the pit 6 area (Webster-Scholten, 1994).

Pit Cover Soil Permeability Tests

Hydraulic conductivity testing has been conducted on the pit 6 soil cover; the upper 1.5 ft was tested at four locations (Fig. 1-26; Table 1-15). The average hydraulic conductivity (K) is 2.5×10^{-4} cm/sec (0.35 in./h). These hydraulic conductivity values are greater than those expected in such soils (Freeze and Cherry, 1979), and may result from secondary permeability created by desiccation cracks and ground squirrel burrows. The testing that we conducted primarily measured the horizontal hydraulic conductivity and provides a conservative estimate because the actual vertical hydraulic conductivity is probably less (Petsonk et al., 1987).

Fluctuations in Ground Water Elevations

Since monitoring began at pit 6 in 1982, ground water elevations have declined in all but one off-site well—W-33C-01. This well is completed in the Tts unit, which is hydraulically isolated from the Qt-Tmss hydrologic unit. The hydrographs for these wells (Webster-Scholten, 1994) show brief intervals of rising water elevations after typical rainy seasons, but the overall trend has been downward since 1982.

Monitor well BC6-10 had the greatest (61.4 ft) water level decline of any other well in the operable unit. Most of the decline has occurred since March 1990 and suggests that quarterly sampling of this well is depleting the hydraulically isolated, near-vertical claystone interval in which the well is screened. An alternate explanation is that declining water levels in surrounding strata may be preventing recharge of this claystone unit.

Table 1-16 shows the estimated maximum depths of waste buried in pit 6, according to an equipment operator who buried most of it (Sutton, 1992). Also listed is the depth to ground water interpreted from the potentiometric surface map (Fig. 1-22). The estimated vertical distance from the buried waste to ground water varied from 17 to 26 ft in December 1991. The negligible impact of the above normal 1983 rainfall (21.16 in.) upon ground water elevations suggests that ground water is unlikely to rise high enough to reach the solid waste in pit 6. The thickness of saturation in the Qt unit was probably, at most, a few feet in December 1991. During 1986, the maximum saturated thickness was approximately 6 ft (Brown and Caldwell, 1987).

Fracture Flow

Extensive fracturing and shearing of bedrock units have been observed in the operable unit, in exploratory trenches excavated across a portion of the Corral Hollow-Carnegie fault zone (Fig. 1-15a). On the hillside north of the fault zone, bedrock surface exposures exhibit abundant fractures; however, most of these fractures result from the opening of joints by weathering. During drilling, the permeability and resultant water production of bedrock strata have been observed to be influenced by fractures (Brown and Caldwell, 1987). Bedrock cores are typically highly fractured and are commonly coated with iron, calcium carbonate, and manganese oxides, which suggests water transport through these fractures (Wade, 1992). Occasionally, slickensides are present.

Bedrock fractures were investigated at some locations using borehole geophysical logs and hydraulic tests. Temperature logging was conducted in well CARNRW3 in conjunction with fluid resistivity profiling along the screened interval from 76.0 to 236.7 ft. Three distinct water-bearing zones were identified in the Cierbo Formation (Madrid, 1991). Unfortunately, no drilling log is available for this well.

Hydrophysical testing was performed on monitor well BC6-12 and the borehole for well K6-26 to define fracture zones in the bedrock aquifer. Hydrophysical testing was conducted by replacing standing ground water in the open borehole or well with deionized water, and then profiling the changes in electrical conductivity, pH, Eh and temperature that occurred as water was removed from the borehole/well by a pump. A downhole wireline sonde was used to vertically profile these parameters. At well BC6-12, three conductive intervals were identified: 24.7 to 35.0 ft, 67.5 ft, and at 81.5 ft with flow rates 0.65, 0.24, and 0.52 gpm, respectively (GZA, 1990). Eight conductive zones were identified in the borehole for K6-26 at depths of 64.2, 102.4, 157.5, 168.3, 227.6, 236.2, 246.1, and 247.7 ft. Estimated flow rates in K6-26 ranged from a low of 0.18 gpm (at 246.1 and 247.7 ft) to a high of 1.35 gpm (at 227.6 ft), with an average flow rate of 0.55 gpm. Though this method is still in development and relies upon assumptions for several unmeasured parameters, these preliminary data suggest that flow into these wells occurs predominantly within zones of limited vertical extent that may be fractures.

Fracture zones encountered at other locations in the operable unit yield little water to the well or borehole. Strata encountered in borehole K6-02 and wells EP6-06 and BC6-10 were essentially dry and had no distinct water-bearing zones or open fractures. These conditions indicate that a continuous, relatively unfractured interval may extend along the southern boundary of pit 6. Water recovery in wells BC6-10 and EP6-06 after sampling may range from several days to months, respectively.

Recharge and Discharge

Several features in the operable unit significantly influence ground water recharge and discharge. These features include:

- Two complex hydrologic units (Qt-Tmss and Qal-Tts) that are not hydraulically connected,
- A 20- to 50-ft-thick vadose zone within the Qt-Tmss hydrologic unit that crops out along the terrace face north of Corral Hollow Road,
- Moderate topographic relief,
- Shallow-dipping and fractured bedrock north of the fault zone and near-vertical and highly fractured bedrock within the fault zone,
- Deep north-south ravines to the east and west of pit 6,
- Perennial discharge at spring 8 and intermittent discharges at springs 7 and 15,
- Laterally discontinuous water-bearing zones within the Qt unit and some of the near-vertical bedrock units,
- Low precipitation (about 10 in./y), and
- High evapotranspiration (about 60 in./y).

Table 1-17 lists the inferred recharge and discharge mechanisms of the various stratigraphic units in the operable unit.

1.3.5. Beneficial Use of Ground Water

1.3.5.1 Water Quality

Table 1-18 summarizes the natural ground water geochemical characteristics of the stratigraphic and hydrologic units in the vicinity of the operable unit. In general, ground water quality is marginal in both the Qt-Tmss and the Qal-Tts hydrologic units. The ground water contains moderate TDS, high sodium concentrations, and high specific conductance. As presented in the SWRI, the average TDS concentration for the Qt-Tmss hydrologic unit is 1,036 mg/L (ppm) for the entire Pit 6 Area study area. Arsenic concentrations range from <0.001 to 0.036 mg/L (ppm). Selenium concentrations range from <0.001 to 0.014 mg/L (ppm). Total organic carbon (TOC) concentrations are low and range from <0.5 to 11.3 mg/L (ppm).

The distribution of natural ground water geochemistry of the Qt-Tmss hydrologic unit creates a distinctive pattern when plotted on Piper trilinear diagrams (Figs. 1-27 and 1-28) and is remarkably similar across the area. The ground water is dominated by the sodium cation and contains low percentages (meq/L) of calcium and magnesium. No particular anion is dominant; the anion signature reflects approximately equivalent percentages of sulfate, chloride, and bicarbonate. The geochemical signature appears relatively similar for ground water samples collected from wells located in the Corral Hollow-Carnegie fault zone and wells to the north. However, TDS concentrations vary greatly across the vicinity of the Pit 6 operable unit, from 600 to 4,500 mg/L (ppm) for an average of 1,129 mg/L (ppm). The ground water is slightly basic with a pH of 7.4 to 8.6. The specific conductance varies from 920 to 3,850 μmhos/cm.

The water quality of the Tnbs_1 regional aquifer is poor to marginal because of moderately high TDS concentrations and sulfurous odor.

Two wells are screened exclusively in the Tmss. Ground water from both wells exhibits a slightly different geochemistry. Water from well K6-23 has the highest percentage of the chloride anion (1,800 mg/L [ppm]) and the sodium cation (860 mg/L [ppm]), and the second highest sulfate anion at 930 mg/L (ppm). Well K6-25 also plots near the edge of the cluster on the Piper trilinear diagram (Fig. 1-27).

Water from off-site wells CARNRW1 and CARNRW2 exceeds the California Title 22 recommended MCLs of 500 mg/L (ppm) for TDS and 900 μmhos/cm for specific conductance (Table 1-18). Water from CARNRW2 contains three dominant anions; in decreasing order, these are bicarbonate, sulfate, and chloride. Sodium is the dominant cation.

Ground water geochemical analyses also were performed on water samples collected from the two wells completed in the Tts unit, W-33C-01 and STONEHAM1. Monitor well W-33C-01 is plotted on Figure 1-28. In general, the ground water major ion chemistry is relatively neutral, is not dominated by any particular anion or cation, and has moderately high TDS concentrations (Table 1-18). It should be noted that STONEHAM1 may also be completed in the Qal unit. Analyses indicate that the water is of poor quality and far exceeds California drinking water standards for TDS, specific conductance, and sulfate.

1.3.5.2. Summary of Water-Supply Well History

As presented in the SWRI, seven active and inactive water-supply wells are located in the Pit 6 Area study area. However, all are located off site and outside of the Pit 6 operable unit. As described in Table 1-19, two water-supply wells (CARNRW1 and CARNRW2) are used by the Carnegie SVRA; four other wells are not usable either because of poor water quality or because they have collapsed. Another water-supply well, the background upgradient well for Site 300 (STONEHAM1), is located on the Corral Hollow Creek floodplain. Four abandoned turn-of-the-century wells are located east of spring 12; these wells probably were once used for the dewatering and/or ventilation of nearby mine workings. Another turn of the century well (W-HS1) is located next to spring 9 (Fig. 1-2).

Although water from the $Tnbs_1$ regional aquifer is of poor to marginal quality, the Carnegie SVRA uses this aquifer to water motocross tracks, irrigate trees, fill the residence pond, and wash vehicles; it is only used infrequently for drinking. Two water-supply wells, CARNRW1 and CARNRW2, are located off site in the Carnegie SVRA residence area (Fig. 1-3). Both wells are screened across the sandstone of the Neroly lower sandstone unit $Tnbs_1$ and possibly also the upper Cierbo Formation. Site 300 does not use ground water from the operable unit for any purpose.

1.3.6. Nature and Extent of Contamination

As presented in the SWRI, the chlorinated solvent TCE and trace concentrations of other VOCs were released to the subsurface from buried debris in pit 6 (Table 1-20). Soil and water samples confirm that no significant concentrations of metals, HE compounds, radionuclides, or other chemicals have been released to the environment at pit 6. However, as a result of the source screening, we have confirmed pit 6 as the primary chemical release site for VOCs in the operable unit.

1.3.6.1. Nature and Extent of Contamination in Soil Vapor

Figure 1-29 shows the locations of the active vacuum-induced soil vapor survey (AVI SVS) points sampled at the Pit 6 operable unit during 1988, and presents an isoconcentration map of TCE concentrations in soil vapor. Details of the SVS are also described in Vonder Haar et al. (1989), Lamarre et al. (1989), and Taffet (1990). Soil vapor data are summarized in Webster-Scholten (1994).

Chemical analyses of the 60 soil vapor samples taken indicate that a plume of TCE soil vapor extends over an area of approximately 4 acres and measures approximately 300 by 900 ft. The plume extends southeastward from pit 6 toward the Carnegie SVRA residence area (Fig. 1-29). As shown in Table 1-21 and Figure 1-29, the maximum detected TCE concentration was 160.0 $ppm_{v/v}$. Other VOCs detected include PCE, 1,1,1-TCA, 1,1-DCE, and 1,2-DCA.

TCE was detected at 14 of the 17 SVS locations within the perimeter of pit 6 (Nos. 34 to 49) at depths of 6.0 and 12.5 ft. These depths correspond to the depth range of buried debris in the three large disposal trenches.

1.3.6.2. Nature and Extent of Contamination in Soil and Rock

To characterize the nature and extent of soil/rock contamination in the vicinity of pit 6, 74 soil samples were collected and analyzed from 15 boreholes and 7 SVS boreholes to depths of 45.4 ft. Two surface soil (<0.5 ft) samples were also collected for site characterization purposes. Soil samples were analyzed for VOCs, aromatic hydrocarbons, BTEX, PCBs, metals, and HE compounds. Subsurface soil samples (≥0.5 to 12.0 ft) were not analyzed for tritium or other radionuclides. These analytical data have identified TCE as the primary chemical of potential concern in soil and rock. Details of the nature and extent of VOCs in soil and rock in the Pit 6 Area study area are also described in Webster-Scholten (1994), Taffet and Lamarre (1988), Taffet (1990), and Taffet et al. (1991).

Figure 1-30 shows TCE concentrations in soil and bedrock samples in the vicinity of pit 6. Figure 1-31 shows the distribution of TCE in soil and bedrock core samples between 0 and 12 ft in the vicinity of pit 6. TCE was detected at six of the seven locations within the perimeter of pit 6 (Fig. 1-30) at depths ranging from 2 to 9 ft. The maximum TCE concentration in soil/rock (0.450 mg/kg [ppm]) was detected within the pit 6 perimeter at a depth of 9 ft near the east end of trench 3. Samples from depths of 5.5 to 9 ft correspond to the depth range of buried debris in the three large disposal trenches. Only one sample was collected above 5.5 ft (i.e., above the buried debris); the soil sample collected at 2 ft yielded a concentration of 0.120 mg/kg (ppm). This concentration may reflect the possible upward migration of TCE vapors from the buried waste.

When detected outside the perimeter of pit 6, TCE concentrations did not exceed 0.022 mg/kg (ppm) (at K6-17) and decreased with depth at each borehole.

Table 1-22 summarizes the maximum concentrations of aromatic hydrocarbons detected in soil and bedrock core samples collected in the vicinity of pit 6. The aromatic hydrocarbons benzene, toluene, and total xylenes were detected at concentrations up to 0.030 mg/kg (ppm) in samples from 9 of the 15 boreholes. No aromatic hydrocarbons were detected in any of the SVS soil samples.

Only soil samples collected from borehole K6-30 were analyzed for PCBs. No PCBs were detected.

Only soil cores were collected from borehole K6-17 and, using the waste extraction test for soluble metals (CDTSC, 1991a), we analyzed the samples for 17 metals. Of the six metals detected, only copper at a concentration of 47 mg/L (ppm) was detected above the state Soluble Threshold Limit Concentration (STLC) of 25 mg/L (ppm). As presented in the SWRI, none of these were metals that had been identified as chemicals of potential concern.

Concentrations of beryllium ranged from 0.14 to 0.42 mg/kg (ppm) in samples from three boreholes (K6-01, K6-02, and K6-03). These concentrations are well below the Total Threshold Limit Concentrations (TTLC) maximum allowable value of 75.0 mg/kg (ppm).

As mentioned previously, we collected two surface soil samples (3SS-49-01 and 3SS-49-02) from pit 6. No BTEX, VOCs, HE, or PCB compounds were detected in these samples. Maximum gross alpha and gross beta activities were 7 and 19 pCi/g, respectively. The maximum tritium in soil moisture was 16 pCi/L. The maximum activities for isotopes ^{234}U,

^{235}U, and ^{238}U were 0.8, <0.1, and 0.9 pCi/g, respectively. HE compounds were not detected in the surface soil samples collected within the Pit 6 operable unit.

1.3.6.3. Nature and Extent of Contamination in Surface Water

Surface water consists of three springs (7, 8, and 15) and the Carnegie SVRA residence pond (Fig. 1-3). Springs 7 and 15 are intermittent whereas spring 8 has perennial flow. Water from spring 7 was first sampled in December 1982. Since 1986, well BC6-13 has been used to sample spring 7. Only one water sample was collected from spring 15 in November 1991, before it went dry. Table 1-23 lists the maximum VOC concentrations in surface water.

Water from spring 7 (well BC6-13) was analyzed for VOCs, PCBs, BTEX, gross alpha and beta emissions, radium 226, uranium isotopes, and tritium. TCE, the primary indicator chemical, was detected at concentrations up to 110.0 μg/L (ppb). Other VOCs, including 1,2-DCE, were detected at up to 45.0 μg/L (ppb). Gross alpha, gross beta, and uranium isotope activities that were reported reflect natural background geochemistry. No PCBs, BTEX compounds, HE, or tritium were detected (Webster-Scholten, 1994).

The one water sample collected from spring 15 was analyzed for VOCs, BTEX compounds, HE, uranium isotopes, and tritium. Only TCE was detected, at a concentration of 1.2 μg/L (ppb). All other constituents were below laboratory detection limits. Because the spring has since gone dry, no confirmatory samples have been collected.

Surface water samples collected from spring 8 and the Carnegie SVRA residence pond were analyzed for PCBs, BTEX compounds, HE, and tritium. None were detected.

Several other suites of analytes are used by LLNL's Environmental Monitoring and Analysis Division for the routine monitoring of Site 300 operations. These suites include nitrogeneous compounds, pesticides, phenols, and total organic halides (TOX). The analytical data are reported in Webster-Scholten (1994). Interpretations of these analyses are reported in LLNL's annual environmental report, the most recent of which is the *Environmental Report 1992* (Gallegos et al., 1993).

1.3.6.4. Nature and Extent of Contamination in Ground Water

Initial ground water samples were obtained from three pit 6 monitor wells in late 1982 (Carpenter and Peifer, 1983). Routine ground water monitoring began at pit 6 in October 1984. Two off-site SVRA water-supply wells (CARNRW1 and CARNRW2) currently are in use and are sampled routinely. A third water-supply well, the Stoneham residence well (STONEHAM1), has been sampled annually since 1991 as the background upgradient well for Site 300. Although STONEHAM1 is not in the Pit 6 operable unit as defined in Figure 1-2, we include a discussion of its analytical data below. Ground water sampling has not been conducted for the four inactive water-supply wells on the Carnegie SVRA (CARNRW3, CARNRW4, CARNRW5, and CARNRW6) or the five on-site historic wells (W-HS1, W-MS1, W-MS2, W-MS3, and W-MS4) (Figs. 1-2 and 1-3). Wells CARNRW3 and CARNRW4 will be sampled in the near future.

Ground water samples have been collected from 27 monitor wells and 3 water-supply wells. These samples have been analyzed for HE compounds, metals, PCBs, pesticides, phenols, radionuclides (including uranium and tritium), aromatic hydrocarbons, and VOCs. These data indicate that TCE is the primary chemical of potential concern in ground water beneath the Pit 6 operable unit. Historically, TCE has been detected in samples from 12 wells and from springs 7 and 15 at concentrations up to 250.0 µg/L (ppb). Other VOCs detected since October 1984 include PCE, 1,1,1-TCA, cis-1,2-DCE, trans-1,2-DCE, 1,2-DCA, Freon 113, methylene chloride, acetone, bis(2-ethylhexyl)phthalate, butylbenzyl phthalate, carbon disulfide, and chloroform. The concentrations, frequency of detection, and distribution of these VOCs are much less than that of TCE. Table 1-24 lists the maximum concentrations of VOCs detected in ground water for the operable unit since October 1984. VOCs have never been detected in water samples collected from the three active water-supply wells (CARNRW1, CARNRW2, and STONEHAM1).

Figure 1-23 presents the fourth quarter 1991 distribution of TCE in ground water beneath the Pit 6 operable unit. Detectable concentrations of TCE were reported in ground water samples from only six shallow wells, all completed in the uppermost part of the Qt-Tmss hydrologic unit (in either the Qt/Tnbs$_1$ or the Tnbs$_1$ strata). The TCE plume is elongate to the southeast. The shape of the TCE plume is a controlled by the irregular contact between the Qt unit and the Tertiary bedrock, and is coincident with an increased thickness of Qt gravel (section 1.3.3.2). The migration of TCE appears also to be controlled by a bedrock ridge approximately 3 ft high, which may have controlled the deposition of the gravel. Bedrock fractures may also influence the distribution of TCE in ground water.

Figure 1-24 shows the distribution of TCE in May–July 1993. Sporadic detections of TCE at concentrations of 2 µg/L (ppb) or less at well K6-17 previously had been observed, interspersed with samples in which TCE was not detected (Webster-Scholten, 1994, Appendix H). Beginning with February 1992, TCE detections in well K6-17 became persistent, confirming that the pit 6 TCE plume had reached K6-17. The maximum concentration of TCE detected to date at well K6-17 was 4.7 µg/L (ppb) in December 1992. The mass and volume of TCE in ground water were estimated based on 1993 analytical results, and the estimates are presented in Appendix A.

It is not known if the one unconfirmed (November 1991) detection of TCE in surface water from spring 15 marks an eastward extension of the plume or if it is from a local source. As described in the Table 1-20, the use of solvents in Building 899A may possibly account for the detection of TCE in water from spring 15.

Table 1-25 lists the maximum concentrations and the number of detections for aromatic hydrocarbons in samples collected from all wells in the Pit 6 Area study area. The highest reported concentration of aromatic hydrocarbons in ground water was 17.0 µg/L (ppb) of toluene from well EP6-09S. Sporadic detections of aromatic hydrocarbons are evident for almost every well. In virtually every case, a reported detection at a particular well was not confirmed by subsequent sampling. Furthermore, as footnoted in Webster-Scholten (1994), Appendix H, the reported detections were not confirmed by duplicate samples analyzed by a different analytical laboratory. Even though detectable toluene was reported 17 times, its presence represents only about 7% of the 247 samples that have been analyzed. No aromatic hydrocarbons have been detected in water samples collected from the three active water-supply wells (CARNRW1, CARNRW2, and STONEHAM1). In the fourth quarter of 1991, no aromatic hydrocarbons were detected in any ground water samples.

Of the other compounds analyzed for, only the metals selenium, cadmium, and silver were detected above MCLs. Phenols were detected up to 9 µg/L (ppb). Although a few radionuclides were detected, the reported activities are all believed to reflect natural geochemistry. Thus, radiologicals have been determined not to be chemicals of potential concern (Webster-Scholten, 1994).

Trends in VOC Concentrations

Over the last two to five years, analytical data indicate that TCE and other VOC concentrations in ground water have been steadily declining at the Pit 6 operable unit. During the fourth quarter of 1991, the maximum VOC concentration detected in ground water was 42 µg/L (ppb) of TCE (Fig. 1-23). By the third quarter 1993, the maximum TCE concentration decreased to 15 µg/L (ppb) (Fig. 1-24). Figures 1-32 and 1-33 show TCE concentrations versus time since the fourth quarter of 1984. All wells except EP6-09 and perhaps K6-17, show a marked decline in concentrations since 1989. Although concentrations in well EP6-09 did not decline initially, data collected since 1992 indicate that VOC concentrations in this well also are declining. TCE concentrations in well K6-17 historically have been below MCLs, varying between <0.5 and 4.7 µg/L (ppb). Since the second quarter of 1989, detection of TCE has become more persistent, suggesting a slight trend of increasing concentrations in this well. We believe that the overall decrease in VOC concentrations may be the result of source depletion, dilute vapor flux from the shallow plume to the ground surface, natural degradation, and/or evapotranspiration along the outcrop face of the water-bearing unit south and southeast of pit 6 (springs 7 and 15 areas). Should the overall declining trend continue, concentrations in most wells could be below MCLs within a few years. The low, decreasing VOC concentrations may also indicate the absence of dense nonaqueous phase liquids (DNAPLs) beneath the operable unit.

1.3.6.5. Nature and Extent of Contamination in Air

Air sampling has not been performed in the Pit 6 Area study area. However, air monitoring is performed routinely in other areas of Site 300 and is described in Webster-Scholten (1994). Air quality monitoring, as well as other environmental compliance activities conducted at Site 300, are discussed in the *Environmental Report 1992* (Gallegos et al., 1993).

1.3.6.6. Nature and Extent of Contamination in Biota

Biota (vegetation) sampling has been conducted to monitor tritium near pit 6. The average tritium activity in vegetation during 1992 was 150 pCi/L (Gallegos et al., 1993). This value is within the range of normal background levels. Biota sampling is also performed routinely in other portions of Site 300; results are described in Webster-Scholten (1994), and in the *Environmental Report 1992* (Gallegos et al., 1993).

1.3.7. Contaminant Fate and Transport

We developed conceptual models to identify the probable migration processes of the chemicals of concern from release sites and source medium in the Pit 6 operable unit to selected potential exposure points. The conceptual models provided the basis for selection of the quantitative models used to generate estimates of release rates and exposure-point concentrations. The exposure-point concentrations were used to estimate the magnitude of exposure to contaminants in the baseline public health evaluation presented in Chapter 6 of the SWRI report (Webster-Scholten, 1994). The release areas, migration processes, and exposure points identified in the Pit 6 operable unit are given in Table 1-26. In addition, this table presents the mathematical models used to estimate release rates and the exposure-point concentrations for the chemicals of concern in each environmental media.

We applied a mathematical model (Hwang et al., 1986) to estimate the rate of VOC flux from subsurface soil (0.5–12.0 ft) to the atmosphere in the vicinities of pit 6 and spring 7. A worst-case exposure scenario is assumed to occur in these locations because these are the regions for which the highest contaminant concentrations detected in subsurface soil have been reported.

In addition, we estimated the concentrations of contaminants in surface soil (≤0.5 ft) bound to resuspended particles throughout the operable unit. The exposure-point concentrations for direct dermal contact and incidental ingestion of contaminants in surface soil are the same as the 95% UCLs of the mean concentration of the chemicals, and they are presented in Table 1-26.

We also estimated the flux rates and emission rates of VOCs from the surface of spring 7 and the Carnegie SVRA residence pond. To estimate the volatilization flux rate of VOCs from the surface of spring 7, we used the methodology of Mackay and Leinonen (1975). Surface water samples collected from the residence pond in December 1991 indicate that no VOCs have been detected. Because the pond is filled with water pumped from the Ranger well, we have used simulated VOC concentrations in ground water to estimate potential emissions of VOCs from the pond. The estimated exposure-point concentrations of VOCs that flux from the surface of spring 7 and the residence pond are presented in Table 1-26.

TCE has been detected in ground water samples collected from monitor wells in the vicinity of pit 6. VOC concentrations indicate that the contaminant has migrated laterally from the buried debris in pit 6 toward the southeast through the Qt-Tmss hydrologic unit. To assess the potential for contaminant migration in ground water, we modeled the TCE transport in Qt-Tmss hydraulic unit from pit 6 to the Carnegie SVRA Ranger well (water-supply well CARNRW2). We used a two-dimensional analytical model (Wilson and Miller, 1978) to simulate the lateral migration of TCE through the Qt-Tmss hydrologic unit.

The maximum TCE concentration in ground water since monitoring began in 1984 has been 250.0 µg/L (ppb). Because the total mass of TCE that has been released from pit 6 is not known, we used the maximum TCE concentration as the source term. In addition, the model assumes that TCE migrates through a saturated, porous media with uniform, steady-state flow. Hydrogeologic parameters based on observed field data were available. Assumptions were made for the other parameters based on values accepted as reasonable for the observed conditions. Sensitivity analyses were run to provide a measure of the variability if other hydraulic parameters were used. A detailed description of how the model was set up and a discussion of results is provided in the SWRI report.

Based on the simulation, the maximum predicted concentration of TCE in the Ranger well is 1.0 µg/L (ppb) and occurs at 60 years. The predicted maximum average 70-y TCE concentration reaching the Ranger well is 0.9 µg/L (ppb), and it occurs between 30 and 100 years. Other VOCs, such as PCE and 1,2-DCE, have also been detected in ground water. We also estimated the transport of PCE and 1,2-DCE by applying the ratio of their measured concentration to the concentration of TCE and then applying that value to the TCE transport results.

1.3.8. Baseline Risk Assessment

This section summarizes the potential human health and ecological risk associated with the chemicals of potential concern at the Pit 6 operable unit. Tables 1-27 and 1-28 present the human health risks and hazard indices (HI) associated with exposure to chemicals of concern. Tables 1-29 through 1-31 summarize the results of the ecological risk assessment. A detailed presentation of the potential human health and environmental risk assessment is in Chapter 6 of the SWRI report.

To assess the potential human health risk associated with the chemicals of concern at the Pit 6 operable unit, we evaluated (1) inhalation of VOCs that volatilize from subsurface soil at the pit 6 rifle range, and in the vicinity of spring 7; (2) inhalation of VOCs that volatilize from the surface of spring 7; (3) inhalation of particulates resuspended from contaminated surface soil; (4) ingestion and dermal exposure to surface soil contaminants; (5) ingestion of contaminated ground water from CARNRW2 (residential and recreational users); and (6) inhalation of VOCs that volatilize from the surface of the residence pond (under the assumption that contaminated water from CARNRW2 is used to fill the pond).

Of the scenarios examined in the baseline risk assessment for the Pit 6 operable unit, only exposure associated with inhalation of VOCs that volatilize from the surface of spring 7 were found to present an unacceptable health hazard. For this scenario, we calculated an HI of 1.5 and a risk estimate of 4×10^{-5} for adults who work outdoors in the immediate vicinity of the spring during their entire career (25 y). Although those adults could also be exposed simultaneously to surface soil contaminants (inhalation of resuspended particulates, ingestion, and dermal absorption), our estimates of total risk (4×10^{-5}) and hazard (1.5) for an adult working outdoors are dominated by the values calculated for exposure at spring 7 and are not affected by contributions to risk or hazard from exposures associated with surface soil contaminants.

As presented in Tables 1-29 through 1-31, we calculated ecological HI associated with the potential exposure of the California ground squirrel, black-tailed deer, and San Joaquin kit fox to VOCs in three locations: spring 7, pit 6 rifle range, and the SVRA residence pond. HI exceeded 1 for juvenile ground squirrel and kit fox (juvenile and adult) exposure to TCE and PCE, and the combined HI exceeded 1 for the adult ground squirrel.

Although VOCs have been detected in subsurface soil in the vicinity of Pit 6 Area study area, an increase in the number of ground squirrel burrows has been noted in the study area (see Chapter 6 of the SWRI report [Webster-Scholten, 1994], Orloff [1986], and U.S. DOE [1992]). Thus, the presence of VOCs in subsurface soil does not appear to have negatively impacted the ground squirrel population. There is no evidence that kit fox inhabit the study area. However, data suggest that they could be at risk from exposure to VOCs should they den in the vicinity of the rifle range.

2. Remedial Action Objectives

Remedial action objectives are specific goals for protecting human health and the environment. The development of these goals involves the integration of all legally Applicable or Relevant and Appropriate Requirements (ARARs) and the results of the remedial investigation, including the human and ecological risk assessments. ARARs and risk-based requirements are discussed below, followed by a summary of the remedial action objectives.

Because of the changing and evolving nature of public policy, risk assessment, environmental law, and remediation technology, the proper development of remedial action objectives is an ongoing and iterative process. As such, final cleanup goals and objectives might not be established until the Record of Decision.

2.1. Identification of Applicable or Relevant and Appropriate Requirements

CERCLA section 121 (d)(2)(A) requires that remedial actions meet any federal standards, requirements, criteria, or limitations that are determined to be legally applicable or relevant and appropriate. CERCLA section 121 (d)(2)(A)(ii) requires state ARARs to be met if they are more stringent than federal requirements. An analysis of state standards or regulations must be done to determine whether they impose additional or exclusive requirements. California received authority to carry out the federal RCRA program in July 1992. The California hazardous waste regulations are not identical to RCRA. To the extent these regulations are "broader in scope" and address additional substances or activities, the regulations may be "more stringent" than the federal RCRA program and may thus be state ARARs. State regulations that are "more stringent" but not "broader in scope" will exist as federal standards. In addition, the National Contingency Plan (NCP), published in 40 CFR 300, requires that local ordinances, unpromulgated criteria, advisories, or guidance that do not meet the definition of ARARs but that may assist in the development of remedial objectives be listed as "to be considered" (TBC).

Based on CERCLA guidance, LLNL has divided ARARs into three areas:

1. Chemical-specific requirements that define acceptable exposure concentrations or water quality standards.
2. Location-specific requirements that may restrict remediation activities at sensitive or hazard-prone locations such as wildlife habitat and flood plains.
3. Action-specific requirements that may control activities and/or technology.

Table 2-1 lists current ARARs developed by the signatories to the Site 300 FFA for the Pit 6 operable unit. Additional TBCs are also included to assist in determining what is necessary to protect human health and the environment. Table 2-2 shows whether the proposed remedial alternatives comply with the ARARs and TBCs.

2.2. Chemical-Specific ARARs

2.2.1. Risk-Based Requirements

40 CFR Section 300.430(e)(i)(A)(2) indicates that excess cancer risks greater than one in ten thousand (10^{-4}) are unacceptable, while excess cancer risks between one in ten thousand (10^{-4}) and one in one million (10^{-6}) are generally acceptable. 40 CFR Section 300 also indicates that "the 10^{-6} risk level shall be used as the point of departure for determining remediation goals for alternatives when ARARs are not available or are not sufficiently protective because of the presence of multiple contaminants at a site or multiple pathways of exposure." U.S. EPA (1989) indicates that a hazard index (HI) greater than 1.0 may be associated with noncarcinogenic adverse health effects. The baseline risk assessment in the SWRI report (Webster-Scholten, 1994) identifies surface water at intermittent spring 7 with a potentially unacceptable level of excess cancer risk (4×10^{-5}) and hazard (HI = 1.5) to human health. Calculations presented in the SWRI report indicate that individuals who work outdoors in the immediate vicinity of spring 7 may be exposed to inhalation of potentially hazardous concentrations of VOCs that evaporate from this spring. Spring 7 has remained dry since the summer of 1990, and the well used to monitor the spring has remained dry since the summer of 1992. Thus, no current pathway exists for inhalation exposure at the spring. Based on historical monitoring at spring 7, the chemicals of potential concern are TCE, PCE, 1,2-DCA, cis-1,2-DCE, trans-1,2-DCE, chloroform, and xylene. Of these, only TCE, PCE, 1,2-DCA, and chloroform are classified by the U.S. EPA and the California EPA as probable or suspected human carcinogens (Table 2-3). The remaining two compounds are a concern, however, due to possible noncarcinogenic health effects (Webster-Scholten, 1994).

As discussed in Chapter 1, the Carnegie SVRA uses ground water for industrial, irrigation, and limited domestic purposes. As part of the SWRI contaminant fate and transport modeling, we considered the potential for VOCs to migrate in ground water to the Ranger well (CARNRW2) at the Carnegie SVRA residence area. Fate and transport modeling results suggest that future exposure-point concentrations for VOCs at the Ranger well will be below maximum contaminant levels (MCLs) and, as discussed previously, are not estimated to result in an elevated risk or hazard for residential or recreational use (Webster-Scholten, 1994). The VOCs in ground water in the general vicinity of pit 6 are listed in Table 2-3. To date, VOCs in ground water at the Pit 6 operable unit have not migrated off site.

Additionally, fate and transport modeling results presented in the SWRI report were used to estimate potential inhalation risks associated with the pond located in the Carnegie SVRA residence area. The risk assessment assumed that ground water from well CARNRW2 was used to fill the pond and that the resulting VOC concentrations in the pond would equilibrate with those in ground water. Under this health-conservative scenario, the SWRI risk assessment indicated that excess cancer risk is potentially unacceptable (3×10^{-6}), while the hazard index is acceptable (7.7×10^{-2}). Hence, the predicted results suggest that potential VOCs in the pond may pose elevated inhalation risk to occupants of the SVRA residence area.

As discussed in Section 1.5, we estimated that potential inhalation exposure to site workers at the rifle range overlying pit 6 contributes the highest risk (5×10^{-6}) and hazard (6.9×10^{-2})

associated with VOCs in subsurface (>0.5 ft–12.0 ft) soil. Thus, VOCs in subsurface soil exceed the 10^{-6} risk threshold and may pose an inhalation risk to site workers at the rifle range.

The ecological risk assessment indicates VOCs present in subsurface soil in the area of the rifle range may pose a risk for the California ground squirrel and, if present, the San Joaquin kit fox, because hazard indices for TCE and PCE exceed 1. However, data indicate that the ground squirrel population at Site 300 has not been negatively impacted, and the potential impact to the kit fox exists only if they den in the vicinity of pit 6 in the future (Webster-Scholten, 1994).

In addition to potential risks and hazards identified in the baseline risk assessment, potential safety hazards may exist at the rifle range and at other portions of the Pit 6 operable unit. Site inspections indicate that safety hazards (such as trip hazards) may occur from localized shallow settling of the landfill cover (Lamarre, 1993). In addition, the pit 6 disposal trenches lack a suitable low-permeability cover or liner, and contain potentially hazardous material including low-level radioactive waste. Because of the limited characterization data on material contained in pit 6 and the fact that no releases of material other than VOCs have been observed, no risk assessment for the pit contents was performed for the SWRI report. Because of the uncertainty regarding the contents of pit 6, action should be considered to limit future exposure to and direct contact with the waste.

2.2.2. Federal and State ARARs

Table 2-3 presents state and federal MCLs for chemicals of concern for ground water in the vicinity of pit 6 and surface water at spring 7. Ground water that discharges intermittently at spring 7 is not considered an adequate water supply for human use. However, the Ranger wells at the Carnegie SVRA are used for industrial, irrigation, and limited domestic water supply. Because ground water is used for drinking water and MCLs apply directly to public drinking water systems with 15 or more service connections, ground water at Site 300 is considered a potential public drinking water source under federal or state law.

The U.S. EPA uses MCLs as a cleanup standard for contaminated water that is, or may be used for, drinking water. Under the Safe Drinking Water Act (SDWA), the state may set more stringent standards for public drinking water systems. As shown in Table 2-3, the state has set more stringent MCLs for 1,2-DCA, cis-1,2-DCE, trans-1,2-DCE, and xylenes. In accordance with CERCLA, the most stringent concentration limit is the ARAR for the chemical of concern.

State Water Resources Control Board (SWRCB) Resolution No. 68-16 reflects the state's policies for "maintaining high quality of waters in California." Commonly referred to as the nondegradation policy, it applies to discharging water that might affect the existing high quality of the water it is discharged into and, in turn, affect its beneficial use. The policy advocates the "best practicable treatment" coupled with "technical and economic feasibility." This policy is an ARAR for the discharge of treated ground water to the surface and for the discharge of waste to ground water.

SWRCB Resolution No. 88-63 specifies that all surface and ground waters of the state are considered suitable, or potentially suitable, for municipal or domestic water supply with the following exceptions: those water bodies with yields below 200 gallons per day (gpd), total dissolved solids (TDS) exceeding 3,000 mg/L (ppm), or contamination that cannot reasonably be treated for domestic use by either best management practices or best economically achievable treatment practices. The average TDS concentration for the entire operable unit is 1,036 mg/L (ppm), which exceeds EPA secondary MCLs by 536 mg/L (ppm), but it is below the limit established by Resolution No. 88-63. Well yields generally exceed the 200 gpd limit. Thus, ground water in the Pit 6 operable unit would be considered potentially suitable for drinking water supply under this resolution. This is consistent with beneficial uses for ground water in the vicinity of Site 300 defined in the RWQCB Basin Plan, an additional state ARAR.

2.2.3. Preliminary Remediation Levels

The Pit 6 operable unit contains only one known significant release area, the pit 6 burial trenches. As previously discussed, these trenches contain potentially hazardous material, including limited quantities of radionuclides. As a result, the U.S. DOE is committed to long-term stewardship of this portion of Site 300 and believes that it should remain a controlled area for the foreseeable future. As a controlled site, on-site exposure mitigation by remedial and/or institutional actions should provide effective protection of human health and the environment.

If it is technically and economically feasible, actions could be taken to restore full beneficial use of ground water. Because ground water near pit 6 is used for drinking water supply, to achieve health-based standards, the preliminary remediation levels are the MCLs presented in Table 2-3. Because pit 6 ground water concentration trends have naturally decreased to levels just above or below MCLs and because of the VOC plume's limited areal extent, this goal is probably achievable. Because of the potential additive health effects of ingestion of water containing one or more chemical of concern at MCLs (Appendix C), and the possibility of contaminated ground water reaching off-site supply wells, we propose that steps be taken to prevent off-site migration, if necessary, and additional treatment or actions to reduce the exposure levels below an excess cancer risk of 10^{-6} and/or HI of 1.

State Water Board Resolutions 68-16 and 92-49 indicate that background conditions should also be a long-term remedial goal. However, at this time, available site data are insufficient to evaluate whether remediation to background levels is technically or economically feasible. The inability to evaluate these factors results mainly from subsurface complexity and uncertainty about the site-specific efficacy of ground water extraction to remediate all portions of the ground water plume. As discussed, field data show that VOCs are naturally attenuating and simple extrapolation of these trends suggests that nondetectable concentration could be reached within ten years. Additionally, available information on pump-and-treat remediation at Site 300 and other sites with similar conditions to those in the Pit 6 operable unit indicates that ground water extraction might accelerate VOC removal. However, industry experience shows that chlorinated solvents, such as TCE, often become sorbed onto low-permeability, clay-rich sediments which have limited capacity to diffuse (i.e., desorb) the contaminant back into ground water, thereby decreasing remediation efficiency and increasing remediation time and cost. In addition, the low-permeability, clay-rich units may continue to contain VOCs for decades or longer and, during periods of nonpumping, recontaminate remediated ground water and sediments. Because of the potential small scale and heterogeneous nature of geologic features that affect sorption and hydraulic properties and the impracticability of characterizing them, these factors are not well understood for the Pit 6 operable unit. Therefore, attaining background conditions may not be possible. However, since this is an important policy issue with the state, it is expected that the achievability of this potential long-term goal will be reevaluated in the future as additional monitoring and remediation performance data and/or new remediation technologies become available. For the purposes of this feasibility study, subsequent chapters will present alternatives containing a scenario for complete plume capture on a conceptual basis (i.e., assuming isotropic and homogeneous conditions) to provide an option for the decision makers to pursue this potential state requirement, if necessary.

Since spring 7 is not a potential drinking water source, and has been dry since the summer of 1990, there are no preliminary restoration levels specific to the spring. If spring 7 discharge recurs, exposure mitigation will be implemented, if necessary.

Risk-based requirements indicate that VOCs in subsurface soil may pose a potential inhalation hazard to site workers. As stated in section 2.2.1, the 10^{-6} excess cancer risk level and an HI of 1 are considered appropriate points of departure for subsurface soil remediation. However, available ground water monitoring data indicate a declining trend in ground water VOC concentrations, which suggests that these VOCs do not represent a continuing source of contamination to ground water. Because of this benign threat to ground water and the generally low contaminant concentrations in subsurface soil (i.e., <0.5 ppm), no additional corrective action beyond risk mitigation is warranted.

2.3. Location-Specific ARARs

2.3.1. Faults

California seismic regulations (22 CCR 66264.18[a]) prohibit location of new treatment, storage, or disposal (TSD) facilities, or substantial modification of existing facilities, within 200 ft of a Holocene fault. Evidence of Holocene activity has been observed along a strand of the Corral Hollow-Carnegie Fault about 100 ft south of pit 6 (Webster-Scholten, 1994 and Carpenter et al., 1991). Figure 2-1 shows the location of the fault strand within the Pit 6 operable unit and the resulting TSD exclusion area. These regulations do not apply to closed landfills, such as pit 6, and currently there are no seismic criteria that are specific to decommissioned landfills.

Carpenter et al. (1991) estimated that the Holocene strand of the Corral Hollow-Carnegie Fault zone may be capable of generating an earthquake of $M_S = 6.3$ to 7.1. Although available geologic data indicate that the risk of a primary fault rupture through pit 6 is unlikely, a major earthquake could lead to fissuring and cracking of the cover over pit 6 (Carpenter et al., 1991).

2.3.2. Wilderness Areas, Wildlife Refuges, and Scenic Rivers

No area within or near Site 300 is designated as a federal wilderness area, wildlife refuge, or scenic river. The California Department of Fish and Game maintains an ecological preserve adjacent to the eastern Site 300 boundary. No remedial action activities related to the Pit 6 operable unit will occur within this preserve.

2.3.3. Floodplains and Wetlands

The Pit 6 operable unit is located adjacent to the Corral Hollow Creek 100-year floodplain. The floodplain is bounded to the north by Corral Hollow Road (Fig. 2-1), and no portion of

Site 300 lies within the floodplain (U.S. DOE, 1992). California regulation, 22 CCR 66264.18(B)(1), states that TSD facilities within a 100-year floodplain must be designed, constructed, operated, and maintained to prevent washout of any hazardous waste. This regulation may be applicable to the Pit 6 operable unit because discharge lines, rip rap, and other components of potential treatment facilities could lie within the adjacent floodplain. Any future treatment facilities that may be built on the floodplain will be constructed in accordance with this requirement, as well as with those outlined in 10 CFR 1022.

Areas that are consistent with the state and federal definitions of wetlands (U.S. DOE, 1992) have been identified at or near Site 300. There are nine springs within the Pit 6 operable unit that create wetland habitats; perennial spring 8 and intermittent springs 7 and 15 are located in the immediate vicinity of pit 6 (Fig. 2-1). Although these areas are not currently regulated as wetlands by the U.S. Army Corps of Engineers (Coe, 1991), any future treatment-related activities will be carried out in accordance with DOE orders and federal regulations for wetlands (10 CFR 1022).

2.3.4. Historical Sites and Archaeological Findings

A discussion of archaeological investigations at Site 300 and descriptions of the historic sites near the GSA are presented in Chapter 6. In 1974 and 1981, sample areas of Site 300 were surveyed for cultural resources, which resulted in the location of 28 archaeological sites: 7 prehistoric, 20 historic, and 1 multicomponent site (Dietz and Jackson 1974; Busby et al., 1981). Seven of the previously recorded historic sites and one newly recorded site are located within the Pit 6 operable unit (Fig. 2-1). A residential portion of the town site of Carnegie (California State Registered Landmark no. 740) is included as a historic site within the operable unit. A reconnaissance of the Pit 6 operable unit was conducted on September 17 and September 22, 1993. No new industrial or residential materials were found; however, one new historic site was located in a small canyon north of the SVRA residence area (Fig. 2-1).

State and federal laws and regulations pertaining to the protection of archaeological sites are presented in Table 2-1. Since additional unidentified archaeological sites may be present, project construction personnel will be alerted to likely indicators.

2.3.5. Rare, Threatened, or Endangered Species

The SWRI report (Webster-Scholten, 1994) and Site 300 EIR/EIS (U.S. DOE, 1992) indicate that portions of Site 300 are habitat for several species that have been designated by the federal and state governments as threatened or endangered. Those species for which habitat have been identified but which have not been observed at Site 300 include the San Joaquin kit fox (endangered) and the Alameda whipsnake (threatened). In addition, the flora species commonly known as the large-flowered fiddleneck (endangered) grows on site. Several federally-designated candidate species, as well as species identified as being of special concern by the state, have either been observed on site (including within the Pit 6 operable unit) or may potentially occur on site.

LLNL is committed to protecting all potential habitats for these species. Mandatory 60-day advance notification of all ground-breaking activities will initiate an ecological survey by an LLNL biologist to identify the presence of sensitive species and to mitigate any adverse impacts of the project.

2.4. Action-Specific ARARs

Most action-specific ARARs address treatment, transportation, and disposal of hazardous waste. Table 2-1 includes descriptions of action-specific ARARs that may be associated with possible remedial actions. A detailed discussion of specific technologies and cleanup activities and their compliance with these ARARs is included in Chapter 5.

2.5. Remedial Action Objectives

In order to comply with all existing ARARs and risk-based requirements, and to be consistent with DOE and LLNL restoration objectives, where applicable, the remedial action shall significantly reduce the potential risk to human health and the environment by:

- Preventing off-site ingestion of ground water that contains VOC concentrations above the state and federal drinking water MCLs.
- Reducing the likelihood of any future releases of or exposure to hazardous materials contained in pit 6.
- Mitigating potential worker inhalation exposure to VOCs that may volatilize from spring 7 to levels below 10^{-4} to 10^{-6} excess cancer risk and a hazard index less than 1.
- Mitigating potential residential inhalation exposure to VOCs that may volatilize from the SVRA residence pond to levels below 10^{-4} to 10^{-6} excess cancer risk and a hazard index less than 1.
- Mitigating potential worker inhalation exposure to VOCs that may volatilize from subsurface soil beneath the rifle range to levels below 10^{-4} to 10^{-6} excess cancer risk and a hazard index less than 1.

Table 2-4 presents the above remedial action objectives with respect to media, contaminants of concern, exposure routes, and acceptable ranges of contaminant levels for each exposure route. Subsequent chapters will assemble response actions and technologies into implementable alternatives that will satisfy these remedial action objectives.

3. Selection, Evaluation, and Screening of General Response Actions and Remedial Technologies

3.1. Overview and Evaluation of Screening Process

Our primary objectives for the Pit 6 operable unit are to control inhalation risks at spring 7 and the rifle range, mitigate future releases from the pit 6 disposal area, and preclude exposure to contaminants in ground water.

We evaluate and screen a number of response actions and remedial technologies capable of achieving the remedial action objectives presented in Chapter 2. In section 3.2 we describe the general response actions we have selected to address our remedial action objectives. In section 3.3 we screen remedial technologies and process options based on applicability, effectiveness, implementability, and cost. In the last section, we present technologies retained through this screening process. The retained technologies will be combined to form the remedial alternatives presented in Chapter 4.

3.2. Selection of General Response Actions

General Response Actions describe those actions that can achieve the remedial action objectives established in Chapter 2. These actions are intended to mitigate risk to human health and the environment posed by chemicals of potential concern in ground water, surface water, air, and the burial trenches at the Pit 6 operable unit. The no action response required for CERCLA Feasibility Studies (EPA, 1988) and the six General Response Actions identified for the Pit 6 operable unit are listed below:

- No action.
- Containment.
- Extraction.
- Source removal.
- Treatment.
- Disposal.
- Administrative controls.

Table 3-1 summarizes the six applicable response actions for the Pit 6 operable unit. For our discussion below, we have combined the extraction and removal actions with their respective treatment and disposal options since, in practice, they are integrated.

3.2.1. No Action

In CERCLA feasibility studies, the no action alternative provides a baseline for comparison to other remedial actions. All ongoing activities except monitoring would cease under this response. Risk reduction would occur through natural degradation, dilution, adsorption, evapotranspiration, and spring discharge. Available data indicate that VOC concentrations in ground water may naturally decline to below MCLs in the next several years. Thus, no action may achieve ARARs. However, no action does not address physical hazards associated with pit 6 or possible future releases from the buried debris in pit 6.

3.2.2. Containment

As a General Response Action, containment is used to control the migration or mobilization of contaminants in the buried debris. At the Pit 6 operable unit, containment could be implemented to reduce or preclude the migration of contaminants from the debris trenches.

Physical surface barriers such as a landfill cover and/or lined ditches can be employed for the purposes of containment. These barriers are used to reroute recharge water away from potential sources of contaminants to prevent the potential leaching of contaminants from the buried debris to ground water. Physical barriers may also be used in combination with extraction techniques such as ground water or vapor extraction.

Additional containment can be achieved using subsurface barriers. A combination of vertical, horizontal, or inclined barriers can be used to encapsulate the burial debris, and prevent migration to ground water. We exclude the use of ground water containment actions such as subsurface barriers to control VOCs migrating in ground water because the depth of the plume and the presence of shallow bedrock exceed the limits of conventional excavation.

Stabilization could potentially be used to contain or limit the movement of contaminants from the burial trenches. Possible innovative containment technologies in this category include solidification and *in situ* vitrification. These technologies incorporate source materials into a monolithic matrix that is resistant to weathering and erosion for an extensive period of time.

3.2.3. Extraction with Treatment and Disposal

Because VOC-bearing ground water intermittently discharged at spring 7 and could potentially reach off-site water-supply wells CARNRW1 and CARNRW2, on-site ground water extraction with treatment would mitigate potential risks. Surface treatment of ground water at the Pit 6 operable unit would include extraction, usually by pumping wells, conveyance to a treatment system, such as granular activated carbon (GAC), followed by discharge of the treated water and air. This combination of response actions is intended to permanently remove contaminants from the site and mitigate risk associated with ingestion of ground water. Extraction, treatment, and disposal technologies are discussed in more detail in section 3.3.

3.2.3.1. In Situ Treatment

A subcategory of treatment technologies are those applied *in situ*. *In situ* treatment is an in-place treatment that affects the mobilization and/or toxicity of contaminants of concern. Possible *in situ* technologies include air sparging, surfactant pretreatment, chemical fixation, and biological degradation.

In situ air sparging has been successfully applied at other sites as treatment for NAPLs. This technology requires a thorough knowledge of the subsurface hydrogeology and surface conditions to control vapor and ground water migration in the subsurface and surface. Because NAPLs are not present in the Pit 6 operable unit, the effectiveness of air sparging on the low concentration (<20 ppb) VOCs in ground water at pit 6 is uncertain and thus innovative. This technology has been retained pending additional demonstration data.

Surfactants can be used as *in situ* pretreatment for NAPLs. These chemicals increase the solubility of VOCs into water allowing easier removal by conventional ground water extraction techniques. Because NAPLs are not present at the Pit 6 operable unit, we exclude the use of surfactants.

A possible innovative treatment technology for debris buried in pit 6 is fixation. This technology chemically treats source material *in situ,* binding it into a state where it presents no exposure risk. Chemical fixation involves chemical alteration so that contaminants become immobile or altered to nontoxic compounds.

Biologically enhanced degradation is an *in situ* treatment that transforms VOCs to harmless compounds. *In situ* biological treatment has generally not been successful in remediating low concentrations of halogenated VOCs. It therefore is not considered further.

3.2.4. Source Removal

Source removal would involve a complex process of locating, excavating, characterizing, treating, and/or disposing of contaminated soil and debris buried at pit 6. A number of tasks must be completed to implement the source removal General Response Action. These tasks include preparation of work and safety plans; removal of the rifle range and site grading; preliminary borehole and geophysical surveys; construction of a waste treatment/storage facility, and a general staging facility for decontamination, transportation, and administrative activities; excavation of the trench and animal pit contents; waste characterization and separation; temporary waste storage; on-site waste treatment; transportation to a disposal facility; off-site treatment/destruction and/or disposal; and protection of the public, workers, and environment from chemical and physical hazards.

This General Response Action is not considered further in the development of remedial alternatives for the Pit 6 operable unit because of the numerous tasks noted above; the high potential for increased exposure risk to the public, pit 6 excavation workers, and the environment; and the extreme cost (as presented in Appendix E).

3.2.5. Administrative Controls

Administrative controls can involve a range of measures, from simply posting signs and installing fences to perpetual deed restrictions limiting development and use of this area. For pit 6, fencing and signs at spring 7, and closure of the rifle range could be considered on site. Off-site controls could include providing an alternate water supply to potential receptors.

3.3. Evaluation and Screening of Remedial Technologies and Process Options

Table 3-2 summarizes the screening and evaluation of the General Response Actions, technology types, and process options available for the remedial alternatives.

The General Response Actions are listed in the first column of Table 3-2. Listed with each General Response Action are one or more technologies that are considered potentially feasible. The table documents our reasons for retaining a technology or eliminating it from further consideration, based on applicability, effectiveness, implementability, and cost. The last column indicates if the technology was retained for development of our remedial alternatives.

The retained response actions and technologies that protect public health and the environment, and/or lead to removal of the constituents of interest from the ground water, and/or prevent further degradation of the ground water are discussed below. Retained innovative technologies are addressed in section 3.4.

3.3.1. No Action

No remedial actions are considered under this response. Historic trends in ground water monitoring results suggest that chemical concentrations are being naturally reduced and MCLs may be reached in all wells in a few years. However, this alternative may allow some further aquifer degradation by allowing continued migration of VOCs in ground water. Additionally, Pit 6 debris will be subject to continued leaching by infiltrating surface water. The no action response, which includes only continued ground water monitoring, is presented as a baseline comparison for other actions.

3.3.2. Containment

3.3.2.1. Infiltration/Drainage Controls

A low-permeability surface cover would be constructed to retard leaching from soil and minimize recharge. This cover would consist of several engineered layers including a low-permeability clay layer, two high-density polyethylene (HDPE) liners, and a vegetative cover. Lined ditches would also be constructed to minimize recharge and leaching of VOCs into the ground water from the vadose zone. Ground water would also be monitored to detect potential contaminant breakthrough.

3.3.2.2. Subsurface Barriers

A combination of horizontal and vertical subsurface barriers can be used to enclose the buried debris, preventing any further migration of contaminants into the vadose zone and/or ground water. An alternate option is to use intersecting inclined barriers to enclose the buried debris in a trough-like cell. The subsurface cells created by these barriers would reduce both the potential for leaching resulting from an unusually high rise in the water table as well as the possible release of any potentially undocumented liquid wastes. The barriers would be created using material such as grout, slurries, or more innovative silica-based fluids.

3.3.3. Extraction

Ground water extraction involves pumping VOC-contaminated ground water from strategically placed extraction wells to prevent further migration of dissolved contaminants and to accelerate mass removal. This process option includes the strategic placement of ground water extraction wells to capture the TCE plume, a network of piezometers to monitor water levels, the progress of the capture zones, and ground water treatment.

3.3.4. Treatment

3.3.4.1. Ground Water

3.3.4.1.1. GAC Adsorption. GAC adsorption is a well established technology for ground water treatment that is generally effective for the types of chlorinated solvents present in ground water at pit 6. Activated carbon removes contaminants from water by adsorbing them onto its surface. A GAC adsorption system consists of a GAC-filled vessel with internal plumbing configured to distribute the water evenly over the carbon bed. Organic compounds contained in the influent stream adsorb onto the surface of the GAC as the water flows through the vessel. The spent GAC may be thermally regenerated by heating the carbon in a natural gas-fired furnace.

GAC is an applicable, effective, and implementable method to remove VOCs from an aqueous medium. The cost is dependent upon flow rates and VOC concentrations. Generally, GAC is cost effective for low flow and low concentration applications (LLNL, 1991b).

3.3.4.1.2. Air Stripping. Air stripping is a process by which VOCs are removed from water by bringing the water into contact with an air stream. Air stripping is most commonly achieved with air stripping towers or trays. In conventional air strippers, ground water is sprayed into the top of an air stripping column. As water cascades down the column and through packing material within the column, a blower forces an upward air stream through the water, transferring the VOCs from water to air.

Tray aeration is achieved by spraying extracted ground water into an inlet chamber. The water flows along baffled aeration trays and air is blown up through small diameter holes in the trays. A froth forms, creating a large mass-transfer surface. The high air-to-water ratio causes the organic contaminants to volatilize into air, leaving substantially reduced concentrations of VOCs in the water.

Air stripper design, operation, and maintenance must be tailored to the general water quality at the site. High calcium and magnesium hardness, which exists at Site 300, can clog the packed towers, reduce efficiency, and increase operating costs.

Packed-column or tray aeration using counter-flow air stripping is an applicable, effective, and implementable method to remove VOCs by physical means from aqueous streams. This technology would be used in conjunction with vapor-phase GAC to eliminate VOC discharge to the atmosphere (LLNL, 1991b). The cost is dependent upon flow rates and VOC concentrations. Generally, air stripping is cost effective for high flow rates and high VOC concentrations unless mineral content causes operating problems.

3.3.4.1.3. Air Sparging. Air sparging employs the same physical process as air stripping by creating a large air-to-water ratio to enhance mass transfer to air. Air sparging consists of forcing air through coarse air bubble diffusers into large tanks filled with contaminated water. The agitation of the water along with contact with forced air promotes the volatilization of VOCs. This technology would be used in conjunction with vapor-phase GAC (LLNL, 1991b). High calcium and magnesium hardness, which exists at Site 300, can clog the sparging tank components, reduce efficiency, and increase operating costs. Generally, air sparging has higher energy requirements than air stripping.

3.3.4.1.4. UV/Oxidation. UV/oxidation is a remedial technology that involves the use of an oxidizing agent, such as hydrogen peroxide or ozone, and ultraviolet (UV) light to augment the dissociation of the oxidizing agent to the hydroxyl free radical. UV/oxidation minimizes waste that otherwise would require further treatment or disposal (LLNL, 1991b).

One type of UV/oxidation technology is Perox-Pure™. The Perox-Pure™ chemical oxidation technology was demonstrated under the Superfund Innovative Technology Evaluation (SITE) program at the General Services Area operable unit. Over a 3-wk period in September 1992, about 40,000 gallons of VOC-contaminated ground water was treated in the Perox-Pure™ system. For the SITE demonstration, the Perox-Pure™ system achieved TCE and PCE removal efficiencies of about 99.7 and 97.1%, respectively. In general, the Perox-Pure™ system produced an effluent that contained (1) TCE, PCE, and 1,1-DCA below detection limits, and (2) chloroform and 1,1,1-TCA slightly above detection limits. The system also achieved chloroform, DCA, and TCA removal efficiencies of 93.1, 98.3, and 81.8%, respectively. The treatment system effluent met California drinking water action levels and federal drinking water MCLs for TCE, PCE, chloroform, DCA, and TCA at the 95% confidence level (U.S. EPA, 1993b).

3.3.4.2. Vapor

3.3.4.2.1. GAC Vapor Adsorption. The use of GAC treatment for vapors is a well-established technology for the removal of VOCs from air streams. With few exceptions, most VOCs can be effectively removed from the vapor exhaust of ground water air stripping or air sparging systems using a fixed-bed GAC method. The GAC is effective over a broad range of constituent concentrations in the air stream. The spent GAC may be regenerated on site or at a commercial facility in a furnace in which the VOCs are desorbed from the GAC and then completely oxidized. GAC treatment of the vapor phase is an applicable, effective, and implementable method to physically remove VOCs from vapors.

3.3.5. Disposal

Treated ground water and any process-generated air emissions would require disposal. The following is a discussion of four disposal options applicable to the Pit 6 operable unit.

3.3.5.1. Treated Ground Water

3.3.5.1.1. On-site Surface Discharge. Surface discharge to the gully on the west side of pit 6 is feasible provided that appropriate permits are granted. We are presently discharging treated ground water to the surface, under NPDES permit No. CA0082651 and RWQCB order No. 91-052, as part of an interim CERCLA Removal Action at the central General Services Area.

3.3.5.1.2. Air Misting. Air misting is the atomization of treated ground water by forcing it through spray heads. This process allows maximum evaporation and areal dispersion of discharge. This process eliminates problems associated with surface discharge (e.g., erosion). Presently, all monitor well purge water containing VOCs is treated and then discharged through misting at Building 833. A similar process for treated ground water is being reviewed for use in the Pit 6 operable unit. Misting is applicable if the flow rate is low enough.

3.3.5.1.3. Reinjection. Reinjection wells or infiltration trenches can function as a means to discharge treated ground water, hydraulically control plume movement, and reduce cleanup times. At the appropriate locations, the reinjection of treated ground water can be an efficient, cost-saving measure. However, the quality of this water is important because of the potential for recontamination and potential scaling from precipitates such as carbonate. Scaling can reduce the efficiency of the injection well and require periodic maintenance. For purposes of flow control, ground water reinjection would need to occur within the capture zones of ground water extraction wells.

3.3.5.2. Treated Air Emissions

Treated vapor emissions, a by-product of ground water treatment technology, can be disposed of by permitted discharge to air. Vapor emissions treatment consists of routing the vapor with entrained VOCs through GAC treatment canisters, then releasing the treated emissions into the atmosphere. Site 300 already has several permits to discharge treated vapor emissions to air.

3.3.6. Administrative Controls

In the Pit 6 operable unit, applicable administrative controls, in particular those controls that affect long-term exposure, are retained to reduce or eliminate exposure to contaminants in the spring 7 area. Fencing and warning signs can be installed to warn people of areas where inhalation could cause exposure to contaminants. The use of existing security guards/patrols, use restrictions, and perpetual deed restrictions can also be implemented.

As a contingency to protect off-site drinking water supplies, point-of-use (POU) treatment would be installed at Carnegie SVRA residence area water-supply wells CARNRW1 and CARNRW2 if ground water analysis detects contaminant concentrations at or above MCLs. These wells are active water-supply wells primarily used for irrigation, watering of motorcross tracks, and filling the residence pond. Due to high TDS and specific conductance (Webster-Scholten, 1994), these wells are infrequently used for drinking water.

3.4. Innovative Technologies

Several innovative technologies are being considered for pilot testing simultaneously with the selected alternative for the Pit 6 operable unit. These technologies include *in situ* air sparging, electron accelerator, and adsorption-regeneration resin (Table 3-2). A description of these technologies is presented in Appendix D.

3.5. Summary of Retained Technologies

Through the development and screening of General Response Actions and remedial technologies, we have retained several actions and technologies. These retained actions and technologies are considered in the development of remedial alternatives discussed in Chapter 4. Table 3-3 summarizes the retained technologies.

4. Description of Remedial Action Alternatives

In this chapter we present four remedial alternatives to address contamination in the Pit 6 operable unit. Each of the remedial action alternatives is developed from the retained technologies described in Chapter 3. All alternatives, with the exception of Alternative 1 (no action), meet the RAOs. The remedial action alternatives are summarized in Table 4-1.

We incorporated specific technologies based on site conditions and professional judgment to develop these four remedial action alternatives. Therefore, not all retained technologies from Chapter 3 are presented as components of the remedial alternatives. For example, we selected liquid-phase GAC treatment of extracted ground water in preference to air stripping, sparging, or UV on the basis of cost; air stripping and air sparging may also require vapor-phase GAC treatment of air emissions.

A project life of 30 years was selected for all alternatives to provide a consistent costing basis, in accordance with EPA guidance (U.S. EPA, 1988). DOE/LLNL will reevaluate remediation performance and effectiveness at least every five years. Based on the outcome of these reevaluations, the project life may be redefined.

For all the alternatives, ground water sampling and elevation monitoring would be conducted throughout the project life. This is to assure that changes in hydrogeologic conditions do not result in the redistribution or migration of VOCs such that the conditions specified in the baseline risk assessment are no longer valid. However, the ground water sampling programs are all alternative-specific and are discussed below in detail for each alternative. Water levels would be measured at least quarterly in all wells. The ground water monitoring programs are also summarized in Table G-5, Appendix G.

4.1. Alternative 1—No Action

A no-action alternative is included to provide a baseline for comparison to other remedial alternatives. Regular ground water sampling and analysis for VOCs in existing monitor wells would continue, as described below, and less frequent analysis for other potential contaminants and inorganic parameters would be conducted in selected wells and springs. No additional monitor wells would be installed.

The current program of conducting ecological resource surveys for sensitive species prior to the initiation of any ground-disturbing activities would also continue. The need for detailed ecological resources surveys would be evaluated every five years as part of the contract renewal negotiations between the University of California and the U.S. Department of Energy. The next ecological resource survey evaluation is scheduled for 1997.

We estimated costs for Alternative 1 based on the ground water monitoring program described below. Cost estimates are presented in Appendix G. These costs include water level measurements, ground water sampling and analysis, QA/QC, project management, database management, and periodic project reporting. Based on 30 years of monitoring, the present-worth cost of Alternative 1 is $1,974,536.

4.1.1. Ground Water Monitoring

The ground water monitoring program includes sampling of 27 wells and spring 15 (spring 7 is monitored by shallow well BC6-13). Samples would be analyzed by EPA Method 8010. One spring (spring 15), two active water-supply wells, and six monitor wells at the southern and eastern margin of the plume would be sampled quarterly to monitor the possible exposure points and off-site migration, if any, of the plume. Twelve monitor wells within or cross gradient of the plume would be sampled semiannually. Three upgradient and four deep, clean monitor wells would be sampled annually to ensure that unexpected lateral and/or vertical migration of the plume is not occurring.

Additionally, 17 monitor wells immediately surrounding the pit 6 boundary, as well as downgradient springs and water-supply wells, would be sampled and analyzed annually for PCBs, drinking water metals, beryllium, and radionuclides. These analyses and specific wells were chosen based on information on the buried debris and inferred migration paths. These same wells would also be sampled annually for inorganic parameters including pH, total dissolved solids, and conductivity. Springs and active water-supply wells would be sampled annually for general mineral anions and cations as well as the above mentioned inorganic parameters.

The ground water monitoring data obtained as part of the Alternative 1 monitoring program will be reviewed every five years as suggested in CERCLA guidance documents (U.S. EPA, 1988). For costing purposes, we have assumed that after 5 years of monitoring, sampling would be reduced to an annual frequency at all locations and would continue for 25 more years. If the data indicate that contaminant concentrations, ground water flow direction, and/or velocity have changed, the monitoring program would be reevaluated. A list of the analyses to be performed, sampling frequency, and sampling locations is presented in Table G-5, Appendix G.

4.1.2. Ecological Resource Surveys

LLNL has an ongoing program to ensure that sensitive species are not negatively impacted by planned ground-disturbing activities at Site 300 (U.S. DOE, 1992). As part of the program, any area proposed for an activity that causes significant surface disturbance must be surveyed by a wildlife biologist for the presence of the San Joaquin kit fox (*Vulpes macrotis mutica*), the burrowing owl (*Athene cunicularia*) and the American badger (*Taxidea taxus*). During the spring, the area must also be surveyed for the large-flowered fiddleneck (*Amsinckia grandiflora*). The survey must be done no longer than 60 days prior to the initiation of any ground-disturbing activity.

In addition to the survey program, LLNL has also initiated an employee awareness program. Flyers and posters describing how to identify sensitive species have been made available to employees. These flyers also identify who to contact if a sensitive species is observed at Site 300. A trained biologist from the LLNL Environmental Evaluations Group regularly attends Site 300 management meetings to keep Site 300 management informed and aware of ecological resource and sensitive species issues.

The SWRI (Webster-Scholten, 1994) identified the localized area of pit 6 underlying the rifle range to have TCE in the subsurface at concentrations that may negatively impact burrowing species. Under this alternative, no additional ecological resource surveys other than those conducted as part of a proposed ground disturbance program would be conducted.

4.2. Alternative 2—Risk Mitigation and Natural Attenuation

Alternative 2 includes:

- Engineering and construction of an impermeable pit cover and associated drainage control.
- ✓ Additional ecological surveys as part of pit cover maintenance.
- ✓ Installation of eight additional monitor wells.
- ✓ Contingency point-of-use (POU) treatment systems at water-supply wells CARNRW1 and CARNRW2.
- ✓ Installation of fencing and warning signs around spring 7, with site access and use controls.
- ✓ Ground water monitoring.

To construct the landfill cover, the existing rifle range would be dismantled and replaced following completion of cover construction. This alternative includes costs for both the demolition and replacement of the rifle range.

As discussed in section 1.3.6.4, concentrations of TCE in ground water have been steadily declining. Ground water sampling would be continued to monitor the plume and the declining concentration trend.

The present-worth cost of Alternative 2 is $5,053,030 based on a 30-year post-construction monitoring period. Assumptions and cost tables are provided in Appendix G.

4.2.1. Construction of Pit Cover

Currently, the three main debris burial trenches at pit 6 are covered by 2 to 3 ft of native adobe-clay loam soil, and the contents of the animal pits are covered with 12 to 14 ft of native soil (Webster-Scholten, 1994). Under this alternative, the existing pit cover would be upgraded to cover all three trenches and the six animal pits to further prevent infiltration of surface water into the pits or trenches that could mobilize contaminants. This cover system would consist of a low-permeability cap and a surface water drainage system. The existing outdoor rifle range and associated earth berm would be removed prior to construction and replaced after completion of the cover.

The approximate areal extent of the pit cover is shown in Figure 4-1. The cover would extend laterally at least 25 ft beyond the perimeter of the pit 6 burial trenches and animal pits, over an area of about 63,000-ft^2. Lined diversion ditches would be installed around the edges of the cover to intercept surface water and collect water drained away from the pit cover. These diversion ditches would be graded to direct water towards the gully southwest of pit 6 (Fig. 4-1).

As presented in Figure 4-2, the preliminary pit 6 cover design consists of six engineered layers (listed below from top to bottom). The final design will be presented in the Pit 6 Operable Unit Remedial Design report.

- A topsoil and vegetative cover (up to 2-ft thick): The topsoil and vegetative cover would be designed to allow runoff while inhibiting erosion. The surface would be graded to follow the current south-sloping topography maintaining a slope of at least three percent.
- A biotic barrier (up to 1-ft thick) consisting of cobbles to prevent rodents from burrowing into the cover. This layer would be placed on top of a 6-in. layer of sand to protect the underlying drainage layer.
- A drainage layer consisting of a high-density polyethylene (HDPE) drainage net sandwiched between permeable filter geotextiles. This layer would drain water that may infiltrate into the topsoil. A perforated pipe would be installed at the edge of the cover, between the drainage layer and the sand layer, to collect drained water and divert it into the perimeter drainage ditches.
- A 60-mil HDPE liner with a textured surface on both sides to reduce the potential for slippage between the underlying clay and the overlying drainage layer.
- A low-hydraulic conductivity layer composed of clay with a permeability of 10^{-7} cm/s or less. The material for this layer would be applied and compacted in six-in. lifts. The total compacted layer would be at least 18 in. thick.
- A foundation layer, consisting of fine-grained silt and clay with varying sand and gravel content. The foundation layer would be placed over the existing ground surface after all plant material is stripped and the site is graded. The material for this layer will be applied and compacted in six-in. lifts. The total compacted layer would be at least 2 ft thick.

Above-grade markers would also be installed along the perimeter of the pit cover at locations shown in Figure 4-1 to provide additional visual delineation of the cover. These markers would be either granite monuments or etched stainless steel signs.

A pit cover maintenance program, to be presented in the Pit 6 Operable Unit Remedial Design report, would be initiated to ensure the future integrity of the cover. As part of this routine maintenance program, the pit cover would be surveyed for the presence of burrowing species, which would be in addition to the ecological resource survey program already in place at LLNL. Should a sensitive burrowing species be observed, mitigation measures outlined in the 1992 Sitewide EIR/EIS (U.S. DOE, 1992) and described in Chapter 6 herein would be implemented, as appropriate. These measures may include relocating the species under consultation with the California Department of Fish and Game.

4.2.2. Installation of Ground Water Monitor Wells

A total of eight new ground water monitor wells would be installed at the proposed locations shown in Figure 4-4. Six of these wells (for the purposes of this FS, they have been identified as P6-01 to P6-06) would be located in the immediate vicinity of the pit 6 burial trenches to allow for the early detection of any future releases from the buried wastes and to provide local monitoring of ground water elevations. In the unlikely event that the local water table encroaches on the buried waste, these wells could also be used for dewatering.

Prior to cover construction, investigations would be conducted to more accurately determine the location of each landfill trench and animal pit. This information would be used to finalize the locations of the monitor wells. This investigation would include one or more of the following techniques: magnetic and/or electrical conductivity surveys, cone-penetrometer testing, boreholes, or ground penetrating radar. Because five of these six proposed well locations lie within the areal extent of the new pit cover, well installation would be completed prior to and in coordination with the pit cover construction to ensure the cover integrity.

Two other ground water monitor wells (K6-32 and K6-33) would be installed downgradient between well K6-23 and the Carnegie SVRA residence area to provide additional downgradient monitoring in both the Qt and Neroly stratigraphic units. As such, these wells will serve as guard wells between the ground water plume and the Carnegie SVRA water-supply wells.

Any drill cuttings would be characterized and disposed of in accordance with all applicable environmental regulations. Because only VOCs have been detected in the subsurface, for costing purposes we have assumed that cuttings could be aerated and disposed of on site.

4.2.3. Contingency Point-of-Use (POU) Treatment

A POU treatment system would be installed at off-site Carnegie SVRA residence area water-supply wells CARNRW1 and CARNRW2 (Fig. 1-3) to protect off-site drinking water supplies, if necessary. These wells are active water-supply wells, completed in the Neroly lower sandstone $Tnbs_1$ stratigraphic unit of the Qt-Tmss hydrologic unit. Plumbing would be installed ahead of time so a POU system could be readily installed.

The POU treatment would consist of a gravity flow aqueous-phase GAC treatment system for each affected well. The treatment elements would consist of two, 1,000-lb GAC canisters connected in series and mounted on double-containment skids. Sampling ports would be provided between the canisters, as well as at the inlet and exit pipes. A particulate filter would be installed on the inlet pipe. POU treatment discharges would meet typical NPDES requirements (e.g., eastern GSA).

In the event that POU treatment becomes necessary, LLNL will develop and submit a plan for regulatory approval to permanently remedy the affected water supply. Since it is impossible to predict when and if these actions will be necessary and the availability of future treatment technologies, no cost estimates for these activities are included here.

4.2.4. Administrative Controls

If necessary, a 10-ft by 15-ft fence surrounding spring 7 would be installed to mitigate the potential for human inhalation exposure to volatilizing VOCs. Warning signs would also be placed along the fence. Because spring 7 is currently dry, there is no current exposure pathway and hence no risk. Therefore, although we have included costs for the fence and warning signs, installation would only occur if the spring exhibits elevated risk or hazard.

Because DOE intends to retain stewardship of the property for the foreseeable future, existing security patrols, access limitations, and fencing along the entire perimeter of Site 300 will be maintained. With continued stewardship, DOE will also continue to restrict any activities, such as above- or below-ground construction that could result in direct exposure to the contents of pit 6. Permanent markers will be provided to identify the pit 6 perimeter (Fig. 4-1) and to notify site workers of the cover and underlying buried waste. Additionally, the closure conditions at pit 6 will be permanently documented in applicable facilities/construction management plans.

4.2.5. Ground Water Monitoring

Ground water monitoring protocol would be the same as described above for Alternative 1 with the addition of quarterly monitoring of the eight new monitor wells P6-01 to P6-06, K6-32, and K6-33.

4.3. Alternative 3—Risk Mitigation with Enhanced Mass Removal

Alternative 3 includes all components of Alternative 2 plus contingency mass removal and plume containment by ground water extraction and treatment.

The ground water monitoring program would be similar to that described for Alternative 2 with the inclusion of four extraction wells and ten new monitor wells (Fig. 4-4).

The present-worth cost of Alternative 3 is $11,251,893. This includes 5 years of pre-extraction monitoring and 25 years of ground water extraction and concurrent monitoring (a total of 30 years of monitoring). Assumptions and cost tables are provided in Appendix G.

4.3.1. Ground Water Extraction and Treatment

This alternative includes ground water extraction and treatment in the event that natural attenuation does not reduce VOC concentrations to acceptable levels. Before committing to ground water extraction, the natural attenuation trend would be monitored for at least five years after acceptance of the Record of Decision (ROD). After this monitoring period, the course of action would be determined by LLNL/DOE and the regulatory agencies. If VOC concentrations have been reached or appear to be capable of reaching acceptable concentrations in the near future, continued monitoring would be implemented. However, if concentrations do not decline sufficiently, installation and operation of a ground water extraction and treatment system may be necessary. Ground water extraction would accelerate mass removal, but available data are insufficient to predict cleanup time under either of these scenarios. However, we expect to collect additional data during the five-year monitoring period that will allow for more accurate predictions of attenuation rates and cleanup times. For costing purposes, we assume that ground water extraction and treatment would be started after five years of monitoring and operated for 25 years. The selection of a five-year monitoring period is arbitrary, and it is expected that the actual monitoring period will be based on future VOC concentration trends, funding, and site-wide project priorities.

Based on the current plume distribution, five extraction wells and 18 monitor wells (8 of which are proposed in Alternative 2) would be installed at locations shown in Figure 4-4. The extraction well locations are based on ground water capture zone estimates presented in Appendix F, and the proposed well field should be capable of capturing the entire ground water plume. The monitor wells would be used in conjunction with existing monitor wells to evaluate capture and progress of cleanup. These wells would not be installed until after the five-year waiting period; their number and placement would be reevaluated prior to installation.

Each extraction well would be fitted with an electric submersible pump. The extracted ground water would be pumped through a particulate filter followed by two 1,000-lb GAC canisters connected in series. Treated ground water effluent would flow into a transfer tank and then be pumped further to the discharge point. The treated ground water would be discharged at one of several possible locations: the gully west of the landfill, an infiltration trench upgradient of pit 6, or an air-misting array located in an area that will not interfere with the rifle range or associated facility operations. Further field studies, such as percolation tests, would be needed to determine the best discharge location. The ground water treatment system would be installed in a small building to protect equipment from weather. A schematic drawing of the ground water extraction and treatment system is shown in Figure 4-5.

As required by the ARARs, the treatment system and all discharge piping would be installed at least 200 ft away from the Holocene strand of the Carnegie Fault (Fig. 4-4). As shown in Figure 4-4, an exploratory trench would be dug to ensure that treatment facilities are not located on or near unknown Holocene faults, as required by the ARARs. Although exploratory trenches have been dug in the Pit 6 operable unit in the past (Fig. 2-1), they are not close enough to the proposed system location to meet state requirements.

We estimate a combined extraction rate of about 11 gpm and an average TCE concentration of about 15 µg/L (ppb) as presented in Table 4-2. These estimates are based on hydraulic and analytical data from existing monitor wells located closest to the proposed extraction wells.

4.3.2. Ground Water Monitoring

During the first five years, while TCE (and other VOC) attenuation is being evaluated, the monitoring protocol would be the same as that for Alternative 2. Should ground water extraction be implemented after the five-year evaluation period, the five new extraction wells and ten additional monitor wells would be added to the monitoring program and sampled quarterly. Monitoring frequency would be increased to quarterly for six existing wells near the proposed extraction wells. Six of the proposed new wells (P6-01 to P6-06), which are to be near the disposal trenches, would also be sampled annually for inorganic substances, general minerals, and other analyses as described in section 4.1.1. After five years of ground water extraction, monitoring frequency would be reevaluated. For costing purposes, we assumed that all wells would be sampled annually for years 10 through 30.

4.4. Alternative 4—Release Mitigation with Enhanced Mass Removal

Alternative 4 includes all components of Alternative 3, plus installation of subsurface permeability reduction barriers to mitigate future releases of contaminants buried in pit 6.

Ground water monitoring would be the same as for Alternative 3. The present-worth cost of Alternative 4 is $18,886,549. This includes 5 years of pre-extraction ground water monitoring and 25 years of ground water extraction and concurrent monitoring. Assumptions and cost tables are provided in Appendix G.

4.4.1. Permeability Reduction Barriers

A total of four V-shaped subsurface barriers would be installed directly adjacent to and beneath trenches 1, 2, and 3, and the animal pits. Figure 4-6 shows the approximate plan view location of the subsurface barriers and Figure 4-7 shows the conceptual cross section of the barriers. These subsurface barriers would reduce the potential for leaching of trench/pit contents caused by an unusually high rise in the water table. The barriers would also contain any potential release of undocumented liquid waste within the trenches/pits. Coupled with the pit cover (described under Alternative 2), the contents of each trench/pit would be contained, thereby significantly reducing the possibility of future releases.

The inclined barrier walls would be installed by drilling boreholes on both sides of each trench at an inclination of about 45 degrees to intersect at a point about 7 to 8 ft below the trench/pit bottom and about 5 ft above the highest recorded water table level. These boreholes would be reamed out to 18 in. to overlap each other and a bentonite/sand slurry would be installed to form a continuous low permeability barrier beside and beneath the trench/pit contents. An alternative installation method would be to use jet-grouting. At each end of the trenches, a vertical slurry wall would be installed to complete the barriers. We expect that a permeability of at least 10^{-6} cm/s can be obtained.

To obtain even lower permeability, the barrier slurry could be supplemented or replaced with polymers or other innovative barrier materials. However, these are still innovative technologies, and further research and/or site demonstrations of the effectiveness of the these materials is required. Recent work at Lawrence Berkeley Laboratory has focused on the potential use of silica-based fluids as "barrier fluids." These materials have the advantage of forming a flexible gel that can lower subsurface permeability to over 10^{-8} cm/s (Moridis et al., 1993). Research of these fluids is ongoing with the intent to use them for underground storage tank isolation at DOE's Hanford site. As more information becomes available on the effectiveness of these innovative materials, we would evaluate the potential for their application for this alternative.

Based on the conceptual design of the permeability reduction barriers, more than 3,000 yd^3 of soil and drilling fluids may be generated during installation. These cuttings would be characterized and disposed of in accordance with all applicable environmental regulations. A preliminary investigation would be conducted, prior to initiating barrier installation, to characterize possible localized contamination in the soil that would be excavated during drilling and slurry wall trenching. Several boreholes would be drilled adjacent to the trenches to collect samples for analysis. Based on analytic results, a waste characterization and disposal program would be devised prior to barrier installation. Because only VOCs have been detected in the subsurface, for costing purposes we have assumed that the majority of cuttings could be aerated and disposed of on site.

5. Detailed Evaluation of Remedial Alternatives

5.1. Criteria and Evaluation Process

This chapter presents our detailed analysis and comparison of the remedial alternatives developed for the Pit 6 operable unit. The U.S. EPA (1988) identifies nine criteria to be used in the detailed analysis of alternatives:

1. Overall protection of human health and the environment.
2. Compliance with ARARs.
3. Long-term effectiveness and permanence.
4. Reduction of toxicity, mobility, or volume.
5. Short-term effectiveness.
6. Implementability.
7. Cost.
8. State acceptance.
9. Community acceptance.

Each of these criteria is discussed below.

5.1.1. Overall Protection of Human Health and the Environment

This criterion addresses whether the alternative achieves and maintains protection of human health and the environment during implementation and after remediation objectives are achieved.

5.1.2. Compliance with ARARs

Unless a waiver is obtained, all alternatives must comply with all location-, action-, and chemical-specific ARARs.

5.1.3. Long-Term Effectiveness and Permanence

This criterion is used to evaluate how each alternative maintains protection of human health and the environment. This includes evaluating residual risk and management obligations after meeting remedial action objectives.

5.1.4. Reduction of Toxicity, Mobility, or Volume

This criterion is used to evaluate if and how well each alternative reduces the toxicity, mobility, and/or volume of contaminants. For the Pit 6 operable unit, this assessment addresses VOCs in ground water and potential contamination in the debris buried in pit 6.

5.1.5. Short-Term Effectiveness

This criterion addresses the effectiveness of each alternative to protect human health and the environment during construction and implementation of each remedial action. This includes the safety of workers and the public, disruption of site and surrounding land uses, and time necessary to achieve protective measures.

5.1.6. Implementability

This criterion addresses the technical and administrative feasibility of each alternative. Factors considered include:

- Availability of goods and services.
- Flexibility of each alternative to allow additional or modified remedial actions.
- Effectiveness of monitoring.
- Generation and disposal of hazardous waste.
- Permitting requirements.

5.1.7. Cost

Capital, operation and maintenance, monitoring, and overhead and contingency costs are estimated for each alternative and presented as present-worth costs.

5.1.8. State Acceptance

State agencies will review and comment on this document. Analysis of technical and administrative concerns that these agencies may have regarding each of the alternatives will be addressed in the ROD.

5.1.9. Community Acceptance

Public comments concerning each of the alternatives will also be addressed in the ROD.

5.2. Detailed Analysis of Remedial Alternatives

This section presents evaluations of how each alternative addresses the first seven EPA criteria defined in U.S. EPA (1988). Table 5-1 summarizes the alternatives with respect to the first six criteria, and Table 5-2 compares costs, the seventh criterion. Evaluations of state and community acceptance will be addressed in the ROD following comments on this document.

5.2.1. Evaluation of Alternative 1—No Action

Alternative 1 may not reduce potential health and environmental risks. Although spring 7 is currently dry, future flow from the spring could cause elevated risk to human health by inhalation of VOCs evaporating from the spring. Sensitive ground-dwelling species may be impacted if they den in the immediate vicinity of pit 6. All ARARs would be met with the possible exception of State Water Resources Control Board (SWRCB) Resolution 68-16 because this alternative does not provide active plume migration control or mass removal, and as such, may result in long-term degradation of ground water. However, at present, at least one of the Regional Water Quality Control Boards is considering modifying its Basin Plan to allow limited areas of ground water contamination to exist unaddressed, thereby altering the applicability of SWRCB Resolution 68-16.

In the event that VOCs migrate off site, beneficial uses of ground water could be affected. However, as discussed in Chapter 1, historical ground water analytic data indicate that VOC concentrations are declining and may naturally attenuate below MCLs within a few years. This alternative does not reduce toxicity, mobility, or volume of waste in pit 6 nor does it address potential safety hazards associated with the current pit cover.

This alternative is the least costly of the four alternatives and is easily implemented.

5.2.2. Evaluation of Alternative 2—Risk Mitigation and Natural Attenuation

Alternative 2 fully protects human health and safety. Potential exposure pathways to contaminated surface water would be eliminated by installing fencing around spring 7 and, if necessary, point-of-use (POU) treatment at downgradient water-supply wells, followed by a permanent remedy to be determined in the future.

Like Alternative 1, Alternative 2 may not be protective of the environment and may not meet SWRCB Resolution 68-16 because it does not provide active migration control of VOCs in ground water. Alternative 2 also relies on natural attenuation to mitigate potential off-site migration and reduce mass. However, as discussed in Chapter 1, historical analytic data indicate that VOC concentrations may naturally attenuate to below MCLs within a few years.

Potential VOC inhalation exposure from subsurface soil and exposure to the buried waste would be eliminated by constructing an engineered cover over the pit 6 burial trenches/pits and installing perimeter markers. The engineered pit cover would also serve to eliminate potential safety hazards associated with the current pit cover. Routine monitoring of the cover would include monitoring for sensitive burrowing species to ensure they do not den in the immediate vicinity of pit 6.

The engineered pit cover and associated perimeter drainage would serve as a means of source containment by preventing the infiltration of surface water into the burial trenches and pits, thus reducing the mobility of the buried waste. Because the cover would be subject to erosion, settlement, and possible seismic activity, its integrity would rely on periodic inspections and maintenance.

Because there is no liner or low-permeability barrier between the trenches/pits bottoms and ground water, this alternative does not mitigate potential liquid releases from the buried waste or leaching induced by a large rise of the water table. The potential for liquid releases in the buried waste is probably limited based on the historical fact that only a small mass of VOCs has been released to the environment in the 20 or more years of burial (Appendix A). Site 300 operational procedures dating back to the period of disposal also suggest that many liquid containers were empty when deposited in the trenches/pits. In addition, the historical declining trend of VOC concentrations suggests that the rate of release has either diminished or stopped. As presented in Appendix C, we estimate that only about 115 grams of TCE (the primary chemical of concern) are dissolved in ground water. It is unlikely that the water table will rise high enough to intercept the buried debris and cause additional releases. Historical water level data from monitor wells in the vicinity of pit 6 indicate that the water table has remained at least 12 ft below the estimated depth of the trenches/pits since water level monitoring began in 1981 (Webster-Scholten, 1994). Furthermore, the pit cover drainage controls would limit local recharge, thus further reducing the chance of a water table rise. Although this alternative does not actively reduce the volume and toxicity of buried wastes, it reduces the potential for future releases and thus reduces the mobility of contaminants in the trenches/pits. Additionally, installation of six new monitor wells adjacent to the trenches/pits would be used to monitor water levels in the vicinity of the trenches and, if necessary, to dewater the area.

In the short term, construction activities would not affect the public, but would require the interruption of the use of the rifle range. The rifle range would need to be dismantled prior to construction of the pit cover and subsequently rebuilt after completion of the cover. During construction, rifle range activities would need to be relocated.

All construction activities would comply with ARARs and safety requirements. Should buried containers be ruptured during pit cover construction or monitor well installation, contingency safety measures would be implemented. The ground water monitoring program would alert LLNL of additional releases or significant VOC migration requiring additional response actions.

This alternative is technically and administratively implementable, and is the least costly of the three proactive remedial alternatives.

5.2.3. Evaluation of Alternative 3—Risk Mitigation and Enhanced Mass Removal

Alternative 3 accomplishes the same objectives as Alternative 2 but adds the contingency for ground water extraction and treatment if ground water VOC concentrations are not sufficiently reduced through natural attenuation.

Implementation of ground water extraction/treatment would protect the environment by preventing off-site migration and reducing the mass of VOCs in ground water. As mentioned above, we estimate that about 115 grams of TCE are present in the ground water plume. Recovered VOCs would eventually be destroyed off site by thermal regeneration of GAC, thus reducing toxicity. In addition, the ground water extraction/treatment system would provide the capability to test innovative ground water treatment technologies at the Pit 6 operable unit, in accordance with DOE objectives.

All construction activities would meet ARARs and safety requirements, but, as with Alternative 2, buried containers could be ruptured during pit cover construction or monitor well installation, requiring contingency safety measures. Treated ground water discharge would comply with NPDES or other requirements. The final discharge method and location would be designed to minimize potential effects to the surface (erosion, possible creation of a localized wetland), subsurface (effects on existing VOC plume), and site activities (use of rifle range and surrounding facilities). The ground water monitoring program would alert LLNL of additional releases or significant VOC migration requiring additional response actions.

This alternative is technically and administratively implementable. Cost is higher than Alternative 2 because of the installation, operation, monitoring, and maintenance of the ground water extraction and treatment system.

By allowing time for additional evaluation of the natural attenuation trend, this alternative affords the opportunity for significant cost savings by not prematurely committing capital and subsequent operation and maintenance and monitoring expenditures. Proceeding with installation and operation of the ground water extraction and treatment system immediately after issuance of the ROD would commit a capital expenditure of $2.64 million and, assuming the system would operate 25 years, an operation and maintenance and additional monitoring cost of at least $3.72 million (including overhead and contingency estimates). However, if the natural attenuation trend does not continue to reduce concentrations as anticipated, and ground water extraction implementation is necessary, a cost of $0.78 million (including overhead and contingency) for the initial five years of monitoring will have been incurred. Because data suggest that the extent of the ground water plume will not increase significantly in the next five years, the potential savings outweigh the potential additional pre-extraction monitoring costs.

5.2.4. Evaluation of Alternative 4—Release Mitigation and Enhanced Mass Removal

Alternative 4 accomplishes all objectives of Alternative 3 and is therefore protective of human health and the environment. Alternative 4 adds subsurface permeability reduction barriers surrounding the contents of each burial trench to reduce the potential for liquid releases and/or leaching caused by a rise of the water table into the trenches. Volume and toxicity of buried waste would not be reduced, but all potential exposure pathways and mechanisms for mobility would be either eliminated or mitigated.

As in Alternatives 2 and 3, the pit cover would require periodic inspections and maintenance to ensure its integrity. The effectiveness of the permeability reduction barriers would be indeterminate as they cannot be visually inspected either at the time of installation or at any point thereafter. We would rely on ground water monitoring to determine if releases occur.

All construction activities would meet ARARs and safety requirements, but there is a greater chance of disturbing the buried waste than with Alternatives 2 and 3 because installation of the permeability reduction barriers requires significantly more drilling in the vicinity of the trenches. In Alternative 4, installation of the permeability reduction barriers would require drilling over 1,300 boreholes in the immediate vicinity of the buried waste. We estimate that permeability reduction barrier installation would take over six months to complete and, as a result, workers and possibly the public would have a greater chance of exposure to waste. In addition, the rifle range would remain out of service for a longer period. This could adversely impact LLNL PSO training schedules and make compliance with DOE security regulations more difficult.

Installation of the permeability reduction barriers is implementable using existing technology. Innovative barrier fluids and installation techniques are being developed by industry and may be available in time to employ at this site. This is the most costly of the four alternatives.

5.2.5. Remedial Alternative Costs

The estimated present worth of the life-cycle costs of the four remedial alternatives is shown in Table 5-2 and Figure 5-1, where capital, operation and maintenance, monitoring, overhead, and contingency costs are broken out. Details of the costing analysis and assumptions used in preparing the cost estimates are presented in Appendix G. For consistency between alternatives, each is costed for a project life of 30 years. Because actual project life may be different, we show cumulative costs in five-year intervals in Figure G-1.

5.3. Comparative Evaluation of Remedial Alternatives

This section presents an evaluation of the characteristics of each alternative with respect to the first seven EPA evaluation criteria. Table 5-3 presents a comparison summary, which shows that the most significant distinguishing features among the alternatives are:

- Effectiveness of eliminating exposure/potential exposure pathways.
- Effectiveness of ground water VOC mass removal and migration control.
- Degree of mobility reduction of buried waste in the pit 6 trenches/pits.
- Cost.

5.3.1. Overall Protection of Human Health and the Environment

5.3.1.1 Human Health

As discussed in Chapter 1 and Appendix C, potential human health risks at the pit 6 operable unit include inhalation of VOCs volatilizing from subsurface soil in the vicinity of the rifle range, inhalation of VOCs volatilizing from spring 7, and inhalation of VOCs volatilizing from the surface of the residence pond. With the exception of Alternative 1 (no action), all alternatives address these potential risks.

Alternatives 2, 3, and 4 address potential VOC inhalation risk at spring 7 by providing contingency fencing around the spring. Contingency POU treatment at CARNRW2 in Alternatives 2, 3, and 4 addresses potential inhalation of VOCs volatilizing from the residence pond. Because POU treatment is not a permanent remedy, other remedies would be evaluated and implemented in the future, as necessary. Additionally, Alternatives 3 and 4 include ground water extraction if ground water VOC concentrations do not naturally attenuate within a few years. By reducing the mass of VOCs in ground water, potential human health risks posed by spring 7 and the SVRA residence pond would be markedly reduced.

The final design of the pit 6 cover proposed in Alternatives 2, 3, and 4 would incorporate future air sampling results to ensure that the pit cover fully encapsulates the affected area. The pit cover would also eliminate any direct contact with the buried waste and would address potential safety hazards posed by the condition of the current cover. The biotic (cobble) barrier in the cover design combined with periodic ecological surveys would ensure that no sensitive ground-dwelling species inhabit areas either within or near the buried waste.

5.3.1.2 The Environment

The only observed damage to the environment is the degradation of ground water quality by the presence of VOCs in ground water. As discussed in Chapter 1, concentrations of VOCs are declining and may naturally attenuate to below MCLs within a few years. If VOCs do not attenuate, Alternatives 1 and 2 have no mechanism for protecting the environment from any potential effects of further VOC ground water plume migration. Alternatives 3 and 4 are protective of the environment because they provide for ground water extraction in the event that VOCs do not sufficiently attenuate.

5.3.2. Compliance with ARARs

ARARs affecting each remedial alternative are presented in Chapter 2 in Tables 2-1 and 2-2. All alternatives comply with all location-, action-, and chemical-specific ARARs, with the possible exception of Alternatives 1 and 2, which may not meet the requirements of SWRCB Resolutions 92-49 and 68-16. These two alternatives rely on natural attenuation to mitigate plume migration and reduce mass of VOCs.

Also, while the ground water extraction component proposed under Alternatives 3 and 4 provides active plume migration control and VOC mass reduction, it may not reduce concentrations to background levels as required under SWQCB Resolutions 92-49 and 68-16. These resolutions provide for establishing alternate cleanup levels above background levels when economic or technical infeasibility is demonstrated. However, current data may be insufficient to establish infeasibility and, as such, compliance with ARARs is indeterminate.

Because Alternatives 2, 3, and 4 involve construction and operation activities, they have considerably more ARARs than Alternative 1. The majority of additional ARARs are related to ground water extraction and/or treatment and the associated transport and disposal of GAC.

5.3.3. Long-Term Effectiveness and Permanence

All alternatives other than Alternative 1 provide for long-term protection of human health from VOCs evaporating at spring 7 by the installation and maintenance of fencing and restricted site access, if necessary. To reduce the magnitude of the quantified potential risk at spring 7, VOC concentrations in ground water would need to be reduced. Alternative 2 relies on natural attenuation to accomplish this, whereas Alternatives 3 and 4 provide for ground water extraction in the event that natural attenuation is not sufficient.

If VOC concentrations increase and VOCs migrate off site to the downgradient water-supply wells, POU treatment may be necessary. Without natural attenuation, Alternative 2 does not provide a means to eliminate the need for continued POU treatment. The ground water extraction component of Alternatives 3 and 4 would reduce the on-site concentrations and prevent off-site migration, which would in turn eliminate the need for POU treatment.

The pit cover in Alternatives 2, 3, and 4 would require periodic inspection and maintenance to ensure its integrity, because no alternative includes reducing the volume or toxicity of the buried waste. The permeability reduction barriers of Alternative 4 would provide additional isolation of the wastes buried in the pit 6 trenches/pits. However, the integrity of these subsurface barriers could not be verified at the time of installation or visually inspected in the future; ground water monitoring would alert LLNL of future releases.

In summary, Alternatives 3 and 4 provide the greatest long-term effectiveness for plume migration control and VOC mass removal, while Alternative 4 provides the greatest degree of long-term effectiveness for containment of wastes buried in pit 6.

5.3.4. Reduction of Toxicity, Mobility, and Volume

As discussed in sections 5.3.1 and 5.3.3, Alternatives 1 and 2 rely on natural attenuation for concentration reduction. Therefore, implementation of these alternatives may not reduce toxicity, mobility, and volume of the VOCs in ground water acceptably. By installing the pit cover and associated perimeter drainage controls, Alternative 2 eliminates infiltration of meteoric water or surface runoff through the pit 6 trenches, thereby reducing the mobility of contaminants. However, Alternative 2 does not address the mobility of any liquids presently in the trenches, or contaminant leaching resulting from a large rise in the water table. As discussed in section 5.2.2, it is unlikely that the water table will rise into the trenches. None of the alternatives reduce the toxicity or volume of waste in the trenches/pits.

Alternative 3 adds a contingency for ground water extraction to remove VOCs from the ground water and to prevent off-site migration if necessary. Extracted VOCs would be adsorbed onto GAC. Toxicity of the VOCs would be eliminated during the off-site thermal regeneration of the GAC. The pit cover in Alternative 3 would be like the one in Alternative 2 in that it would reduce mobility of the waste in the trenches caused by infiltration, but it would not reduce the potential mobility of the waste as a result of liquid releases or leaching caused by large water table rises. However, by eliminating infiltration through the pit, the pit cover and drainage controls would reduce the chance for a local water table rise. Alternative 3 does not reduce the toxicity or volume of waste in the trenches, although it would reduce the toxicity and volume of VOCs in ground water if ground water extraction and treatment are implemented.

Alternative 4 addresses toxicity, mobility, and volume of VOCs in ground water in the same manner as Alternative 3. Alternative 4 differs from Alternative 3 by further reducing potential mobility of the buried wastes in the pit 6 trenches/pits through the use of permeability reduction barriers. Along with a pit cover and drainage controls, permeability reduction barriers described in Chapter 4 would mitigate potential liquid release migration from the buried waste to the underlying ground water. Like Alternatives 1, 2, and 3, this alternative does not reduce toxicity or volume of waste in the trenches.

5.3.5. Short-Term Effectiveness

Alternative 1 does not include any construction activities and therefore has no impact on the general public. Standard operating procedures used during continued ground water monitoring would require workers to use the appropriate protective procedures, clothing, and equipment to mitigate exposure.

Pit cover and well construction activities in Alternatives 2, 3, and 4 could result in worker or public exposure to contaminants and releases from the pit 6 trenches following a cave-in or a rupture of buried waste containers. There also might be dust produced by heavy equipment operation or drilling in the vicinity of the pit 6 trenches/pits. As discussed in Chapter 4, additional field investigations would be conducted prior to cover or well installation to more accurately determine the location of each trench/pit. This would minimize the chance of intercepting buried waste during drilling. Safety precautions including planning, screening, monitoring, and personal protection equipment would be used to mitigate risk to workers and the general public.

Because pit cover construction requires dismantling of the rifle range, rifle range operation would need to be interrupted and possibly relocated. The rifle range would be rebuilt after completion of the cover and associated monitor wells.

Ecological surveys, as described in Chapter 4, would be conducted before and after construction activities in Alternatives 2, 3, and 4 to ensure that construction activities do not impact the habitat of any endangered species.

Construction and operation of the ground water extraction and treatment component of Alternatives 3 and 4 would have no impact on the general public. Workers would follow appropriate safety measures to prevent exposures during well installation and construction, and later during operation of the extraction and treatment system. The selected ground water discharge option would not adversely affect the environment. Because Alternative 2 does not include ground water extraction, if natural attenuation does not reduce VOC concentrations, off-site migration might occur.

As discussed in section 5.2.4, Alternative 4 has a significantly greater chance of intercepting buried waste because of the number of drilled boreholes required for installation of the permeability reduction barriers. Installation of these barriers would take more than six months, thereby increasing the chance for worker exposure. As with all construction activities, appropriate safety procedures would be followed.

A specific health and safety plan and administrative operational safety plan would be developed prior to implementation of the selected remedial action.

As discussed in Chapter 1, there is no current elevated risk in the Pit 6 operable unit. In the event that conditions change such that risks become elevated, Alternatives 2, 3, and 4 provide for rapid deployment of protective measures, including fencing at spring 7 and POU treatment at downgradient water-supply wells.

5.3.6. Implementability

Each of the alternatives can be implemented. However, implementation becomes more complicated with each additional remedial action.

Alternative 1 can be implemented easily with only a slight modification to the existing ground water monitoring program. No additional permitting would be required.

Alternative 2 can be implemented using standard design, and standard construction techniques and materials. An agreement with the operators of the rifle range would need to be made prior to design and construction. Training schedules and security regulations may have to be adjusted to accommodate construction. Ground water monitoring provides for effective monitoring of both the integrity of the pit cover and the attenuation and/or migration of the VOC plume. Of the three active response alternatives, Alternative 2 produces the smallest quantity of potentially hazardous waste that may require treatment and/or off-site disposal. Installation of the eight new monitor wells would produce approximately 20 yd^3 of soil cuttings.

Alternative 3 adds ground water extraction and treatment to the remedial actions of Alternative 2. An estimated additional 600 yd^3 of soil would be excavated for the 15 additional extraction and monitor wells and for trenching (extraction system piping and exploratory trenching). Some of this soil may require treatment and/or off-site disposal.

The use of GAC for the treatment of ground water containing VOCs is a reliable and proven technology. The discharge of treated ground water may require an NPDES or other discharge permit(s) depending on the option selected. Commercial permitted facilities are readily available to regenerate GAC with adsorbed VOCs. Ground water monitoring and periodic site inspections would effectively monitor the integrity of the pit cover and progress of ground water cleanup.

The ground water treatment system would be designed to allow testing of innovative ground water treatment technologies. The GAC system would remain on-line during any such testing to ensure compliance with discharge requirements.

Alternative 4 adds the installation of permeability reduction barriers to the remedial actions of Alternative 3. Although the technology exists to install these barriers, there are some technical concerns regarding their implementability. As discussed in section 5.3.5, installation is likely to take over six months during which workers will need to wear personal protective equipment and follow strict safety procedures. Additionally, we estimate that more than 3,000 yd^3 of soil cuttings might be generated during barrier installation. This soil would require analysis and possible treatment and/or off-site disposal. Once installed, there is no current means for verifying the barrier integrity other than by ground water monitoring.

5.3.7. Cost

The estimated present worth of the life-cycle costs for the Pit 6 operable unit remedial alternatives ranges from $1.97 million to $18.89 million. Costs are summarized and compared in Table 5-2 and Figure 5-1. Capital, operation and maintenance, and monitoring costs were developed for each alternative and subtotaled. Overhead and a 20% contingency were added to develop total estimated present-worth costs for each alternative to an accuracy of –30% to +50%.

The costs for each alternative (except Alternative 1) were developed on the basis of preliminary engineering designs to meet remedial action objectives and the ARARs presented in Chapter 2. Cost estimates do not include implementation, operation, or maintenance of innovative technologies. Detailed cost and design assumptions regarding labor, equipment, construction, project and construction management, operations and maintenance, monitoring, overhead, and contingency are presented in Appendix G.

Significant differences in the costs of the alternatives are due to the relative differences in the alternatives listed below. Compared to the other alternatives:

- Alternative 1 has a low cost because it includes only monitoring and no remedial actions.
- Alternative 2 has a moderate cost because it includes capital construction projects (pit cover, installation of eight new wells, POU treatment, and fencing) and ground water monitoring, but no remediation by long-term ground water extraction and treatment.
- Alternative 3 has a high cost because, in addition to all costs of Alternative 2, it has the capital costs of 15 new wells (in addition to the 8 wells proposed in Alternative 2) and the ground water treatment system. Even more significantly, this alternative includes the

costs for operation and maintenance of the ground water extraction and treatment system for 25 years.

- Alternative 4 is the most costly of all the alternatives because it includes all costs of Alternative 3 plus the capital cost of the permeability reduction barriers.

6. Environmental Considerations

6.1. Introduction

The Record of Decision (ROD), issued on January 21, 1993, for the August 1992 *Final Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore* (U.S. DOE, 1992) published DOE's decision to continue operation of LLNL, including near-term (within 5 to 10 years) proposed projects. One of the proposed actions described in the 1992 EIS/EIR is the remediation of soil and ground water contamination at Site 300.

As stated in the *Federal Register*, Vol. 55, No. 67 (April 1990), when DOE remedial actions under CERCLA trigger the procedures set forth in the National Environmental Policy Act (NEPA), the procedural and documentation requirements of NEPA and CERCLA are to be integrated. According to DOE Order 5400.4, integration is to be accomplished by conducting the NEPA and CERCLA environmental planning and review procedures concurrently to avoid duplication, conflicting analysis, and delays in implementing remedial action on procedural grounds. The primary instrument for this integration is the RI/FS process, supplemented as needed to meet the requirements of NEPA. In compliance with the requirements of the DOE NEPA Implementing Procedures (10 CFR 1021), DOE Order 5400.4 (issued October 6, 1989) and the Council of Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of the NEPA (40 CFR 1500–1508, July 1986, as amended), this chapter provides additional information necessary to evaluate po tential environmental impacts of the remedial alternatives under NEPA.

6.2. Relationship of the Proposed Remedial Alternatives to Other Activities at LLNL

The proposed remedial efforts are part of a larger effort by LLNL to mitigate contamination caused by past activities at Site 300. Past corrective actions and facility upgrades that have been implemented by LLNL at Site 300 are described in section 1.2.3. In addition to the pit 6 FS activities, several other feasibility studies actions will be conducted at Site 300 over the next two years. Specifically, these concern the Building 850/Pits 3 and 5 Area, the HE Process Area, the General Services Area (GSA), and the Building 834 Complex. Additional RI/FS actions may be necessary, depending on the results of ongoing characterization efforts at Site 300.

Ground water from three Site 300 CERCLA Removal Actions (the Building 834 Area and the central and eastern GSA) is being treated at the respective extraction/treatment facilities. The NPDES permit for the discharge of treated ground water from the eastern GSA to Corral Hollow Creek is Order No. 91-052, NPDES No. CA0082651. It was issued on February 22, 1991. The treated ground water from the other two locations will be discharged on site via air misting or surface discharge, as approved in the RWQCB Substantive Requirements for these two removal actions. Treated ground water from the proposed Pit 6 operable unit treatment facility would be discharged on site.

None of the proposed pit 6 Remedial Alternatives will have impacts on, or interactions with, other remedial actions at Site 300.

6.3. Environmental Setting and Potentially Affected Environment

The location of the Pit 6 operable unit, surrounding land uses, and descriptions of the geology, hydrology, and other aspects of the natural environment are summarized in Chapter 1. The descriptions presented below are those necessary to assess impacts as required under NEPA and those that have not been presented in other sections of this feasibility study. A more detailed description of the Site 300 environment can be found in the 1992 EIS/EIR (U.S. DOE, 1992) and the SWRI report (Webster-Scholten, 1994).

6.3.1. Vegetation, Wildlife, and Sensitive Species

The Site 300 rifle range, located on top of pit 6, consists of a cleared area with paved walkways, vehicle access, a metal canopy, targets, and earth berms. The rifle range extends over several of the burial pits. Outside of the rifle range, most areas of the Pit 6 operable unit are covered with introduced annual grasses, are not in the annual burn areas, and are relatively undisturbed.

Annual grassland habitat is generally not attractive to the prey base of sensitive burrowing species that may occur at Site 300 (primarily kangaroo rats and ground squirrels). In addition to being the prey base, these species normally provide the burrows used as dens by kit fox and burrowing owls. Upland areas (areas at higher elevations above the valley floor or the Corral Hollow Creek floodplain) are located north of pit 6, and American badger, burrowing owl, and kit fox are not generally identified with this habitat type. The immediate pit 6 area and areas located immediately south of Pit 6 are highly disturbed. Furthermore, kit fox are not considered to be a resident species at Site 300 at this time (U.S. DOE, 1992). For these reasons, sensitive species that may be present at Site 300 are not expected to occur in the Pit 6 operable unit and vicinity. A preliminary survey of the area for kit fox, American badger, and burrowing owl conducted on February 3, 1994, verified that none of these species were present.

Populations of the endangered plant species *Amsinckia grandiflora* occur in four locations at or near Site 300: in Draney Canyon, in Droptower Canyon, within the California Department of Fish and Game ecological preserve, and on the Connolly property (Pavlik, 1992). This species does not occur near the Pit 6 operable unit. The known locations of elderberry bushes at Site 300 are in Elk Ravine, far to the northeast of pit 6, and none are within a 300-ft radius of any portion of pit 6.

On February 2, 1994, the U.S. Fish and Wildlife Service published their intention to consider the California red-legged frog as endangered pursuant to the Endangered Species Act of 1973, as amended (*Federal Register*, Vol. 59, No. 22, February 2, 1994). The red-legged frog is also a state species of special concern. This species is known to exist in wetland areas near Site 300, primarily in the California Fish and Game preserve in Corral Hollow Creek east of Site 300. Red-legged frogs were also found in the SVRA residence pond east of pit 6 during surveys conducted in support of the 1992 Sitewide EIS/EIR (U.S. DOE, 1992). The residence pond is maintained using ground water pumped from drinking water-supply wells CARNRW1 and

CARNRW2. Because there is no wetland habitat at pit 6 or in the areas immediately adjacent, the area is not suitable habitat for the red-legged frog.

Since the ROD was issued, none of the nonspecial status species that may be present at Site 300 have gained federal or state listing as sensitive species. In addition, there have been no new designated or proposed critical habitats at Site 300 or other designation changes that would alter the U.S. Fish and Wildlife determination that the continued operation of Site 300 would not adversely affect federally-listed species or their habitats. One federal candidate species mentioned in the 1992 Site-wide EIS/EIR (San Joaquin Pocket Mouse [*Perognathus inornatus inornatus*]) has since been reclassified to status category 3B ("names that do <u>not</u> represent distinct entities meeting the Endangered Species Act definition of species") (50 CFR Part 17, 56 FR 58805).

6.3.2. Land Use and Socioeconomics

The Pit 6 operable unit consists of approximately 43 acres located in the southwest corner of Site 300. It is located in San Joaquin County, a leading agricultural county with associated industries for food processing, wholesale trade, and transportation. Important nonagricultural employers include educational institutions, federal defense installations, and related service industries. Major transportation networks and facilities in the county include interstate and local highways, several major rail carriers, the Stockton Metropolitan Airport, and the Port of Stockton. Industrial activities are allowed if they are compatible with the County's applicable criteria for industrial land use.

Most of the area surrounding Site 300 is ranch land, privately held in parcels of section size (640 acres), although land immediately adjacent to Corral Hollow Road in the vicinity of Site 300 generally is held in smaller parcels ranging in size from 5 to 640 acres. The San Joaquin County General Plan has four designations for land use in the Site 300 area. The portion of Site 300 located in San Joaquin County is designated "Public and Quasi-Public—Other Governmental and Institutional." Areas north and east of Site 300 are designated "Agricultural." Areas south of Site 300 are designated "Recreation" or "Conservation."

LLNL operations at Site 300 are consistent with the San Joaquin County General Plan land use designations (U.S. DOE, 1992). Although there is no prime agricultural land at Site 300 or immediately adjacent to it, surrounding land is used primarily for cattle grazing. Much of the land adjacent to the Site 300 southern boundary is part of the Connolly and Gallo Ranches. Along the eastern site boundary is a 15-acre ecological preserve operated by the California Department of Fish and Game. The preserve was formerly part of Site 300, but, with the exception of seven acres, was declared excess property in 1973 and transferred to the State of California. The California Department of Forestry (CDF) leases a small portion of the Connolly ranch located about 2,500 ft southeast of the main entrance to Site 300. The CDF Castle Rock Fire Station is located on this property. Two private companies, Physics International and SRI International, also test high explosives on private land east and south of the site, respectively. The State of California operates the 1,300-acre Carnegie State Vehicular Recreation Area (SVRA) located along the southwest side of Site 300 on Corral Hollow Road.

An EIR has been adopted for the proposed City of Tracy Urban Management Plan/General Plan. The Tracy Planning Area (TPA) encompassed by the plan would "build out" to a population of 160,000 by the year 2013. Under the plan's land use map, Site 300 is designated as "Federal Reserve/Open Space." Site 300 operations are consistent with this land use designation. Under the plan, the City of Tracy also designates land adjoining the east portion of the Site 300 north border and the northern portion of the Site 300 east border as "Residential—Very Low (Density)" or "Open Space" and, together with its commercial and industrial elements, has a projected population of 23,000 by 2013. This area, bounded by Site 300 on the southwest side and extending beyond I-580 to the northeast, is the location of the proposed Tracy Hills Community Area/Urban Center, which would consist of developed areas with two dwelling units per gross acre or less, and open space.

An important factor relative to land use in San Joaquin County is the availability of suitable water supplies. Ground water accounts for 30 percent of all San Joaquin County's water needs (San Joaquin County, 1992). The Tracy area has three major water sources: the Delta-Mendota Canal, the California Aqueduct, and San Joaquin Valley ground water aquifers. The Delta-Mendota Canal and the California Aqueduct are operated by the U.S. Bureau of Reclamation and the State Department of Water Resources, respectively.

The population of San Joaquin County increased by 18.6 percent between 1985 and 1990, to a total population of 480,628. In 1989, San Joaquin County had a total employed labor force of 181,000. The annual work force at Site 300 averages about 300 people, with temporary increases during construction projects. Most of the Site 300 work force is based within the GSA, where about 150 employees are currently assigned.

6.3.3. Air Quality

The California Air Resources Board conducts criteria pollutant monitoring in the San Joaquin Valley Air Basin to determine the area's ambient air quality and to determine the area's compliance with federal and state ambient air quality standards. When an area meets compliance standards, it is classified as an "attainment" area under federal law. The entire San Joaquin Valley Air Basin, including Site 300, is designated as an attainment area for all criteria pollutants except ozone (O_3) and particulate matter less than 10 microns in size (PM_{10}). Elevated levels of O_3 and PM_{10} are a result of transport from urban areas, mobile source emissions, and agricultural activities. Ambient air quality at Site 300 is very good because of the region's sparse population and limited industrial and commercial development.

6.3.4. Noise and Traffic

The background noise at Site 300 is primarily from wind and vehicle traffic on Corral Hollow Road. Away from structures, wind noise levels may range from 70 to 80 decibels (dB), with gusts on ridgetops up to 90 dB (U.S. DOE, 1992). Detonations of explosives during experiments at firing tables at Site 300 can cause instantaneous short-term peak impulse noise level increases, occasionally to levels near 126 dB (Kang and Kleiber, 1993). Other noise sources include I-580; the Tracy Airport; the explosives testing at Physics International, Inc. and SRI International; traffic on Corral Hollow Road; and off-road vehicles operating in the SVRA.

Site 300 lies 18 road miles from the LLNL Livermore site and 10 road miles from central Tracy. The only access to Site 300 is from Corral Hollow Road, on the southern boundary of the site. I-580 lies to the north and east of the site. Patterson Pass Road is located near the northwestern edge of Site 300, but provides no access to the site. The primary access routes in the area are Corral Hollow Road from either the Livermore Valley or from I-580 and Tracy.

Approximately 32 percent of the Site 300 workers reside in Tracy. Because there are only about 300 employees at Site 300, the various street segments traveled by Site 300 commuters are virtually free of traffic congestion. Traffic counts on Corral Hollow Road indicate that of the 325 average daily trips, approximately two-thirds are to or from Site 300 (LLNL, 1988). Traffic density on Corral Hollow Road will undoubtedly increase if the Tracy Hills Community Area/Urban Center matures to the projected 23,000 population.

6.3.5. Aesthetics

Site 300 is predominantly hilly grassland, with some blue oak trees, coastal sage scrub, and rock outcrops. Paved roads link the widely scattered facilities. The rifle range that has been built over pit 6 is nearly 300 ft from Corral Hollow Road and is surrounded on the south and east sides by protective earth berms.

Annual controlled burning of grass at Site 300 impacts the aesthetic quality of portions of the site. However, those portions that are burned are only partially visible from Site 300's southern boundary along Corral Hollow Road and/or the northern and eastern boundaries. Pit 6 is not in a controlled burn area.

6.3.6. Cultural Resources

Archaeological evidence indicates that the Central California area has been inhabited since 9000 B.C. Although little is known about the earliest prehistoric peoples, the Site 300 area is within the ethnohistoric tribal boundaries of two California Native American groups: the Costanoans (Ohlone) and the Northern Valley Yokuts. Current sentiment holds that the area was probably used sporadically by both tribes for marginal hunting and gathering.

During the Hispanic period (ca. 1750–1850), Corral Hollow Canyon, where Site 300 is situated, was used as a minor thoroughfare between the valley and the San Francisco Bay Area. The Canyon was not directly explored by the Spanish, and no missions were established. Under Mexican rule, a land grant (Las Positas) was established northwest of Corral Hollow. The minimal water supply and difficult access to economic centers relegated the Canyon to the low capital enterprise of ranching.

The early American period (1850–1916) brought the first intensive exploitation of Corral Hollow Canyon, beginning with coal mining in the 1850s. Over the next 40 years, various mining interests operated there, but the coal was very low grade, difficult to mine and, consequently, never became economically viable. However, in 1890, high quality clay beds associated with the coal seams began to be mined (Ward and Williams, 1971). In time, two pottery manufacturing plants were built: one in Pottery (in the middle of Corral Hollow at Walden Spur) and the other at Carnegie, approximately two miles further east (within and south of the Site 300 southern boundary near pit 6). Three company towns (Tesla, Pottery at Walden Spur, and Carnegie) were also built to support the mines and factories. The largest town, Carnegie (population 2,500), was located partly inside the southern boundary of Site 300 and partly south of Corral Hollow Road. By 1912, Carnegie was abandoned and, shortly thereafter, completely dismantled. By 1919, only mine tailings, plant foundations, dredging mounds, and miscellaneous depressions marked the industrial past of Corral Hollow Canyon (Busby et al., 1981). In 1960, the Carnegie site was approved as California State Registered Landmark number 740. The California State Park Commission, in cooperation with the Tracy District Chamber of

Commerce, placed a plaque at the edge of Corral Hollow Road 5.9 miles west of I-580 (across the road from Site 300 gate 110).

In 1974 and 1981, sample areas of Site 300 were surveyed for cultural resources, which resulted in the location of 28 archaeological sites: 7 prehistoric, 20 historic, and 1 multicomponent (Dietz and Jackson, 1974; Busby et al., 1981). Seven of the previously recorded historic sites and one newly recorded site are located within the Pit 6 operable unit boundary.

It is unclear from the 1981 survey report whether the pit 6 area was surveyed during the investigation. In addition, no clear boundaries for the Site 300 portions of the Carnegie site were recorded. Consequently, on September 17 and 22, 1993, field spot checks were conducted to determine whether portions, other than Locus 4, of the Carnegie site exist within the pit 6 area (U.S. DOE, 1992). No industrial or residential materials were found. However, one new cultural site was located in a small canyon directly north of the fire trail that winds north around the small piece of Carnegie SVRA property that extends north of Corral Hollow Road. The site consists of historic graffiti consisting of the letters "F V" and the date "1910" written on a wall of a small rock shelter.

6.4. Potential Environmental Impacts of the Remedial Alternatives

The human health and ecological risks associated with wastes buried in pit 6 are assessed in the SWRI, and a summary of these risks is presented in Chapter 1 of this Feasibility Study. The goals of the remedial alternatives are to mitigate the potential for worker inhalation exposure, prevent the chance of off-site migration of VOCs, and reduce the likelihood of any future releases of hazardous materials from pit 6. The implementation of the remedial alternatives would result in the same or less human and ecological risk with respect to the potential migration of contaminants from pit 6 to exposure points. Other potential environmental impacts associated with the construction and operation of the remedial alternatives are presented in this section.

6.4.1. Alternative 1

Under this alternative, no action would be taken to remove buried wastes or contaminants in soil and ground water in the Pit 6 operable unit. A 30-year ground water monitoring program would be implemented to sample and analyze water from 26 wells and from spring 15. Site 300 would continue to be a restricted-access federal facility for the foreseeable future, and public access to the Pit 6 operable unit would be prohibited. A detailed description of this alternative is presented in Chapter 4. Consideration of Alternative 1 serves as a basis from which to evaluate proactive remediation alternatives, as well as the postulated basis of the baseline public health evaluation. Consideration of a no-action alternative is required by CEQ NEPA regulations.

The only on-site physical activity required under Alternative 1 is the sampling of existing monitoring wells and the maintenance of wells and pumps. Those areas of the environment that could be impacted by implementing Alternative 1, other than the human health and ecological risk discussed in Chapter 1, are discussed below.

6.4.1.1 Wildlife and Sensitive Species

The impact to ecological receptors from contaminants detected in soil and ground water in the Pit 6 operable unit was considered in the SWRI report (Webster-Scholten, 1994). The HI exceeded 1.0 for juvenile ground squirrel and kit fox (juvenile and adult) exposure to TCE and PCE, and the combined HI exceeded 1.0 for the adult ground squirrel. The reduction in the abundance of aquatic and/or amphibian populations was also selected as an assessment endpoint (as mentioned in section 6.4.1, red-legged frogs have been observed in the SVRA residence pond). However, due to the lack of either direct bioassay data on the Site 300 surface water, or data required to estimate individual HIs for aquatic/amphibian species, the calculation of Toxicity Quotients (TQs) was used as the measurement endpoint. This entailed calculating the ratio of the detected contaminant concentrations in the surface water to an appropriate standard. The standards considered were the Federal Ambient Water Quality Criteria (U.S. EPA, 1986) and the State of California Applied Action Levels (CDTSC, 1991b). A TQ greater than 1 indicates a potential hazard to aquatic/amphibian populations. California Applied Action Levels were not developed for TCE. Federal Ambient Water Quality Criteria listed only acute and chronic lowest observable effect levels (LOELs) for TCE (45,000 µg/L and 21,900 µg/L, respectively). None of the samples of surface water at Site 300, including water in the SVRA residence pond, exceeded these values. Although not explicitly considered in the ecological assessment, contaminant transport modeling results presented in the SWRI report and in section 1.3.7 of this report indicate that TCE at concentrations up to 1 µg/L (ppb) could reach water-supply wells used to fill the residence pond. Thus, although Alternative 1 potentially allows VOCs to reach surface water, concentrations would be well below applicable standards.

However, because the criteria used to calculate TCE TQs involved the use of LOELs, it is recognized that a TQ less than 1.0 based on these criteria may not necessarily be protective of amphibian or aquatic species. Therefore, bioassay tests are planned for 1994 on Site 300 spring water samples, including springs 7 and 15 within the Pit 6 operable unit, if water is present. The analyses under consideration include: EPA Method 1002 Cladoceran survival and reproduction test (*Ceriodaphnia dubia*), EPA method 1003 Algal gross test (*Selenastrum capricornutum*), and ASTM-D3978-80 Algal gross potential test (*Selenastrum capricornutum*). TCE has not been detected in the residence pond, so bioassay tests on samples from the pond are not planned. However, the results of the planned bioassay tests will provide a better estimate of the potential threat that TCE in Site 300 surface water might pose to aquatic and amphibian populations. In addition, the Carnegie SVRA residence wells CARNRW1 and CARNRW2 will continue to be regularly monitored for the presence of TCE, and bioassay tests on the SVRA residence pond will be considered in the future if TCE is detected in either of the water-supply wells.

In addition to risks resulting from exposure to buried wastes, some temporary and minor disturbances to vegetation and wildlife could occur from monitoring activities at on-site wells. Impacts would be relatively minor and short-term, and would be minimized by restricting vehicular movement to existing access routes.

6.4.1.2. Air Quality

If Alternative 1 were to be implemented, an extremely slow release of VOCs by evapotranspiration from surface soils and possibly from spring 7 would continue to occur. As discussed in section 1.3.8, there is a potential adverse health risk for Site 300 workers if they were to be exposed over long periods of time to concentrations of VOCs that volatilize from surface water at spring 7. The HI for this exposure is 1.5, which indicates that the amount of VOCs that could be released from surface water at spring 7 are just slightly in excess of the amount that may pose an adverse health risk. Since these VOCs will be greatly dispersed in ambient air when they reach the Site 300 boundary, the released VOCs should have no effect on air quality in the Site 300 area.

6.4.1.3. Noise and Traffic

Vehicular activity associated with monitoring and sample collection would continue to result in minor periodic incremental increases in ambient noise levels in the Pit 6 operable unit. These impacts are anticipated to be insignificant.

6.4.1.4. Land Use

Ground water in the vicinity of the Pit 6 operable unit is of poor to marginal quality, although the Carnegie SVRA uses ground water for industrial, irrigation, and limited domestic purposes. Fate and transport modeling presented in the SWRI report suggests that contaminants from pit 6 will not reach the Carnegie SVRA water-supply well (CARNRW2) in concentrations that exceed the MCLs. Since the contaminants in pit 6 do not appear to threaten this ground water, the range of feasible uses of land surrounding Site 300 are not constrained, nor is the land's economic value limited.

As discussed in section 1.3.8, if spring 7 begins to flow, VOCs may be present and could volatilize and be released to the atmosphere. As a result of the potential health risk associated with a long-term exposure to this release, the potential future uses of the pit 6 area may be limited, with a corresponding reduction in economic value. With time, contaminant levels in soils and ground water around the Pit 6 operable unit would decrease through dispersion and natural attenuation processes. However, pit 6 and the immediately surrounding areas probably will not be developed at any time in the future, due to the uncertainty about the nature of the wastes buried and the potential danger of disturbing them during development activities. The area may not even support agricultural use, due to the potential presence of VOCs or other contaminants in springs. Because its potential uses would be extremely limited under the no action alternative, there would be little, if any, economic value to pit 6 and the immediately adjacent areas.

6.4.2. Alternative 2

Alternative 2 would include the activities proposed under Alternative 1 plus the construction of an impermeable cap and associated drainage control, installation of additional ground water monitor wells, and the contingent installation of point-of-use (POU) treatment systems at wells CARNRW1 and CARNRW2. In addition, institutional controls on access to spring 7 would be implemented. This alternative would require that the rifle range be dismantled prior to the cap installation, and reinstalled over the finished cap. Should ownership of the Pit 6 operable unit change in the future, restrictions would be placed in the property deed that would prevent using the area in ways that potentially could expose humans or the environment to materials buried in pit 6 or to contaminants released from pit 6. The following are the potential environmental impacts associated with Alternative 2.

6.4.2.1. Surface Water and Ground Water

The placement of an impermeable cap and drainage controls would eliminate the infiltration of surface water into pit 6, thereby reducing the potential for migration of contaminants from the pit. The installation of a cap and drainage controls would, therefore, reduce the potential for adverse impacts to ground water quality at Site 300 and to surface water in nearby springs, primarily springs 7 and 15. Thus, this alternative would have a beneficial environmental impact.

Under certain geologic conditions, wells or boreholes can create pathways for the downward migration of contamination through impermeable layers of native material. Standard operating procedures employed by LLNL follow State of California well installation criteria, including annular grout seals and secured wellheads. All wells and boreholes are installed under the supervision of a California Registered Geologist or Engineering Geologist. Therefore, the procedures used to install ground water monitor wells would employ controls to limit the chances of creating conduits for migration of contaminants from pit 6.

The top layer of the impermeable cap would be topsoil and vegetative cover. The vegetative cover would inhibit erosion that would normally result from precipitation, and prevent cap materials from being washed away during storms. Paved ditches would be installed around the perimeter of the cap to channel storm runoff away from the pit area and towards a natural drainage to the southwest. This drainage would be large enough to accept the anticipated flow that would be diverted from the cap.

The habitat that would result after the vegetation layer is established on the cap would not generally be attractive to burrowing animal species. However, if burrows are identified that are not used by sensitive species, the animals that create the burrows (most likely ground squirrels) would be removed and the burrows would be plugged. The monitoring program, therefore, would minimize the potential for penetration that could allow surface water to enter the landfill. Section 6.5.2.4 discusses procedures to be followed in developing measures to protect sensitive species discovered burrowing in the cap area.

Best management practices appropriate for site conditions would be followed during excavation work to prevent the transport of disturbed soils or construction materials from the construction site. Construction activities would be in accordance with the requirements of the NPDES California General Construction Activity Storm Water Permit. None of the activities proposed under this alternative would impact a natural drainage, and a California Department of Fish and Game Streambed Alteration Agreement would not be required.

6.4.2.2. Vegetation, Wildlife, and Sensitive Species

The hazard to wildlife from soil contamination associated with this alternative would generally be the same as discussed in section 6.4.1.1. Institutional controls implemented under this alternative would not restrict wildlife movement or prevent borrowing animals from using the area around pit 6. Impacts to vegetation and wildlife that could occur as a result of construction activities would be relatively minor and short-term, and would be minimized by restricting vehicular movement associated with monitoring and construction to existing access routes.

As discussed in section 6.4.1.1, sensitive species that may occur at Site 300 have not been identified in the Pit 6 operable unit, and this area is not considered critical habitat for these species. Preconstruction surveys of wildlife and vegetative species (listed as federal or state species of special concern at the time of the survey) would be conducted within 60 days prior to ground-disturbing activities. The survey area would include a minimum 300-ft buffer zone around the proposed cap area and drainage controls, around new monitor wells, and around any areas disturbed during the construction of POU treatment facilities. Depending upon the results of the survey, additional mitigation measures specified in the 1992 Sitewide EIS/EIR may be required, including the establishment of exclusion zones around any active dens found and the posting of these dens.

The cap that would be placed over pit 6 would include a layer of topsoil and vegetative cover. Since the Pit 6 operable unit is not in one of the areas at Site 300 that is burned annually or is disked for fire suppression, the vegetative cover normally would not be disturbed. The type of habitat that would result after vegetation is established on the cap would be very similar to the habitat that currently exists in the area. As discussed in section 6.4.1.1, this habitat is not considered critical for sensitive species that may occur at Site 300. In addition, after the completion of the cap, the rifle range would be reinstalled over the cap. These factors would limit the potential for sensitive species to inhabit the landfill area after the cap installation.

As part of the long-term monitoring of the pit cap, the cap surface would be periodically inspected for new animal burrows that could be used by sensitive species. If new burrowing activity is discovered, the burrows will be evaluated by a trained biologist following techniques acceptable to the U.S. Fish and Wildlife Service and the California Department of Fish and Game (U.S. Fish and Wildlife Service, 1989). Appendix F of the 1992 Sitewide EIS/EIR specifies several measures to mitigate the potential for adverse impacts to threatened or endangered species found during this evaluation (Mitigation Measures 7.2.6M through S, and 7.2.6U through W). These measures would be implemented as deemed appropriate by the biologist in consultation with the U.S Fish and Wildlife Service and the California Department of Fish and Game. These measures could include the establishment of exclusion zones around active dens and the posting of these dens, or the destruction of potential dens that are not occupied. These measures could also include the relocation of animals that are denning in that area.

The placement of the cap over pit 6 would preclude the infiltration of surface water, thereby preventing the subsequent leaching of contaminants. This would tend to reduce the risk of further downgradient contaminant migration to exposure points such as springs 7 and 15 and the SVRA residence wells or pond. By reducing the potential for contaminant migration, the installation of a cap would reduce the potential risk to humans and the environment.

6.4.2.3. Air Quality

VOCs that may be present in soil cuttings produced during monitor well drilling may volatilize if the soils are exposed to the atmosphere after they are removed from the borehole and before they are placed in a closed container. The Bay Area Air Quality Management District (BAAQMD) has determined that a release of 0.25 lb per day or less of TCE (the primary VOC identified in ground water) would not pose a significant health risk to on-site workers or off-site receptors. The concentrations of TCE that would be expected in soil cuttings should be no greater than the highest historical concentration of TCE detected in soil (0.45 mg/kg). The amount of TCE that would volatilize from exposed soil cuttings during the short exposure to air would be far less than the amount that the BAAQMD has determined could pose a health risk.

The construction of an impermeable cap, drainage control ditches, and POU treatment facilities may also result in temporary air emissions of VOCs in very minor concentrations from disturbed soils and increased dust levels. Because there is no evidence of a surface release of TCE in the area of pit 6, soil disturbance would not be expected to cause the release of any significant amount of VOCs to the atmosphere. Dust released to the atmosphere due to construction activities would have insignificant impacts on air quality. During construction activities, water would be applied as necessary to meet regulatory limits for dust suspension.

The contingency POU treatment systems would use aqueous-phase granular activated carbon (GAC) to treat ground water pumped from the Carnegie SVRA water-supply wells. Because the GAC would adsorb VOCs, there would be no release of VOCs to the atmosphere.

6.4.2.4. Soils

Prior to the installation of the impermeable cap over pit 6, the rifle range would be dismantled and removed. As part of this removal, earth berms that serve as barriers at the range would be spread over the surface prior to the placement of the cap. The installation of the monitor wells would also create excess soils in the form of drill cuttings, and these excess soils would be spread over the pit 6 area along with the soils from the earth berms. Prior to reapplication of removed soils, however, the soil cuttings would be placed in sealed containers and evaluated according to applicable California Regional Water Quality Control Board procedures in effect at the time of cap placement. Preconstruction soils samples would be collected from the earth berms and assessed according to the same procedures. If this assessment determines that the soils could cause a further degradation of ground water quality, the soils would be disposed in accordance with approved LLNL and regulatory-agency procedures. For estimated costs that are purposed in Chapter 5 and Appendix G, we assumed drill cuttings would be disposed of off site. Since there is no evidence that transuranic (TRU) waste was disposed in pit 6, TRU contamination in soils is not expected.

Currently, there are few treatment or disposal options for wastes with both hazardous and radioactive components (mixed wastes). Soils that do not meet the requirements for reapplication to the landfill cover and are considered mixed wastes would be stored on site at the LLNL Livermore site until treatment and disposal options become available. On-site storage capacity currently is sufficient to store the amount of mixed waste that could be generated during remedial activities, and no new storage facilities would be required.

The GAC used in the POU treatment systems would be replaced as necessary to maintain the efficient removal of VOCs. We estimate that the GAC would need to be replaced once every three to four years. The used GAC would be regenerated at a commercial off-site facility and reused.

After the cap is installed, the rifle range would be reinstalled. A metal canopy similar to the existing canopy would be erected and earth berms would be placed as necessary for safety. Some areas may be paved or concrete pads may be installed as necessary for vehicle access and structure support. Clean soils would be used to construct new earth berms during the reinstallation of the range.

6.4.2.5. Noise and Traffic

The construction of the impermeable cap, the drainage controls, the POU treatment facilities, the ground water monitor wells, and the reinstallation of the rifle range would result in noise increases from standard construction practices. Vehicular activity associated with continued monitoring and sample collection after the installation of these features would also result in minor periodic noise increases. These impacts would be short-term and insignificant. The operation of the POU treatment system may result in minor increases in ambient noise levels; these also are not anticipated to be significant.

6.4.2.6. Aesthetics

The Pit 6 operable unit is partially visible from Corral Hollow Road and the Carnegie SVRA. Construction activities associated with this alternative would temporarily impact the aesthetic quality of the area. This impact would be short-term and would be limited to the duration of the construction. The new pit cap would also be noticeable to users of the Carnegie SVRA until the vegetative cover was fully established. These impacts to the aesthetics of the Site 300 area are temporary and not considered significant.

6.4.2.7. Land Use

Institutional controls implemented under this alternative would limit the range of feasible uses of the spring 7 area and the capped area of pit 6. As discussed in section 6.4.1.4, however, uncertainty about the waste buried in pit 6 would limit demand for the site as property suitable for development or agriculture use even without institutional controls. Therefore, this alternative would tend to reinforce the limitations on perceived suitable uses, but would not further restrict those uses. As a result, these restrictions would only marginally reduce the economic value of the property from the value seen under Alternative 1. The other actions under this alternative (installing a cap, ground water monitor wells, and contingency POU treatment systems) would tend to increase the potential that the economic value of the Pit 6 operable unit would someday return to values seen for similar properties in the area. However, the allowable uses of the capped area would be limited to activities that do not disturb or penetrate the cap surface.

6.4.3. Alternative 3

Alternative 3 would include the activities proposed under Alternative 2 plus the installation of a ground water extraction and treatment system, including new extraction wells, and downgradient monitor wells. Approximately 10 to 15 gpm of treated ground water would be released either to the arroyo or to an infiltration area southwest of pit 6. The infiltration area would consist of either an infiltration trench or a subsurface leach field. Additional investigations are necessary to determine if there is a geologically suitable location for an infiltration area that is downgradient from pit 6. The following are the potential environmental impacts associated with this alternative.

6.4.3.1. Surface Water

Although selenium has not been detected in surface water at the Pit 6 operable unit, ground water samples from some wells in the operable unit have sporadically contained selenium at concentrations up to 22 µg/L (Webster-Scholten, 1994). However, none of these wells are within the capture zone of the proposed ground water extraction system.

If extracted and treated ground water contains selenium and is discharged to the ground surface, selenium could accumulate in sediments and biota in the discharge area(s) and could result in food chain contamination (Lemly and Smith, 1987). Studies have shown that selenium bioaccumulation in the food chain has caused poor reproductive success (Ohlendorf et al., 1986a,b; Hoffman et al., 1988) and mortality in aquatic birds (Ohlendorf et al., 1986a).

The MCL for selenium in drinking water is 10.0 µg/L. The U.S. EPA has established National Ambient Water Quality Criteria for the protection of fresh-water aquatic life (Marshack, 1991). The EPA criteria for selenium in fresh water is 5.0 µg/L. Since it is anticipated that the concentration of selenium in treated water would be below 5.0 µg/L, the discharge of treated ground water would not adversely effect human health or fresh-water aquatic life that moves into the release area. If selenium concentrations in treated ground water exceeded 5.0 µg/L, additional treatment steps would be taken to reduce the concentration to below 5.0 µg/L prior to discharge.

6.4.3.2. Vegetation, Wildlife, and Sensitive Species

The primary impacts associated with this alternative would result from the release of treated ground water to the arroyo. The arroyo ends a short distance below the proposed release point at the confluence with the Corral Hollow Creek floodplain. An elevated section of Corral Hollow Road bounds the south side of this junction, creating a small basin. Although no studies have been done on the infiltration rate for surface releases in this area, the continuous release of 10 to 15 gpm into the arroyo could create standing water and support the establishment of obligate riparian species in the arroyo and in the basin area bounded by Corral Hollow Road. Dense riparian vegetation could be expected to become established adjacent to the outflows wherever surface water is present throughout the dry season.

The treatment system would be designed to remove contaminants in ground water, including TCE and PCE, to below MCLs. As discussed in section 6.4.3.1, if selenium is found in concentrations that exceed the U.S. National Ambient Water Quality Criteria, additional steps would be taken to remove selenium to below this criteria.

As riparian vegetation and wetlands become established, aquatic insects and amphibians would be expected to move into the area. Red-legged frogs have been observed near the SVRA residence pond, and areas near Site 300 has been identified as potential habitat for the tiger salamander. Other amphibians that could move into established wetland areas are tree frogs, western toads, and foothill yellow-legged frog. Cattails that become established would provide nesting habitat for the tri-colored blackbird. The creation of wetland habitat would be beneficial to these sensitive species and to other nonsensitive species that are known to occur at Site 300.

Riparian vegetation that becomes established downstream of the release point would be expected to die following termination of the ground water extraction program. Species that inhabit riparian areas created by treated water releases would likely migrate to other nearby suitable habitat (such as the SVRA residence pond or the Fish and Game Reserve to the east).

If treated ground water is released to an open infiltration trench, riparian vegetation and wetland habitat could become established along the trench perimeter. The same species discussed above could also move into the infiltration trench area. If treated ground water is released to a subsurface leach field, riparian areas would not be established and there would be no vegetation die-off at the termination of the ground water extraction program.

In the Pit 6 operable unit, contaminants in soil vapor have been identified as a potential health hazard for burrowing animals (such as ground squirrels or kit fox if they use the area for denning). The mass removal of contaminants from ground water under this alternative may reduce the concentration of VOCs in soil vapor. Thus, the potential health risk to burrowing animals should also be reduced under this alternative.

6.4.3.3. Air Quality

VOC contamination in extracted ground water would be removed by passing the air effluent of the treatment process through two vapor-phase GAC canisters in series prior to release to the atmosphere. The treatment facility would be operated in accordance with an air permit from the San Joaquin Valley Unified Air Pollution Control District, and the air releases would be within permit limitations. Because mass removal of contamination from ground water would reduce the potential for VOCs to volatilize into the atmosphere, the impact to air quality under this alternative would be beneficial.

6.4.3.4. Noise and Traffic

Drilling and installation of extraction wells would result in temporary noise increases from equipment operation. During construction of the treatment facilities, there would be noise generated by standard construction practices. Vehicular activity associated with continued monitoring and sample collection would also result in temporary and minor noise increases. These impacts would be short-term and are not considered significant.

Up to 85 dB of noise could be generated by the treatment equipment in the immediate proximity of the facility. This noise level is the permissible exposure limit for this type of equipment. Due to the remote nature of the facilities and lack of immediately adjacent sensitive receptors, the noise generated would not have a significant impact.

6.4.3.5. Land Use

Implementation of Alternative 3 would have beneficial effects on land use. The treatment operations would remove contaminants from ground water, thereby reducing the potential for restrictions on the range of feasible land uses. However, land use restrictions at pit 6 would remain due to the potential for disturbing the cap and buried waste during development activities.

It is anticipated that implementation of this alternative would not require more than three additional permanent workers. However, the number of workers actually at the Pit 6 operable unit and the duration of their residence would be neither constant nor continuous. This increase in work force would not represent a significant change, and it falls within the range of variability seen for normal operations at Site 300.

6.4.3.6. Aesthetics

Depending upon the final site chosen, the new treatment facility would be exposed to view from Corral Hollow Road and the Carnegie SVRA. Also, riparian vegetation that could become established in the arroyo (or possibly along an infiltration trench, depending on the location chosen) would be visible from Corral Hollow Road.

Areas of riparian vegetation would not adversely affect the aesthetics of the Site 300 area and normally would be considered aesthetically pleasing. The ground water treatment facility would be small in size (approximately 30 by 30 ft), and any structures would be painted a neutral earthtone color to allow the structure to blend in with background vegetation.

6.4.4. Alternative 4

Alternative 4 would include the activities proposed under Alternative 3 plus the installation of four trench-specific subsurface permeability reduction barriers. These barriers would consist of an impermeable layer of a low-permeability bentonite/sand slurry. To reduce the permeability of the layer, stable polymers may be added. The following are the potential environmental impacts associated with this alternative.

6.4.4.1. Ground Water

The migration of contamination from pit 6 to soils and ground water is discussed in Chapter 1 and in the SWRI report (Webster-Scholten, 1994). The minimum depth of ground water observed was about 12 ft below the assumed floor of the lowest trench. Although not likely, there is a remote chance that leaching from pit 6 could occur as a result of an unusually high rise in the water table, or an undocumented liquid waste could begin to leak. The installation of impermeable subsurface barriers would reduce the potential that ground water could enter or liquid waste could leach from the pit.

The barriers would be constructed of a bentonite/sand slurry with the possible addition of polymers. This mixture is designed to be stable and impermeable, and would not present an environmental risk.

6.4.4.2. Soils

The installation of subsurface barriers could create additional volumes of contaminated soil cuttings. These soils would be stored in large covered containers until they can be analyzed according to the procedures described in section 6.4.2.4. The procedures for the subsequent handling of these soils are also the same as those described in that section.

6.4.4.3. Noise and Traffic

The installation of subsurface cells would result in noise increases from standard construction practices. These impacts would be short-term and not significant.

6.4.4.4. Aesthetics

Construction activities associated with this alternative would temporarily impact the aesthetic quality of the area. This impact would be short-term and would be limited to the duration of the construction. These impacts to the aesthetics of the Site 300 area are temporary and not considered significant.

6.4.4.5. Land Use

The subsurface barriers installed under Alternative 4 are intended to prevent the further release of contaminants from pit 6 to ground water, thereby reducing the potential for restrictions on the range of feasible land uses. This alternative, therefore, would have a beneficial effect on land use. However, land use restrictions at pit 6 would remain due to the potential to disturb the buried waste or containment system during development activities.

6.5. Potential Accidents

The CEQ has issued regulations for implementing the procedural provisions of NEPA. The CEQ has determined that NEPA reviews of proposed actions need to consider environmental impacts that might result from reasonably foreseeable accidents. The NEPA review need not, however, consider potential impacts resulting from incredible accidents that are based on pure conjecture and are not within the rule of reason (CEQ, 1986). To evaluate all foreseeable impacts of the no-action alternative and the construction and operation of facilities required under the other remedial alternatives, potential accidents should be examined. For the remedial alternatives considered in the Pit 6 operable unit, the reasonably foreseeable accident that would result in the greatest potential for adverse human health effects is discussed below.

6.5.1. Accidental Exposure of Contaminated Soils to the Atmosphere

Pit 6 is unlined, and it is possible that some wastes have leaked from the pit and may be present at high concentrations in soils immediately surrounding the pits. Although care would be taken to avoid drilling into the pits, it is possible that soils with high concentrations of contaminants may be encountered during the placement of planned boreholes, wells, or subsurface barriers. During drilling, contaminated soils in the form of drill cuttings could be brought to the surface. The release of contamination from excavated soils to the atmosphere during borehole drilling operations would represent the reasonably foreseeable accident.

This scenario anticipates that the soils would be brought to the surface during the drilling of a 20-ft long, 9-in. diameter borehole. It is assumed that the bottom 10 ft of the borehole cuttings would be saturated with contaminants that had leaked from pit 6, and the drill cuttings would be mistakenly placed on the ground without being covered. Because the normal procedure is to place excavated material in a covered container, the accidental placement of this material on the ground without cover is assumed to result from human error. It is assumed that the material is left uncovered for a period of 60 hours, which would approximately correspond to a period beginning on a Friday afternoon and ending on the following Monday morning. During this time, the contaminants would volatilize from the extracted soils or be bound to soil particles, which would then be resuspended. The scenario further assumes that the exposed soils would be discovered on Monday morning and placed in covered containers, thereby ending the release of contaminants to the atmosphere.

In a Site 300 Waste Material logbook (LLNL, 1973c), LLNL personnel recorded the contents and burial locations of 55 shipments of waste that were placed in pit 6. Although the logbook provides information about the general types and approximate sizes of wastes buried in the landfill, the specific identifications, quantities, volumes, and physical states of the wastes were not listed. The only chemical specifically identified in the logbook was mercury, although the highest concentration of mercury in downgradient soil and ground water samples was 2 ppb. For this accident scenario, it is assumed that elemental mercury from lamps and ignition tubes or other discarded devices was present in buried waste. In addition, the more than 2,000 capacitors buried in the landfill may have contained residual polychlorinated biphenyl (PCB) dielectric fluids, although anecdotal information suggests that large-volume PCB containers were drained prior to shipment to Site 300. Analyses of 6 soil samples from one borehole and ground water samples from 23 monitor wells and one water-supply well, which are located downgradient from the trenches and in the Pit 6 operable unit, indicate that PCBs were not present in excess of the detection limit. However, residual PCB contamination potentially could remain in the trenches because the persistent and low-mobility properties of PCBs may prevent significant migration to downgradient wells. Although TCE was not specifically identified in the LLNL logbook, soil and rock core sampling, soil vapor surveys (SVS) and ground water analysis conducted during remedial investigation activities indicate TCE contamination at locations downgradient from the trenches.

For these reasons, the accident scenario considers that drill cuttings brought to the surface are contaminated with TCE, PCBs, and/or mercury.

6.5.2. Potential Human Health Impacts of the Scenario

6.5.2.1. Potential Health Impacts to On-site Individuals

Site 300 workers in the vicinity of the drilling operations could be exposed to contaminants present in drill cuttings via multiple exposure routes. In addition to drill operators, security or maintenance personnel may be present in the pit 6 area during the postulated accident. An individual working in this area could simultaneously inhale resuspended contaminated soil particles or volatilized contaminants, absorb contaminants present in drill cuttings through dermal contact, and ingest small quantities of contaminated soil (from drill cuttings).

Table 6-1 lists the concentrations of contaminants in drill cuttings and in air near a borehole. These concentrations are the result of volatilization and resuspension of contaminants from drill cuttings. The American Conference of Governmental Industrial Hygienists (ACGIH) has established a "Threshold Limit Value-Time Weighted Average" (TLV/TWA) concentration for a normal 8-hour workday and a 40-hour workweek to which nearly all workers may be repeatedly exposed, day after day, without adverse effect (ACGIH, 1993). Table 6-1 shows that on-site workers would not be exposed to airborne contaminants in excess of the TLV/TWA values. These comparisons indicate that on-site workers would not be expected to experience adverse health effects as a result of the postulated accident.

To reduce the potential for exposure by inhalation, dermal contact, or incidental ingestion, all site workers at pit 6 would be required to wear respirators and protective clothing during drilling operations. Identical safety procedures would be implemented during remedial activities involving excavation. During all remedial activities, access to the pit 6 area would be controlled and warning signs would be posted to prevent entry by non-project personnel.

6.5.2.2. Potential Health Impacts to Off-site Individuals

The Carnegie SVRA ranger residence is located to the east of pit 6. Because the prevailing winds at Site 300 are from the west, this residence is generally downwind from pit 6. However, the nearest site boundary to pit 6 is directly south along Corral Hollow Road. For the purpose of assessing the maximum potential risk and hazard to individuals off site, it was assumed that an individual would be present at the site boundary along Corral Hollow Road during the entire 60-hr release period. This is a health-conservative assumption, and unlikely to occur. The maximum potential concentration of airborne contaminants at the ranger residence would be less than the concentration at the site boundary, which is closer. An individual at the site boundary could inhale contaminants bound to resuspended soil particles, and contaminants that have volatilized from drill cuttings and been transported to the site boundary. Table 6-1 lists the exposure-point concentrations of contaminants in air at the nearest site border associated with the postulated accident.

The methods used to calculate exposure dose, and the cancer risk and noncancer hazard to off-site individuals who could be exposed during the postulated accident are the same as those described in Chapter 6 of the SWRI report (Webster Scholten, 1994). In that report, pathway exposure factors (PEFs) were used to convert the exposure-point concentrations of contaminants into estimates of contaminant intake over time. For each chemical at the site border, the risk attributable to that chemical was determined by multiplying each pathway-specific intake by the corresponding pathway-specific cancer potency factor (CPF). The total cancer risk and total hazard were calculated by summing the risk or HIs for all contaminants at this location, where each chemical-specific estimate of risk or hazard represents exposures from multiple pathways (e.g., contaminants that volatilize from drill cuttings and contaminant bound to resuspended soil particulates).

The potential total individual excess lifetime cancer risk and total noncancer HI associated with short-term exposure to these contaminants at the site border, where the relevant exposure period is 2.5 days for adults off site (24 hr/day), are presented in Table 6-2. The postulated accident would result in a total cancer risk of 4×10^{-7} for an adult off site. The total noncancer HI associated with off-site individuals is 5.1×10^{-1}.

Table 6-1 also lists the reference exposure level (REL) for mercury, which is published in the California Air Pollution Control Officers Association *Risk Assessment Guidelines for AB-2588* (CAPCOA, 1992); RELs for TCE and PCB's have not been established. For a single substance, exposure at or below the REL is not expected to result in adverse health effects. The maximum concentration of airborne mercury to which the off-site individual would be exposed would be less than the REL.

6.5.2.3. Potential Ecological Impacts

Under this scenario, contaminants that volatilize from exposed contaminated soils or that are bound to resuspended particles are assumed to be carried downwind and deposited on surface soils. Both mercury and PCB persist for long periods of time in the environment (Eisler, 1986; 1987). Therefore, in addition to estimating the risk and hazard resulting from acute human exposure resulting from an accidental release of these substances, the long-term ecological impacts also were considered.

Table 6-3 lists the estimated surface concentrations of TCE, PCBs, and mercury that would be present at two selected exposure points to the east of pit 6 and springs 7 and 15. These locations were chosen as being attractive to wildlife due to the potential presence of surface water. In addition, although these springs currently are dry, they do support year-round green vegetation. Most contaminants would be deposited closer to the exposed soil cuttings, and modeling of deposition indicates that it is extremely unlikely that any significant amount of contaminants would be carried as far as the Carnegie SVRA residence pond. In addition, spring 7 currently is dry, and significant amounts of ponded surface water have not been observed at spring 15. For these reasons, this accident scenario assumes that the deposition of contaminants would not result in the contamination of surface waters.

To determine the potential for the postulated release to result in adverse ecological impacts, soil criteria for mercury, PCBs, and TCE were developed that would be protective of both primary and secondary consumers (i.e., herbivores and carnivores). The food chain consisting of primary producer (plant) to primary consumer (rodent) to secondary consumer (fox, coyote, or raptor) is common and important at Site 300 (Webster-Scholten, 1994). The criteria for mercury and PCBs are based on dietary levels for birds and mammals, and are obtained from reports prepared for the U.S. Fish and Wildlife service, which summarized the literature (Eisler, 1986; 1987). Other terrestrial taxa, such as amphibians, reptiles, and arthropods, were not well represented in these reviews. However, the available data indicated these taxa to be less sensitive to PCB and mercury than birds and mammals (Eisler, 1986; 1987). Similar data are not available for TCE. To develop dietary levels for TCE, we selected the no-observable-effect level reported by Tucker et al. (1982) for the mouse.

The soil criteria developed were then compared to the estimated soil concentrations of TCE, mercury, and PCB resulting from the accidental release of these substances. As shown in Table 6-3, modeling indicates that the concentrations of contaminants that are expected as a result of deposition in soil at springs 7 and 15 would be less than the values considered protective of terrestrial taxa. The postulated accident, therefore, is not expected to present an unacceptable ecological hazard.

6.6. Cumulative Impacts

The long-term environmental impacts that may occur in conjunction with, or as a result of, the pit 6 remediation activities potentially could contribute to the cumulative impacts of all remediation projects occurring simultaneously at Site 300 over the next 30 to 70 years (the estimated duration of ground water cleanup in many areas). The potential areas of concern in relation to cumulative impacts of site-wide remediation activities are human health, land use, air emissions, the generation of hazardous waste (primarily in the form of spent carbon), and the discharge of treated ground water.

6.6.1. Cumulative Impacts to Human Health

Existing soil and ground water contamination from pit 6 currently contributes to the potential for risks to human health from the past release of hazardous materials at Site 300. Three of the alternatives discussed in this chapter would reduce the potential for human exposure by implementing institutional controls, reducing the concentrations of contaminants, and reducing the potential for the further release of contaminants from pit 6. The remedial alternatives for the Pit 6 operable unit, therefore, would tend to reduce the cumulative potential for human exposure to contamination at Site 300.

6.6.2. Cumulative Impacts to Land Use

Since the availability of ground water is a significant constraint to land use, ground water contamination at Site 300, including contamination in the Pit 6 operable unit could have the potential to adversely affect land use in the Site 300 area. Land use in the pit 6 area would also be limited by deed restrictions for the spring 7 area and for the pit 6 area. Future uses of the pit 6 area would have to be consistent with the maintenance of the landfill cap.

6.6.3. Cumulative Impacts to Air Quality

Under the no-action alternative, minor amounts of VOCs in soils or from nearby springs could volatilize into ambient air. Also, as discussed in section 6.5, human error could result in the exposure of contaminated soils to the atmosphere. In these two cases, contamination and remedial activities could contribute to adverse impacts to air quality at Site 300.

Ground water extraction and treatment would reduce the amount of contaminants that may volatilize into ambient air at Site 300. The remedial alternatives for the Pit 6 operable unit would, therefore, tend to reduce the potential adverse impacts to air quality from contamination at Site 300.

6.6.4. Cumulative Impacts Resulting from Hazardous Waste Generation

Spent carbon generated at the treatment facilities would increase the amount of waste generated at Site 300. This type of waste is routinely regenerated at a permitted off-site facility. The proposed action, therefore, would not require new on-site facilities for the regeneration of used carbon. There is existing space at off-site landfills for the disposal of soils contaminated with hazardous materials. Soils that are considered low-level radioactive waste, if any, would most likely be disposed at the Nevada Test Site. Until final treatment/disposal options are selected, there is adequate storage capacity on site for soils that are considered mixed wastes.

6.6.5. Cumulative Impacts to Surface Water

The estimated discharge rate of ground water from the proposed pit 6 treatment facility would be between 10 and 15 gpm. The discharge area would not be used by any of the other proposed treatment facilities. No surface flow would be created that could reach Corral Hollow Creek or any other proposed treated-water discharge point at Site 300. Therefore, remedial action for the Pit 6 operable unit would not contribute to the potential impacts ground water discharges from other treatment facilities at Site 300.

References

References

ACGIH (1993), *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio.

Anonymous (1890), *Map of the Corral Hollow Coal Field located in Alameda and San Joaquin Counties, California*, with cross-section, map scale 1, 320 ft/in., Map Collection of the Bancroft Library, University of California at Berkeley.

Anspaugh, L. R., J. H. Shinn, P. L. Phelps, and N. C. Kennedy (1975), "Resuspension and Redistribution of Plutonium in Soils," *Health Phys.* **29**.

Aubury, L. E. (1906), *The Structural and Industrial Materials of California*, California State Mining Bureau, Bulletin No. 38.

Bouwer, H., and R. C. Rice (1976), "A Slug Test for Determining Hydraulic Conductivity of Unconfined Aquifers with Completely or Partially Penetrating Wells," *Water Resour. Res.* **12**, pp. 423–428.

Brown and Caldwell (1987), *Hydrogeologic Investigation, Lawrence Livermore National Laboratory, Site 300, Pit 6*, University of California Purchase Order No. 9929905, (UCRL-15915).

Bryn, S. M., R. K. Landgraf, and S. E. Booth (1990), *Draft Remedial Investigation and Feasibility Study for the Lawrence Livermore National Laboratory Site 300 Building 834 Complex*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-ID-103963).

Busby, C. I., D. M. Garaventa, and L. S. Kobori (1981), *A Cultural Resource Inventory of Lawrence Livermore National Laboratory's Site 300, Alameda and San Joaquin Counties, California*, prepared for Lawrence Livermore National Laboratory, Livermore, Calif., by Basin Research Associates, Inc., Hayward, Calif.

Caldera, R. (1991), State ranger, Carnegie State Vehicular Recreation Area, personal communication with J. Copland, SAIC.

California Department of Toxic Substances Control (CDTSC) (1991a), "Criteria for Identification of Hazardous and Extremely Hazardous Wastes—Persistent and Bioaccumulative Toxic Substances," *Title 22 California Code of Regulations Division 4.5, Environmental Health*, Section 66261 (as amended July 1, 1991), Department of Toxic Substances Control, Sacramento, Calif.

California Department of Toxic Substances Control (CDTSC) (1991b), *Applied Action Levels*, Sacramento, Calif., August 1, 1991.

California Department of Water Resources (CDWR) (1979), *Re-evaluation of Seismic Hazards for Clifton Court Forebay, Bethany Dams and Reservoir, Patterson Reservoir, Del Valle Dam and Lake Del Valle*, State of California, Department of Water Resources, Sacramento, Calif.

CAPCOA (1992), *Risk Assessment Guidelines for AB-2588*, California Air Pollution Control Officers Association.

Carpenter, D. *et al.* (1991), *Investigation of Holocene Faulting Near Closed Landfill Pit 6, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-ID-106316).

Carpenter, D. W., A. L. Lamarre, N. B. Crow, and P. M. Swearengen (1988), *Closure Plan for the Decommissioned High Explosives Rinse-Water Lagoons at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCID-21369).

Carpenter, D. W., and D. W. Peifer (1983), *Supplementary Data Report: Site 300 Chemical and Hydrogeological Assessment*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCID-19801).

Carpenter, D. W., J. J. Sweeney, P. W. Kasameyer, N. R. Burkhard, K. G. Knauss, and R. J. Shlemon (1984), *Geology of the Lawrence Livermore National Laboratory Site and Adjacent Areas*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-53316).

Carpenter, D. W., J. R. Copland, A. L. Lamarre, R. S. Mateik, M. J. Taffet, and W. M. Wade (1991), *Investigation of Holocene Faulting Near Closed Landfill Pit 6, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-ID-106316).

Carpenter, D. W., M. J. Taffet, J. R. Copland, R. S. Mateik, and W. M. Wade (1992), "Halocene Faulting Near Lawrence Livermore National Laboratory, Site 300," in *Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, G. Borchardt*, Chief Ed., California Department of Conservation, Division of Mines and Geology, Special Publication 113, pp. 333–338.

Carter, B. (1991), State ranger for the Carnegie State Vehicular Recreation Area, personal communication with J. Copland, SAIC.

CH2M HILL California, Inc. (1985), *Hazardous Waste Site Assessment: Inactive Landfill, Site 300, Lawrence Livermore National Laboratory*, prepared by CH2M HILL California, Inc., Emeryville, Calif., for Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-15850).

Clark, W. B. (1955), "Mines and Mineral Resources of San Joaquin County, California," *California Journal of Mines and Geology* **51**(1).

Coe, T. (1991), U.S. Army Corps of Engineers, Sacramento, Calif., personal communication with Tina Carlsen, LLNL environmental scientist.

Cooper, H. H., and C. E. Jacob (1946), "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well Field History," *Amer. Geophys. Union Trans.* **27**, pp. 526–534.

Copland, J. R. (1992), hydrogeologist, SAIC, written communication for hydraulic test analyses.

Council on Environmental Quality (CEQ) (1986), *Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act*, Council on Environmental Quality, Executive Office of the President, Washington D.C. (40 CFR Parts 1500–1508).

Crow, N. B., and K. C. Toney (1991), *Logs of Wells and Boreholes Drilled During Hydrogeologic Studies at Lawrence Livermore National Laboratory Site 300: June 30, 1988 to January 1, 1991*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCID-21536, Addendum 1).

Decker, R. F. (1971), "Exhumation of D-38 at Site 300," Lawrence Radiation Laboratory [LLNL], memorandum to D. S. Myers, June 23, 1971.

Deere, D. U., R. F. Coon, and A. H. Merritt (1969), *Engineering Classification of In-Situ Rock*, Technical Report AFWL-TR67-144, Kirtland Air Force Base, N. Mex., 280 pp.

Dibblee, T. W., Jr. (1980), *Preliminary Geologic Map of the Midway Quadrangle, Alameda and San Joaquin Counties, California*, USGS Open-File Report 80-535.

Dietrich, W. F. (1928), *The Clay Resources and the Ceramic Industry of California*, California Division of Mines and mining, Bulletin No. 99.

Dietz, S. A., and T. Jackson (1974), *Report of the Preliminary Archaeological Reconnaissance of the Lawrence Livermore Laboratory Site 300, San Joaquin County, California*, Lawrence Livermore National Laboratory, Livermore, Calif.

Dugan, W. R., and R. Mateik (1990), personal communication with Michael Taffet, Lawrence Livermore National Laboratory.

Eaton, J. (1986), *Tectonic Environment of the 1892 Vacaville/Winters Earthquake, and the Potential for Large Earthquakes Along the Western Edge of the Sacramento Valley, California*, USGS Open-File Report 86-370.

Eisler, R. (1986), *Polychlorinated Biphenyl Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review*. U.S. Fish and Wildlife Service, U.S. Department of the Interior. Biological Report 85(1.7).

Eisler, R. (1987), *Mercury Hazards to Fish; Wildlife, and Invertebrates: A synoptic Review.* U.S. Fish and Wildlife Service, U.S. Department of the Interior. Biological Report 85(1.10).

Ferris, J. G., and D. B. Knowles (1963), "The Slug-Injection Test for Estimating the Coefficient of Transmissibility of an Aquifer," U.S. Geological Survey, Water Supply Paper 1536-I, pp. 299–304.

Ferry, R. A. (1988), hydrogeologist, Weiss Associates, written communication for hydraulic test analyses.

Ferry, R. A. (1990), hydrogeologist, Weiss Associates, written communication for hydraulic test analyses.

Ferry, R. A. (1992), hydrogeologist, personal communication with J. Copland, SAIC.

Fischer, K. (1992), SAIC engineer, personal communication with J. Copland, SAIC.

Freeze, R. A., and J. A. Cherry (1979), *Groundwater* (Prentice-Hall, Englewood Cliffs, N. J.).

Fuller, D. (1991), State Ranger supervisor, Carnegie State of Vehicular Recreation Area, personal communication with J. Copland, SAIC.

Gallegos, G. M., S. M. Wander, B. K. Balke, E. Christofferson, P. J. Tate, K. A. Surano, R. J. Harrach, L. M. Garcia B. C. Fields, W. G. Hoppes, and R. A. Failor (1993), *Environmental Report 1992*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-50027-92).

Gonzalez, I. (1992), LLNL surveyor, personal communication with J. Copland, SAIC.

GZA (1990), *Hydrophysical Logging of Wellbores K6-26 and BC6-12, LLNL Site 300 Landfill Pit 6*, San Joaquin County, California, Goldberg-Zoino & Associates, Inc., Newton Upper Falls, Mass. (GZA File No. 12015).

Hairr, G. M. (1965), "Carcass Burial," Berkeley: Lawrence Radiation Laboratory, memorandum GMH-292-65 to D. J. Kvam, June 17, 1965.

Hantush, M. S., and C. E. Jacob (1955), "Non-Steady Radial Flow in an Infinite Leaky Aquifer," *Am. Geophy. Union Trans.* **36**(1), pp. 95–100.

Hauk, T. (1990), physicist, Earth Sciences Department, Lawrence Livermore National Laboratory, "Seismicity and Location Resolution with LLSN near Site 300," personal communication with D. W. Carpenter, geologist, Earth Sciences Department, LLNL.

Henry, R. (1992), environmental scientist, Operations and Regulatory Affairs Division, Lawrence Livermore National Laboratory, personal communication with J. Copland, SAIC.

Hoffman, D. J., H. M. Ohlendorf, and T. W. Aldrich (1988), "Selenium Teratogenesis in Natural Populations of Aquatic Birds in Central California," *Arch Environmental Contaminant Toxicology* **17**, pp. 519–525.

Huey, A. S. (1948), "Geology of the Tesla Quadrangle, California," California Division of Mines, Bulletin 140, p. 75.

Hwang, S. T., J. W. Falco, and C. H. Nauman (1986), *Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup*, Office of Health and Environmental Assessment, Exposure Assessment Group, U.S. Environmental Protection Agency, Washington, D.C. (PB86-232774).

Jacob, C. E., and S. W. Lohman (1952), "Nonsteady Flow of a Well of Constant Drawdown in an Extensive Aquifer," *Am. Geophys. Union Trans.* **33**, pp. 559–569.

Johnsen, R. E. (1965), "Contaminated Animals," Livermore: Lawrence Radiation Laboratory (LLNL), memorandum to D. Kvam, LLNL Hazardous Waste Management, June 10, 1965.

Kang, Sang-Wook, and J. Kleiber, Jr. (1993), *Blast Wave Characteristics Near Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-LR-114995).

Kilness, A. W., J. L. Simmons, R. K. Stroud, D. J. Hoffman, and J. F. Moore (1988), "Selenium Toxicosis in Wild Aquatic Birds," *Journal of Tox. and Environmental Health* **24**, pp. 67–92.

Kloepping, R. J. (1971), "Disposal of Cow 10 and Cow 21 at Site 300," Lawrence Radiation Laboratory (LLNL), memorandum to B. L. Rich, April 26, 1971.

Kvam, D. (1985), personal communication between D. Kvam, LLNL Hazardous Waste Management, and W. McConachie, LLNL Environmental Restoration Division, on February 5, 1985.

Kvam, D. J. (1971), "Comments of Site 300 Waste Burial," Lawrence Radiation Laboratory, memorandum to B. L. Rich, January 12, 1971.

Laforge, R., and W. H. K. Lee (1982), "Seismicity and Tectonics of the Ortigalita Fault and Southeast Diablo Range, California," in *Proceedings of the Conference on Earthquake Hazards in the Eastern San Francisco Bay Area*, E. W. Hard, S. E. Hirschfeld, and S. S. Schultz, Eds., California Division of Mines and Geology, Sacramento, Calif., Special Publication 62, pp. 93–102.

Lamarre, A. (1993), Memorandum from Albert L. Lamarre, Site 300 Restoration Section Leader, Environmental Restoration Division to J. R. Shingleton, LLNL Hazards Control Department, dated March 22, 1993.

Lamarre, A. L., and M. J. Taffet (1989), *Firing Table Gravel Cleanup at Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCAR-10282).

Lamarre, A. L., Ed. (1990a), *Lawrence Livermore National Laboratory Site 300 Environmental Investigations Quarterly, January–March 1990*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCAR-10194-90-1).

Lamarre, A. L., Ed. (1990b), *LLNL Site 300 Environmental Investigations Quarterly, April–June 1990*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCAR-10194-90-2).

Lamarre, A. L., H. K. Otsuki, T. D. Eply, D. W. Carpenter, K. G. Fischer, S. Matthews, E. L. Miner, and K. C. Sixt (1993), *Closure Plan for the High-Explosives Open Burn Treatment Facility at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-ID-111753).

Lamarre, A. L., W. A. McIlvride, M. J. Taffet, and N. B. Crow (1989), *LLNL Site 300 Environment Investigations Quarterly, April–June 1989*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCAR-10194-89-2).

Lamarre, A. L., W. A. McIlvride, M. J. Taffet, J. M. Beiriger, S. E. Booth, S. M. Bryne, P. L. Cederwall, N. B. Crow, R. O. Devany, R. A. Ferry, R. K. Landgraf, R. L. Nations, J. A. Oberdorfer, J. P. Pavletich, B. J. Qualheim, and S. P. Vonder Harr (1988), *LLNL Site 300 Environmental Investigations Quarterly, October–December 1988*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCAR-10194-88-4).

Landgraf, R. K. (1990), hydrogeologist, LLNL, written communication for hydraulic test analyses.

Landgraf, R. K., and E. Miner (1994), *Draft Feasibility Study for the Building 834 Operable Unit, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-113863).

Lawrence Radiation Laboratory (1971), "Large Animal Disposal," Operational Safety Procedure No. 300-710426, April 26, 1971.

Lemly, A. D., and G. J. Smith (1987), *Aquatic Cycling of Selenium: Implications for Fish and Wildlife,* Fish and Wildlife Leaflet 12, U.S. Department of the Interior, Washington D.C.

Lerbekmo, J. F. (1961), "Genetic Relationship Among Tertiary Blue Sandstones in Central California," *Jour. Sedimentary Petrology* **31**, pp. 594–602.

Lienkaemper, J. J., G. Borchardt, and M. Lisowski (1991), "Historic Creep Rate and Potential for Seismic Slip Along the Hayward Fault, California," *J. Geophys. Res.* **96**(18), pp. 261–18, and 283.

Liss, P. S., and P. G. Slater (1974), "Flux of Gases Across the Air-Sea Interface," *Nature*, **247**, pp. 181–184.

LLNL (1964), Lawrence Livermore National Laboratory, *Contaminated Material Burial Area—Pit No. 1 & No. 2*, Plant Engineering drawing no. PSC63-300-006CB, September 14, 1964.

LLNL (1968), Lawrence Livermore National Laboratory, *Waste Burial at Site 300*, Hazards Control Manual Section DD-21, August 27, 1968.

LLNL (1973a), "Pistol Range Pit #6," Lawrence Livermore National Laboratory, Plant Engineering Drawing, unnumbered, June 21, 1973.

LLNL (1973b), Lawrence Livermore National Laboratory, *Waste Material Site 300*, unpublished pit 6 log book for July 1, 1964, to March 2, 1973; 54-pages; notes by Calvin E. Moore, James C. Williams, Charles A. Harder, James C. Wells, R. J. Lloyd, and Lyle K. Kerns, Jr.

LLNL (1973c), *Waste Material Site 300*, unpublished pit 6 logbook for July 1, 1964, to March 2, 1973; 54 p.; notes by Calvin E. Moore, James C. Williams, Charles A. Harder, James C. Wells, R. J. Lloyd, and Lyle K. Kerns, Jr., Lawrence Livermore National Laboratory, Livermore, Calif.

LLNL (1984), "Pit No. 6—Material Site 300," Lawrence Livermore National Laboratory, Plant Engineering Drawing No. PSC84-300-001D, March 20, 1984.

LLNL (1988), *Site 300 Development and Facilities Utilization Plan (1988)*, Lawrence Livermore National Laboratory, Livermore, Calif. (K-89-008).

LLNL (1991a), *Site 300—Site Development Plan*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-106744).

LLNL (1991b), CERCLA Feasibility Study for the LLNL Livermore Site, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-104040).

Lohman, S. W. (1979), "Ground-Water Hydraulics," *Geological Survey Professional Paper 708*, United States Government Printing Office, Washington, D.C.

Mackay, D., and P. J. Leinonen (1975), "Rate of Evaporation of Low-Solubility Contaminants from Water-Bodies to Atmosphere," *Environ. Sci. Technol.* **9**, pp. 1178–1180.

Madrid, V. (1991), project geologist, personal communication with M. Wade, Geologist, Weiss Associates, Emeryville, Calif.

Marshack, J. B. (1991), *A Compilation of Water Quality Goals,* California Regional Water Quality Control Board, Central Valley Region, Sacramento, Calif.

Matthews, S. M., A. J. Boegel, D. W. Camp, R. A. Caufield, J. O. Cunningham, P. F. Daley, J. J. Greci, M. C. Jovanovich, J. A. Loftis, and P. D. Soran (1992), "Remediation of a TCE Ground Spill Using an Electron Accelerator," in *Proceedings of the International Topical Meeting on Nuclear and Hazardous Waste Management, Spectrum '92*, August 23–27, 1992, Boise, Idaho, published by the American Nuclear Society, Inc., La Grange Park, Ill.

McIlvride, W. A., R. A. Ferry, S. P. Vonder Haar, W. M. Wade, and L. L. Glick (1990), *Draft Remedial Investigation of the General Services Area (GSA), Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-103161).

Moridis, C. J., P. Persoff, H. Y. Holman, S. J. Muller, K. Pruess, and C. J. Radkc (1993), "New Barrier Fluids for Subsurface Containment of Contaminants," Paper Presentation, ER'93 Environmental Remediation Conference, October 24–28, Augusta, Georgia, Earth Sciences Division, Lawrence Berkeley Laboratory, University of California, Berkeley, Calif. (LBL-34673).

Mosier, D. L. (1983), *Corral Hollow Coal Mining District*, Mines Road Books, Fremont and San Leandro, Calif.

Namson, J. S., and T. L. Davis (1988), "Seismically Active Fold and Thrust Belt in the San Joaquin Valley, Central California," *Geol. Soc. Am. Bull.* **100**, pp. 257–273.

Ohlendorf, H. M., M. K. Saiki, and T. W. Aldrich (1986a), "Embryonic Mortality and Abnormalities of Aquatic Birds; Apparent Impacts of Selenium from Irrigation Drainwater," *Science Total Environment* **52**, pp. 49–63.

Oppenheimer, D. H., W. H. Bakun, and A. G. Lindh (1990), "Slip Partitioning of the Calaveras Fault, California and Prospects for Future Earthquakes," *J. Geophy. Res.* **95**, pp. 8483–8498.

Orloff, S. (1986), *Wildlife Studies of Site 300 Emphasizing Rare and Endangered Species, Lawrence Livermore National Laboratory, San Joaquin County, California*, prepared for Lawrence Livermore National Laboratory by BioSystems Analysis, Inc., Sausalito, Calif.

Page, B. M. (1982), "Sequential Geologic Indicators of Plate Interactions, Central California," *Am. Geophys. Union Trans.* **63**(45), p. 911.

Papadopulos, S. S., J. D. Bredhoeft, and H. H. Cooper, Jr. (1973), "On the Analysis of Slug Test Data," *Water Resour. Res.* **9**, pp. 1087–1089.

Pavlik, B. M. (1992), *Inching Towards Recovery: Evaluating the Performance of* Amsinckia grandiflora *Populations under Different Management Regimes,* prepared for the Endangered Plant Program, California Department of Fish and Game, Sacramento, Calif.

Petsonk, A. M., W. Romanowski, and V. Richards (1987), "Field Permeability Testing for a RCRA Landfill Final Cover," in *Proceedings of HAZMACON 1987*, Santa Clara, Calif.

Plafker, G., and J. P. Galloway, Eds. (1989), *Lessons Learned from the Loma Prieta Earthquake of October 17, 1989*, U.S. Geological Survey, Washington, D.C., Circular 1045.

Potter, G. (1965), "Disposal of Cows #2, #7, and #8 at Building 290," Lawrence Radiation Laboratory (LLNL), May 9, 1966 memorandum to H. DiGrazia May 9, 1966, and annotated by D. J. Kvam, May 10, 1966.

Prescott, W. H., M. Lisowski, and J. C. Savage (1981), "Geodetic Measurement of Crustal Deformation of the San Andreas, Hayward, and Calaveras Faults Near San Francisco, California," *Geophys. Res.* **86**, pp. 10853–10869.

Raber, E., and D. W. Carpenter, Eds. (1983), *An Evaluation of the Hydrogeology and Groundwater Chemistry Associated with Landfills at LLNL's Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-53416).

Raymond, L. A. (1969), *The Stratigraphy and Structural Geology of the Northern Lone Tree Creek and Southern Tracy Quadrangles, California*, M.S. thesis, San Jose State College, San Jose, Calif.

Raymond, L. A. (1973), "Tesla—Ortigalita Fault, Coast Range Thrust Fault and Franciscan Metamorphism, Northwestern Diablo Range, California," *Geol. Soc. Am. Bull.* **84**, pp. 3547–3562.

Rezowalli, J. (1988), *Magnetic Gradient and Total Field Survey, Lawrence Livermore National Laboratory Site 300, Pit-6, Corral Hollow Road, Livermore, California*, J. R. Associates, Oakland, Calif., October 7, 1988.

Rich, B. L. (1971), "Site 300 Burial," Lawrence Radiation Laboratory [LLNL] memorandum BLR-71-5 to D. C. Sewell, February 11, 1971.

Rueth, L. S. (1994), Weiss Associates project hydrogeologist, personal communication with R. K. Landgraf, hydrogeologist, Lawrence Livermore National Laboratory.

San Joaquin County (1992), *San Joaquin County General Plan*, San Joaquin County Board of Supervisors, Stockton, Calif.

Shedlock, K. M., R. K. McGuire, and D. G. Herd (1980), *Earthquake Recurrence in the San Francisco Bay Region, California, from Fault Slip and Seismic Moment*, U.S. Geological Survey, Menlo Park, Calif., Open-File Report 80-999.

Slemmons, D. B., and D. H. Chung (1982), "Maximum Credible Earthquake Magnitudes for the Calaveras and Hayward Fault Zones, California," in *Proceedings of the Conference on Earthquake Hazards in the East Bay Area*, E. W. Hart, S. E. Hirschfeld, and S. S. Schulz, Eds., California Division of Mines and Geology, Sacramento, Calif., Special Publication 62, pp. 115–124.

Steinbrugge, K. V., J. H. Bennett, H. J. Lagorio, J. F. Davis, G. Borchardt, and T. R. Toppazada (1987), *Earthquake Planning Scenario for a Magnitude 7.5 Earthquake on the Hayward Fault in the San Francisco Bay Area*, California Division of Mines and Geology, Sacramento, Calif., Special Publication 78.

Sutton, J. S. (1992), LLNL heavy equipment operator for Lawrence Livermore National Laboratory Labor Shop, personal communication with J. Copland, SAIC.

Taffet, M. J. (1990), *Draft Remedial Investigation of Landfill Pit 6, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-ID-103961).

Taffet, M. J., A. L. Lamarre, and W. A. McIlvride (1989), *Lawrence Livermore National Laboratory Site 300 Environmental Investigations Quarterly, January–March 1989*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCAR-10194-89-1).

Taffet, M. J., and A. L. Lamarre (1988), *Solid Waste Assessment Test (SWAT), Inactive Landfill Pit 6, Lawrence Livermore National Laboratory Site 300, San Joaquin County, California*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCAR-10242).

Taffet, M. J., and J. A. Oberdorfer (1991), *Draft Feasibility Study of the Building 850/East Firing Area, Lawrence Livermore National Laboratory Site 300, April 1991*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-107033).

Taffet, M. J., J. A. Oberdorfer, T. M. Carlsen, W. R. Dugan, and R. S. Mateik (1990), *Draft Remedial Investigation of the Building 850/East Firing Area, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-ID-104335).

Taffet, M. J., J. R. Copland, and R. A. Ferry (1991), *Draft Feasibility Study for Landfill Pit 6, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-106307).

Tera Advanced Services Corporation (1984), *Final Report, Seismic Hazard Analysis of Department of Energy Sites*, consultant's report to D. W. Coats, engineer, Lawrence Livermore National Laboratory.

Theis, C. V. (1935), "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," *Am. Geophys. Union Trans.* **16**, pp. 519–524.

Tucker, A. N., V. M. Sanders, D. W. Barnes, T. J. Bradshaw, K. L. White, Jr., L. E. Sain, J. F. Borzelleca, and A. E. Munson (1982), "Toxicology of Trichloroethylene in the Mouse," *Toxicol. Appl. Pharmacol.* **62**, pp. 351–357.

Turner, D. B. (1982), *Workbook of Atmospheric Dispersion Estimates*, Office of Air Programs, U.S. Environmental Protection Agency, Research Triangle Park, N.C. (Publication No. AP-26, revised 1970).

U.S. DOE (1982), *Final Environmental Impact Statement, Lawrence Livermore National Laboratory and Sandia National Laboratories—Livermore Sites*, Livermore, California, U.S. Department of Energy, Washington, D.C. (DOE/EIS-0028).

U.S. DOE (1992), *Environmental Impact Statement and Environmental Impact Report for Continued Operation of Lawrence Livermore National Laboratory and Sandia National Laboratories, Livermore, California*, U.S. Department of Energy, Washington, D.C. (DOE/EIS-0157).

U.S. EPA (1986), *Quality Criteria for Water*, Office of Water Regulations and Standards, Criteria and Standard Division, Washington, D.C. (EPA 44015-86-001).

U.S. EPA (1988), *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final*, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. (EPA/540/G-89/004, OSWER Directive 9355.3-01, October 1988).

U.S. EPA (1989), *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual,(Part A) Interim*, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. (EPA/540/1-89/002).

U.S. EPA (1990), *Exposure Factors Handbook*, Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, D.C. (EPA 600-8-89-043).

U.S. EPA (1993), *Application Analysis Report, Peroxidation Systems, Inc. Perox-Pure™ Chemical Oxidation Technology*, Research and Development (RD 681), U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio (Contract No. 68-C0-0047, May 1993).

U.S. Fish and Wildlife Service (1989), *Wildlife and Fisheries*, U.S. Fish and Wildlife Service, Department of the Interior, January 1989 (and revisions).

USDA (1966), *Soil Survey—Alameda Area*, California, by L. E. Welch et al., U.S. Department of Agriculture Soil Conservation Service, Series 1961, No. 41, 95 pp. plus plates.

USDA (1990), *Soil Survey, San Joaquin County*, preliminary draft, U.S. Department of Agriculture, Stockton, Calif.

Van Dyke, O. R. (1985) Memorandum to W. M. McConachie, LLNL Environmental Restortation Division, February 6, 1985.

Vonder Haar, S. P., J. P. Pavletich, W. A. McIlvride, and M. J. Taffet (1989), *Soil Vapor Survey at the LLNL Site 300 General Services Area, Adjacent Portions of the Connolly and Gallo Ranches and the Site 300 Landfill Pit 6 Area, San Joaquin County, California*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-21183).

Wade, M. (1992), geologist, Weiss Associates, personal communication with J. Copland, hydrogeologist, SAIC.

Ward, B., and E. Williams (1971), "Alameda and San Joaquin Railroad Company," *The Western Railroader* **34**(10), Issue No. 380, Guido, F. A., Ed., San Mateo, Calif.

Warr, R. (1988), *Carnegie State Vehicular Recreation Area* (brochure), California State Department of Parks & Recreation.

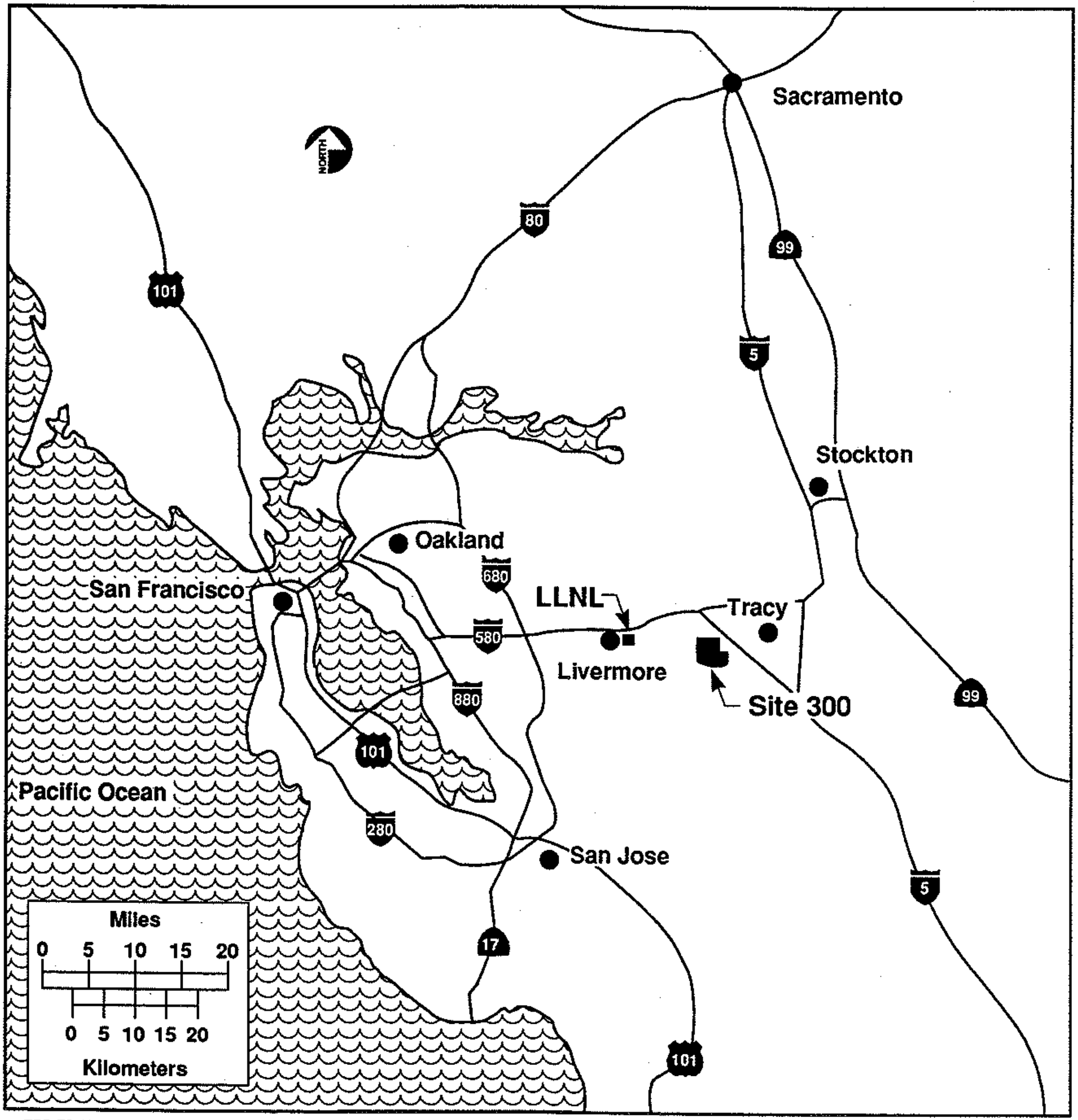
Webster-Scholten, C. P., Ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-108131).

Wentworth, C. M., and M. D. Zoback (1989), "The Style of Late Cenozoic Deformation at the Eastern Front of the California Coast Ranges," *Tectonics* **8**, pp. 237–246.

Wesson, R. L., E. J. Helley, K. R. Lajoie, and C. M. Wentworth (1975), "Faults and Future Earthquakes," in *Studies for Seismic Zonation of the San Francisco Bay Region*, U.S. Geological Survey, Washington, D.C., Professional Paper 941-A, pp. 5–30.

Wilson, J. L., and P. J. Miller (1978), "Two-Dimensional Plume in Uniform Ground-Water Flow," Proceedings of the American Society of Civil Engineers, *Journal of the Hydraulics Division* **104**(HY4), pp. 503–514.

Figures



ERD-FS-All-3031

Figure 1-1. Locations of LLNL Main Site and Site 300.

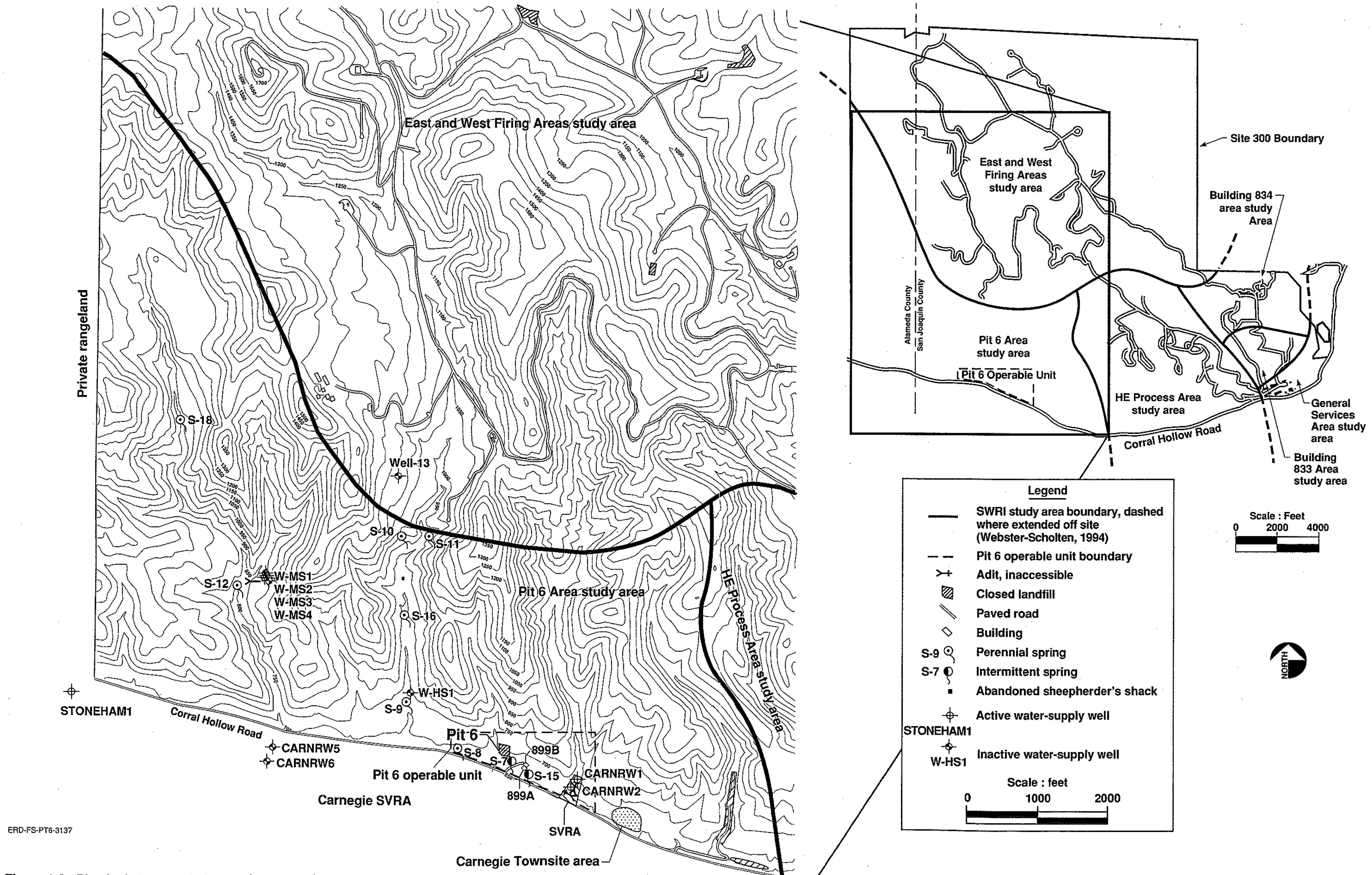


Figure 1-2. Physical characteristics, springs, supply wells, and adits of the Pit 6 Area study area and vicinity.

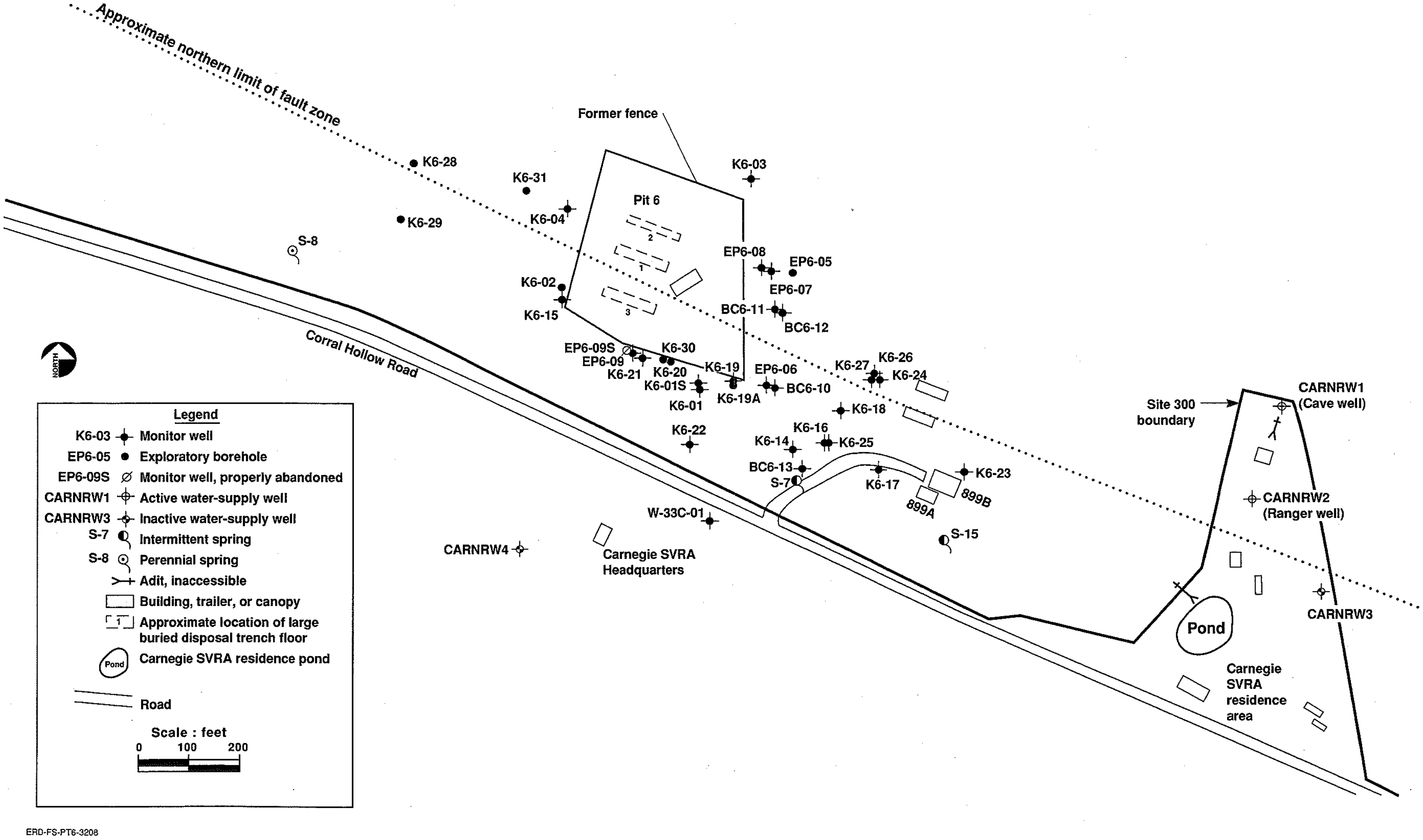
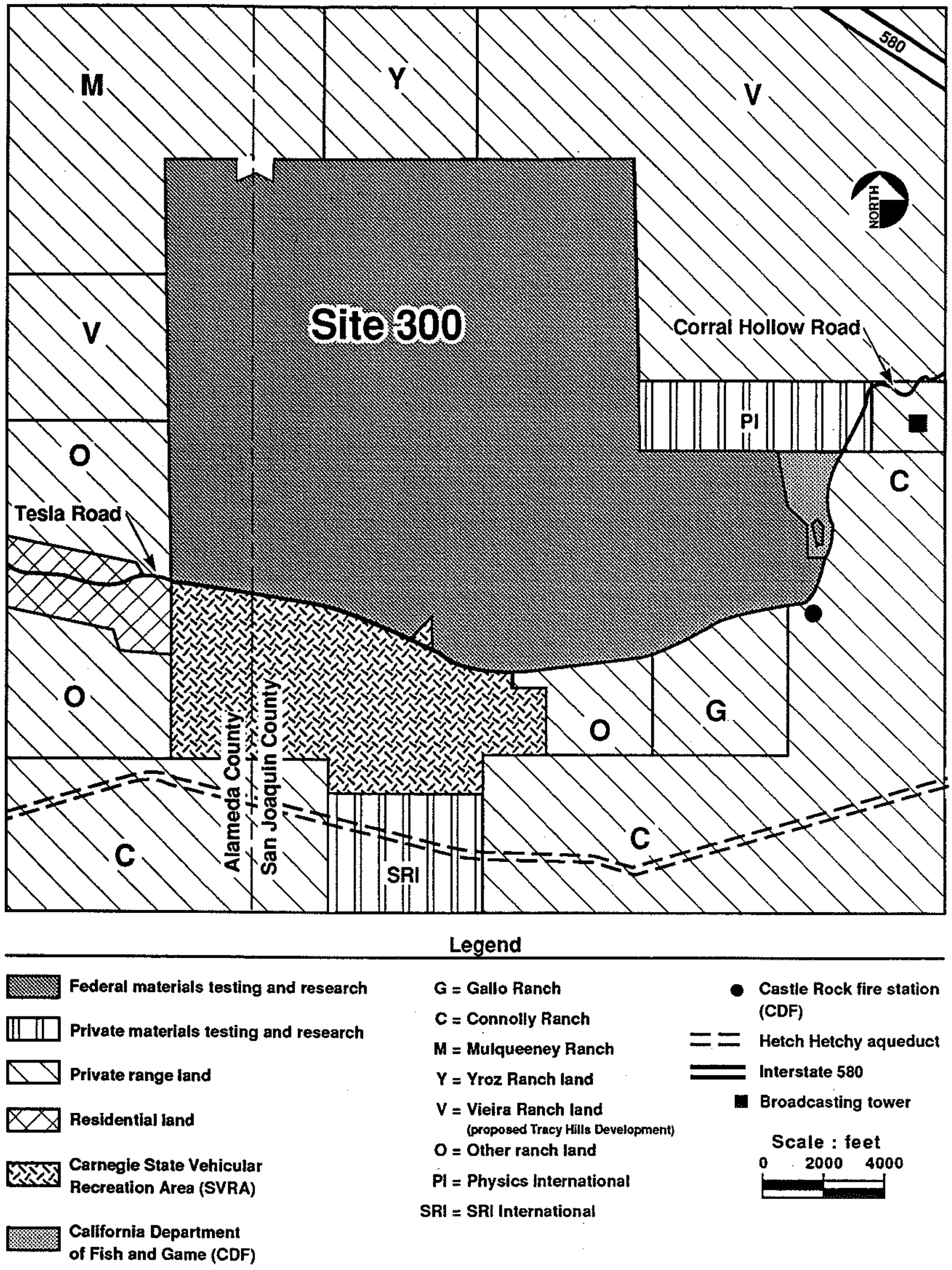
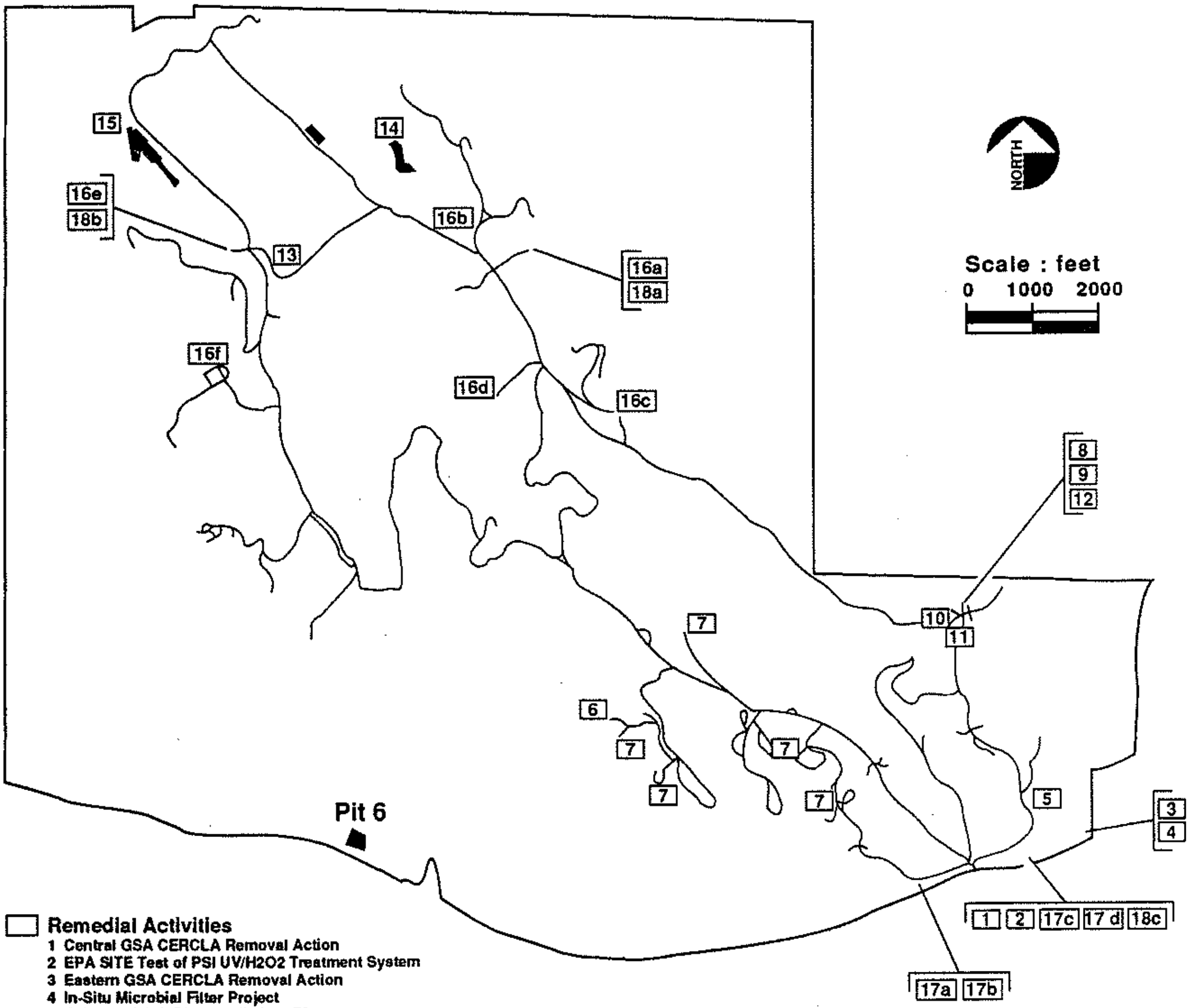


Figure 1-3. Monitor wells and exploratory boreholes in the Pit 6 operable unit.



ERD-FS-All-3032

Figure 1-4. Land use in the vicinity of Site 300.

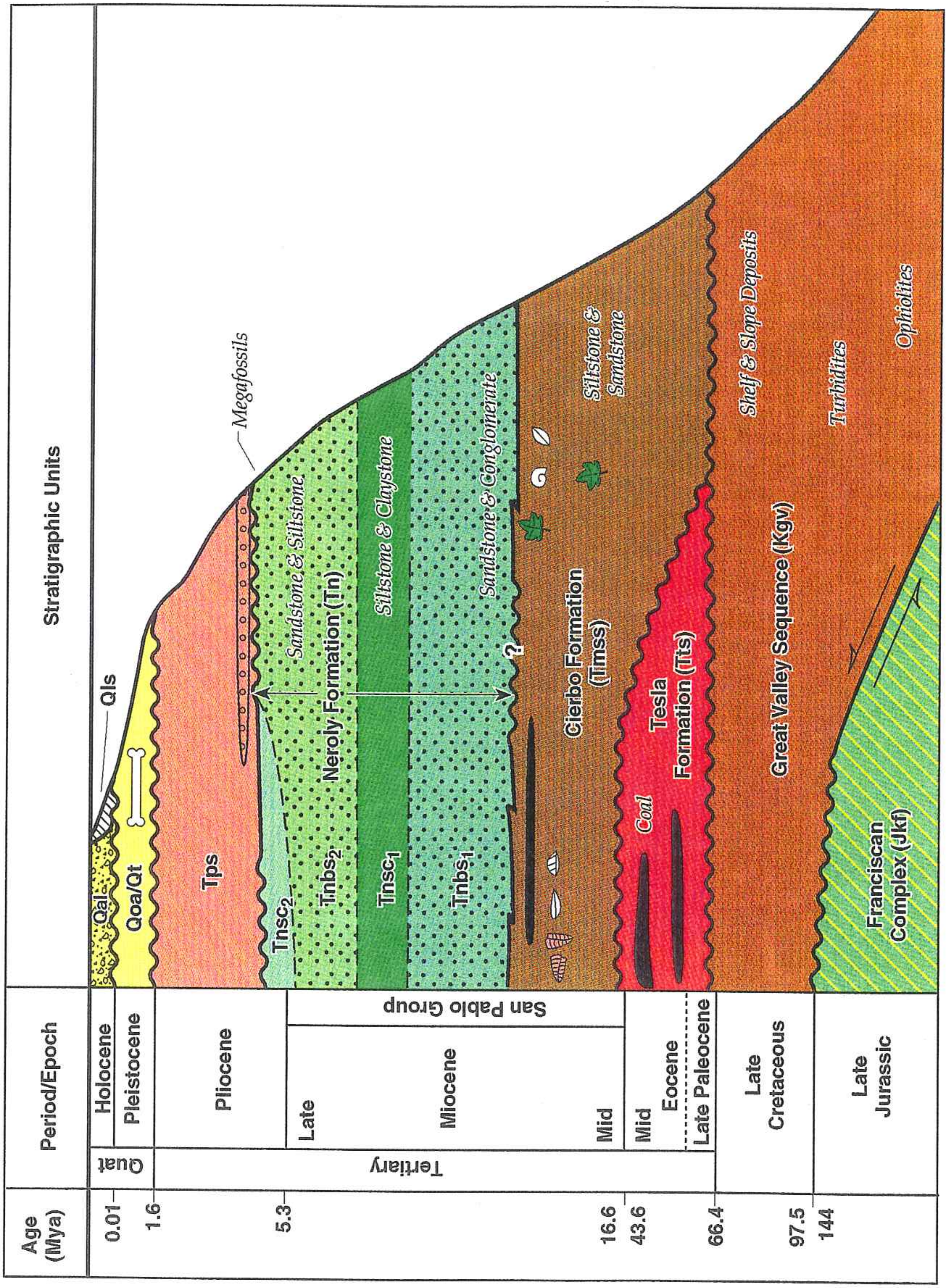


☐ **Remedial Activities**

1 Central GSA CERCLA Removal Action
2 EPA SITE Test of PSI UV/H2O2 Treatment System
3 Eastern GSA CERCLA Removal Action
4 In-Situ Microbial Filter Project
5 Enhanced Soil Bioremediation (Diesel)
6 High Explosive Burn Pit Facility RCRA Closure
7 High Explosive Rinse-Water Lagoon Closures
8 Building 834 Complex CERCLA Removal Action
9 EPA SITE Test of PURUS Pulsed UV System
10 Electrical Soil Heating Project
11 Electron Accelerator Demonstration Project
12 Fiber Optic Monitoring of Remediation
13 Pilot Tritium Evaporator
14 RCRA Capping of Pit 1
15 RCRA Capping of Pit 7
16 Removal/Replacement of Firing Table Gravels
  16a - Building 801 (removed and replaced)
  16b - Building 802 (removed)
  16c - Building 812 (removed)
  16d - Building 845 (removed)
  16e - Building 850 (removed and replaced)
  16f - Building 851 (removed and replaced)
17 Sealing/Abandonment of Water-Supply Wells
  17a - Well 4
  17b - Well 6
  17c - Well 7
  17d - Well 18
18 Underground Fuel Storage Tank Removal/Remediation
  18a - Building 801
  18b - Building 850
  18c - Building 874

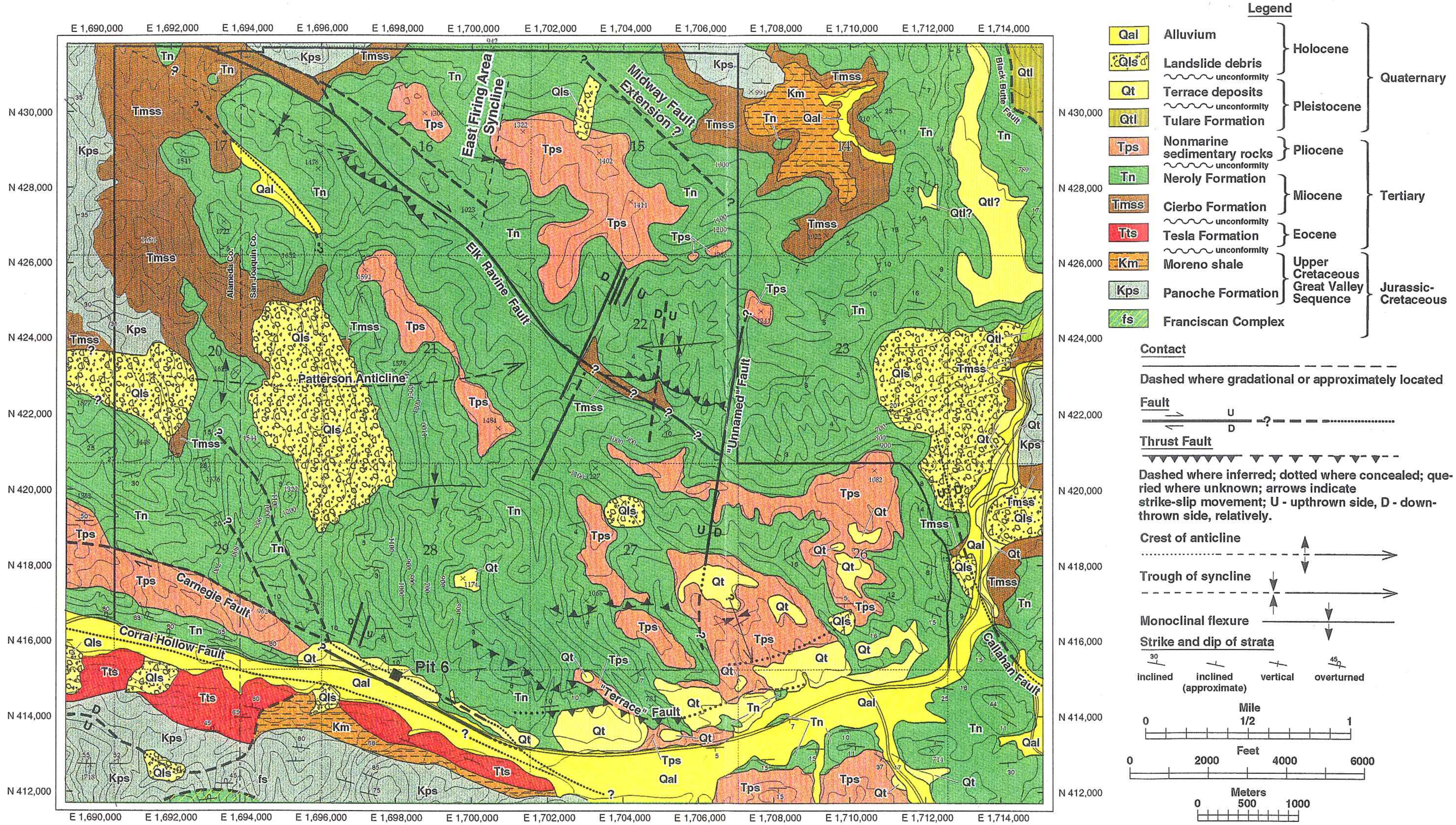
ERD-FS-PT6-3209

Figure 1-5. Corrective actions and facility upgrades at LLNL Site 300.



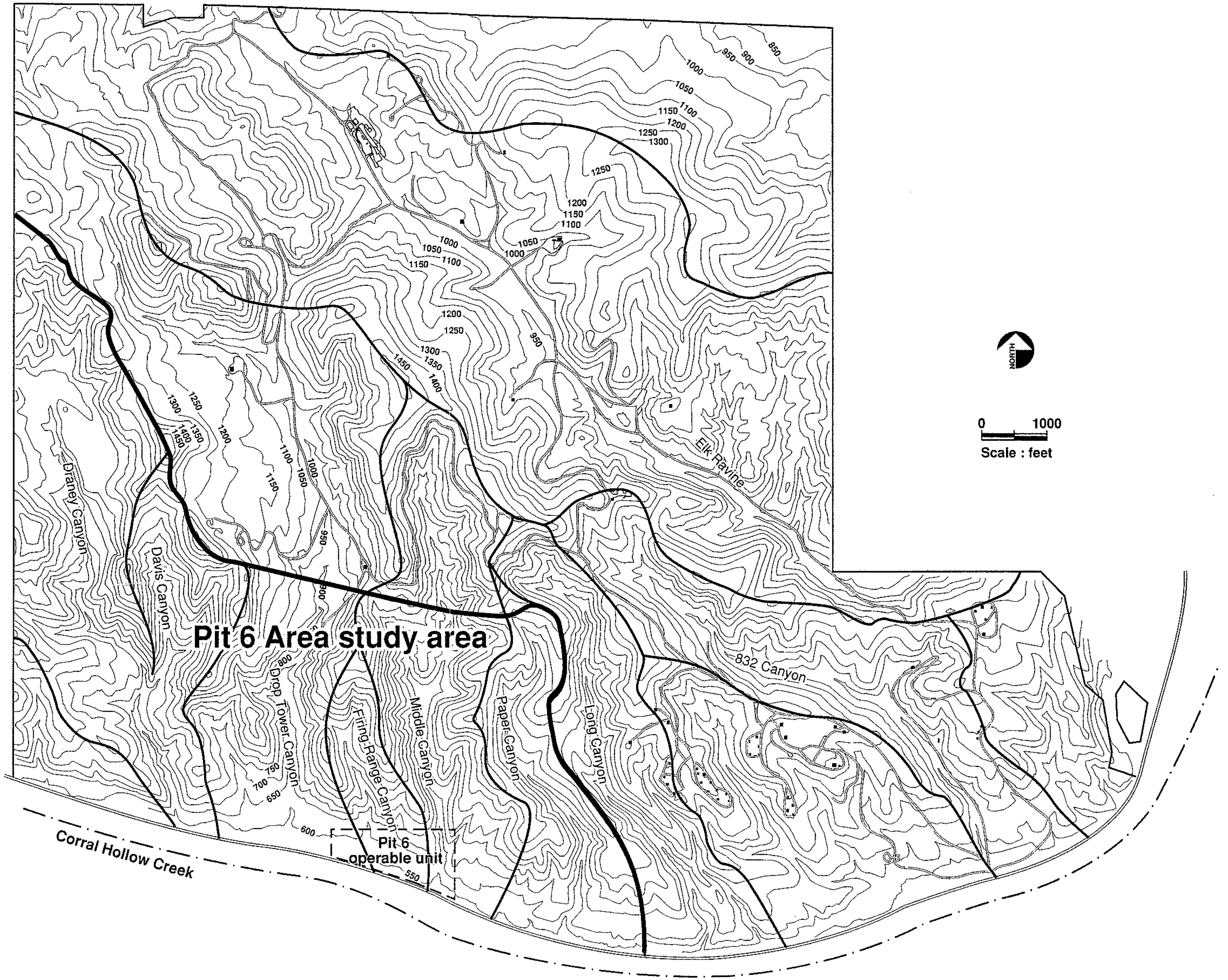
ERD-FS-All-3002

Figure 1-6. Schematic stratigraphy of Site 300.



ERD-FS-ALL-3001

Figure 1-7. Geologic map of Site 300 area.



ERD-FS-PT6-3160

Figure 1-8. Surface water drainage basins at Site 300.

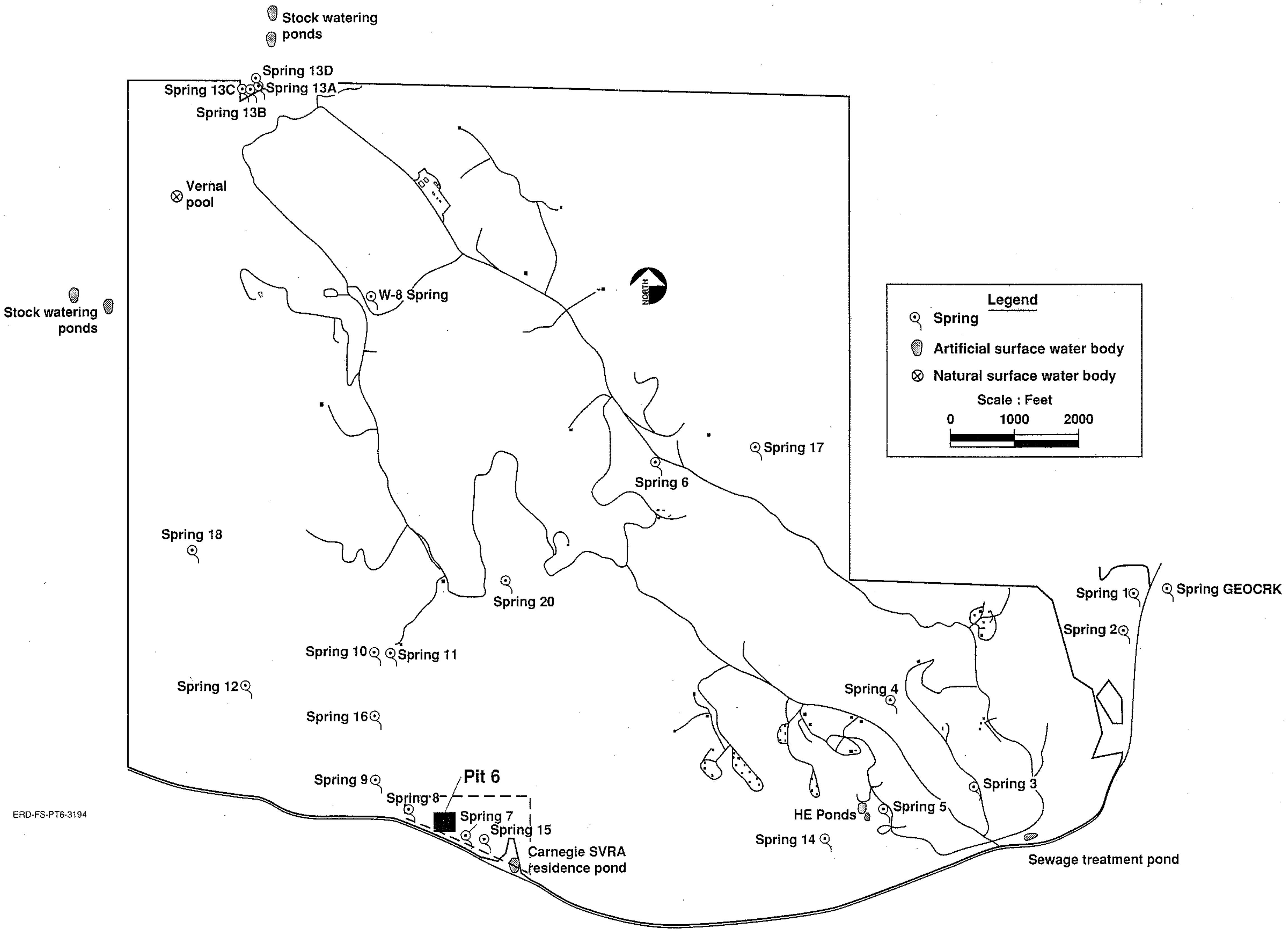
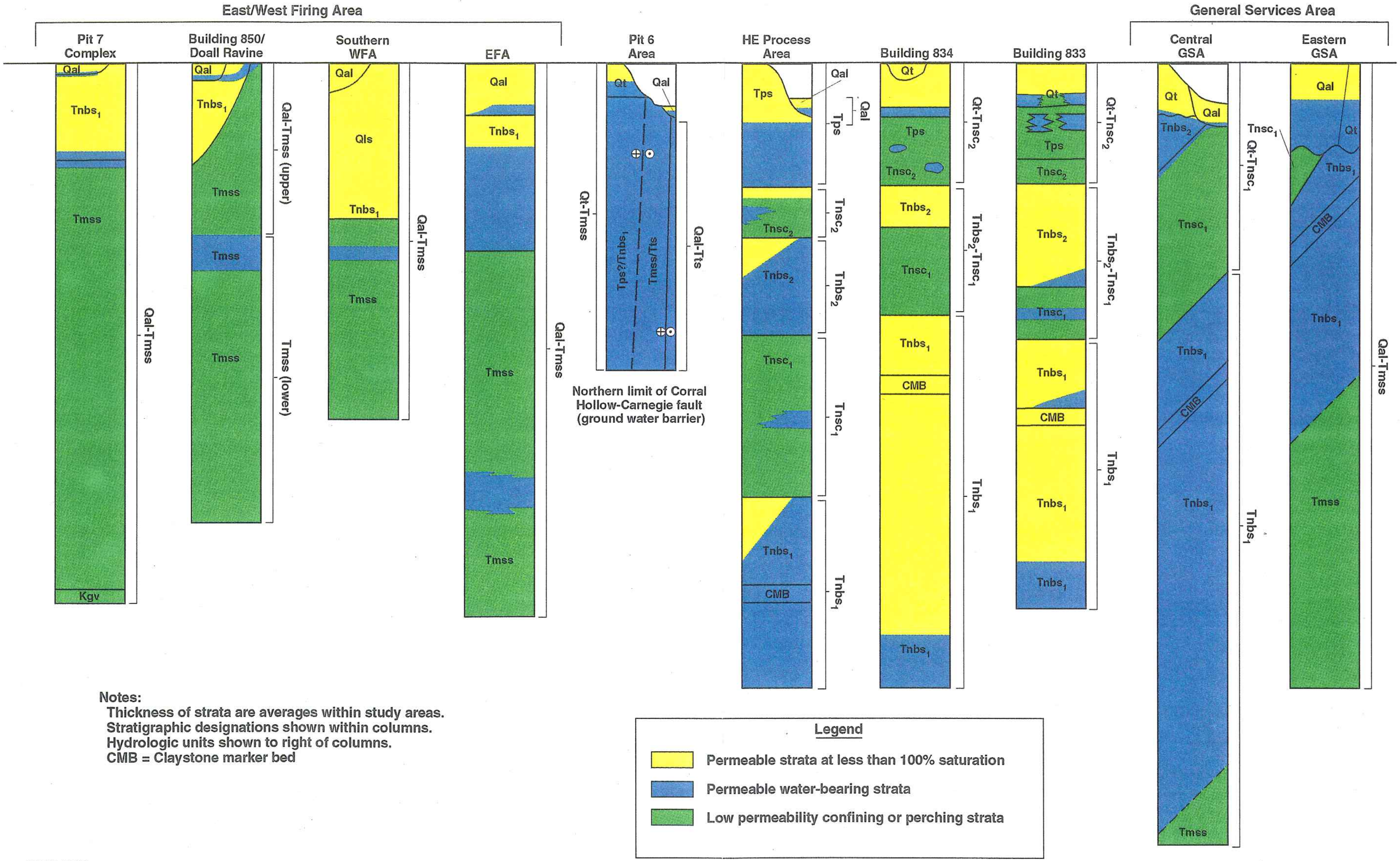


Figure 1-9. Surface water at Site 300.



Notes:
Thickness of strata are averages within study areas.
Stratigraphic designations shown within columns.
Hydrologic units shown to right of columns.
CMB = Claystone marker bed

Legend

🟨 Permeable strata at less than 100% saturation
🟦 Permeable water-bearing strata
🟩 Low permeability confining or perching strata

ERD-FS-AII-3004

Figure 1-10. Stratigraphic and hydrologic units within the study areas at Site 300.

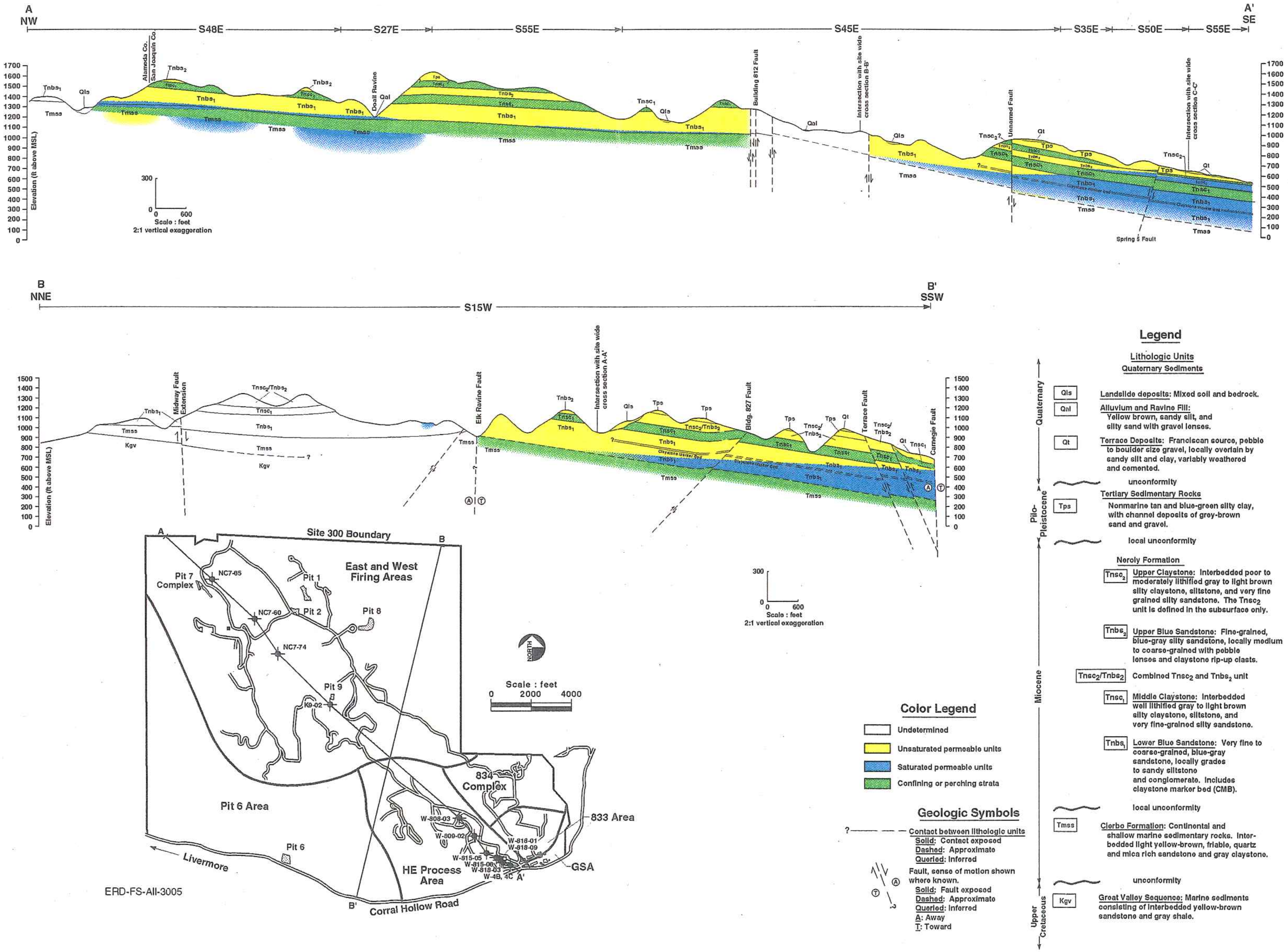
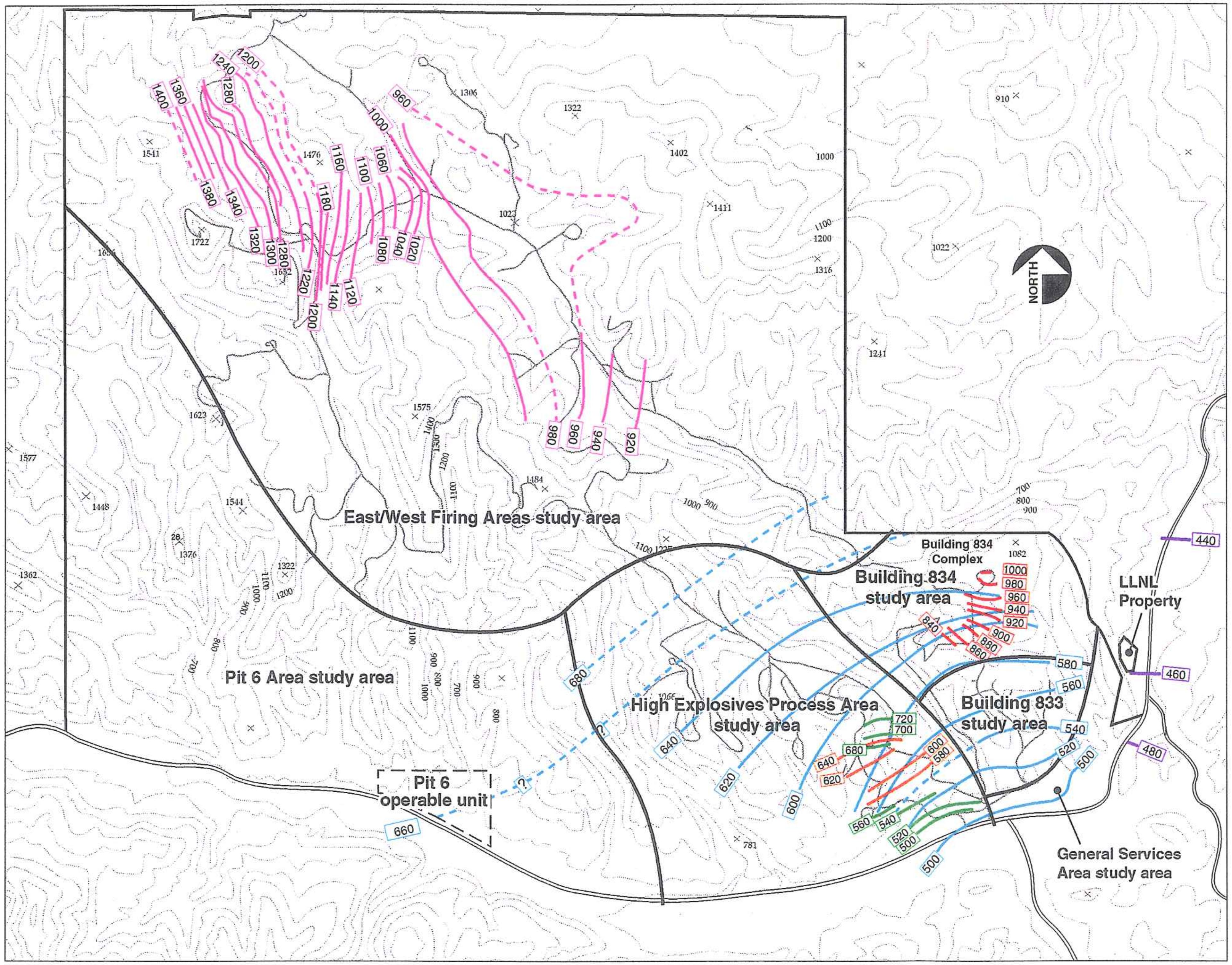


Figure 1-11. Site-wide hydrogeologic cross-sections A-A' and B-B'.

Figure 1-11

This page intentionally left blank.



ERD-FS-PT6-3161

Legend

— **Qt-Tnsc$_1$ (Central GSA) and Qal-Tmss Unit (Eastern GSA)**
Contours are shown for the first water-bearing zone within the Corral Hollow Creek alluvium and terrace deposits, and include some shallow bedrock wells. Ground water in this aquifer is semi confined to unconfined. Ground water in the Qt-Tnsc$_1$ unit in the central GSA is partially derived from outflow from the bedrock aquifer north of the GSA. All bedrock strata that subcrop beneath the Quaternary alluvium (Qal) in the Corral Hollow Creek stream channel are in hydraulic communication via the alluvium.

— **Qal-Tmss Unit (Northwest Site 300)**
Contours include data from wells completed in the Doall Ravine alluvium, and from some wells completed in bedrock, primarily the Neroly Formation lower blue sandstone (Tnbs$_1$) and the Cierbo Formation (Tmss), which is in direct contact with the alluvium. Hydraulic continuity of the Tnbs$_1$ regional aquifer with the southern portion of Site 300 is not established. Hydraulic continuity may be intermittent and dependent on temporal variations in recharge.

— **Tps Unit (Building 834)**
Contours are based on data from shallow wells completed in the perched water-bearing zone within the Pliocene nonmarine unit (Tps). The perched zone outcrops and discharges on the hillslopes.

— **Tps Unit (HE Process Area)**
Potentiometric surface contours are based on water levels measured in ground water monitor wells completed in the Pliocene nonmarine unit (Tps). Ground water in the Tps unit is perched in the northern part of the HE Process Area. Saturation in the Tps strata increases southward, and ground water is under artesian conditions near the southern boundary of Site 300.

— **Tnbs$_2$ Unit (HE Process Area)**
Data contours are from wells completed in the Neroly Formation upper blue sandstone (Tnbs$_2$) unit. The Tnbs$_2$ aquifer is saturated only in the HE Process Area in southeastern Site 300. Hydraulic conditions range from unconfined in the northern HE Process Area to flowing artesian to the south near Corral Hollow Road. This unit serves as a local off-site water-supply aquifer.

— **Tnbs$_1$ Unit (Southern Site 300)**
Contours based on data from wells completed in the Neroly Formation lower blue sandstone (Tnbs$_1$) unit. The Tnbs$_1$ unit is unsaturated in the central portion of the site. Ground water in the Tnbs$_1$ is under flowing artesian conditions near Corral Hollow Road. The Tnbs$_1$ unit is in hydraulic communication with the Qt-Tnsc$_1$ and other water-bearing units in the southeastern portion of the site, either through direct contact or through mutual communication with the Corral Hollow Creek alluvium (Qal). This unit serves as a water-supply aquifer both on and off site.

- - - Ground water potentiometric surface elevation contours in feet above mean sea level, dashed where approximately located and queried where uncertain

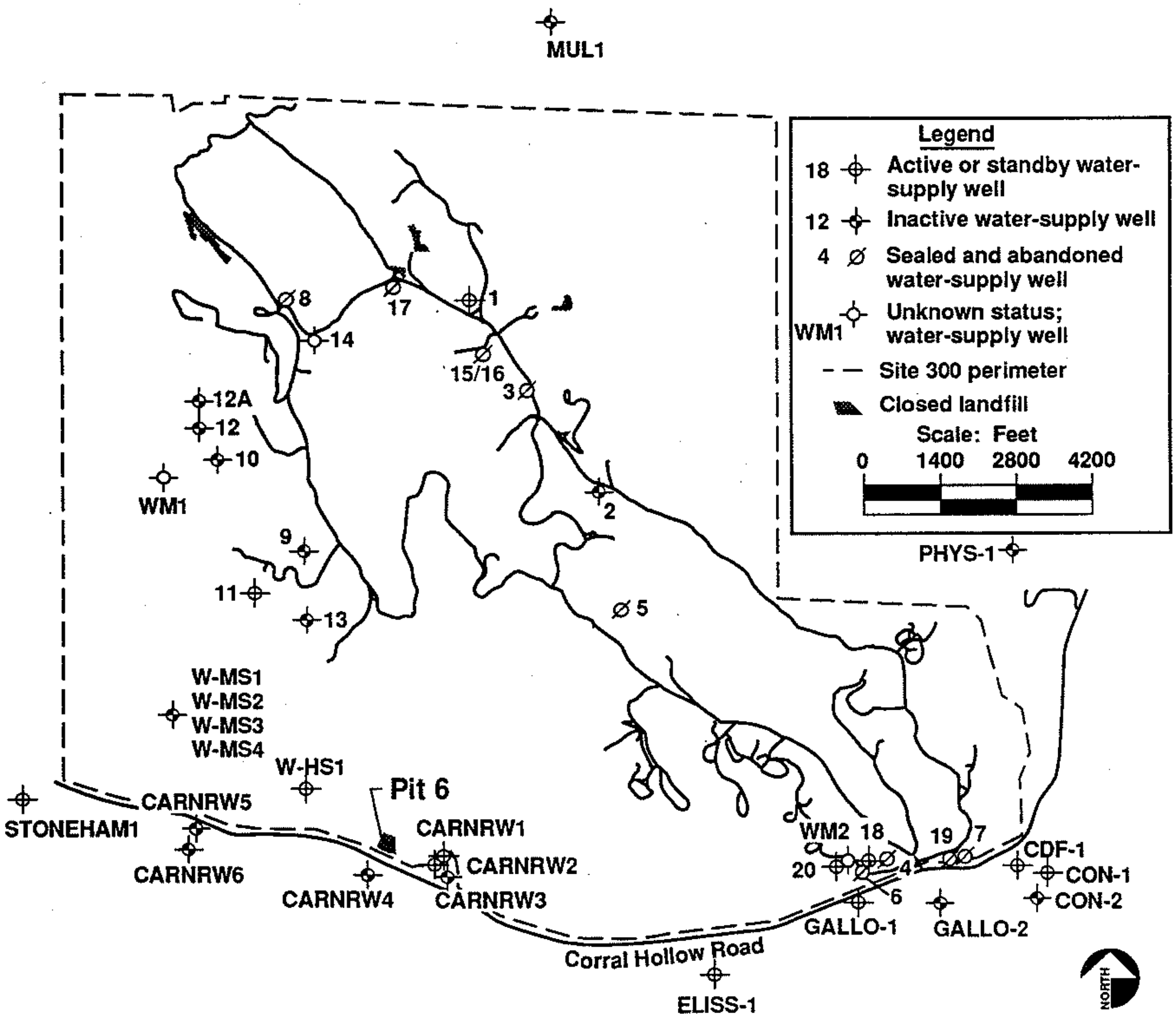
Notes:
1) Ground water elevation data from December 1991.
2) Potentiometric contours shown on this plate are taken from figures presented in the hydrogeology sections of Chapters 9-14 in the SWRI report (Webster-Scholten, 1994). Wells and water level data used to generate potentiometric contours are included in those sections.

Feet
0 2000 4000 6000

Meters
0 500 1000

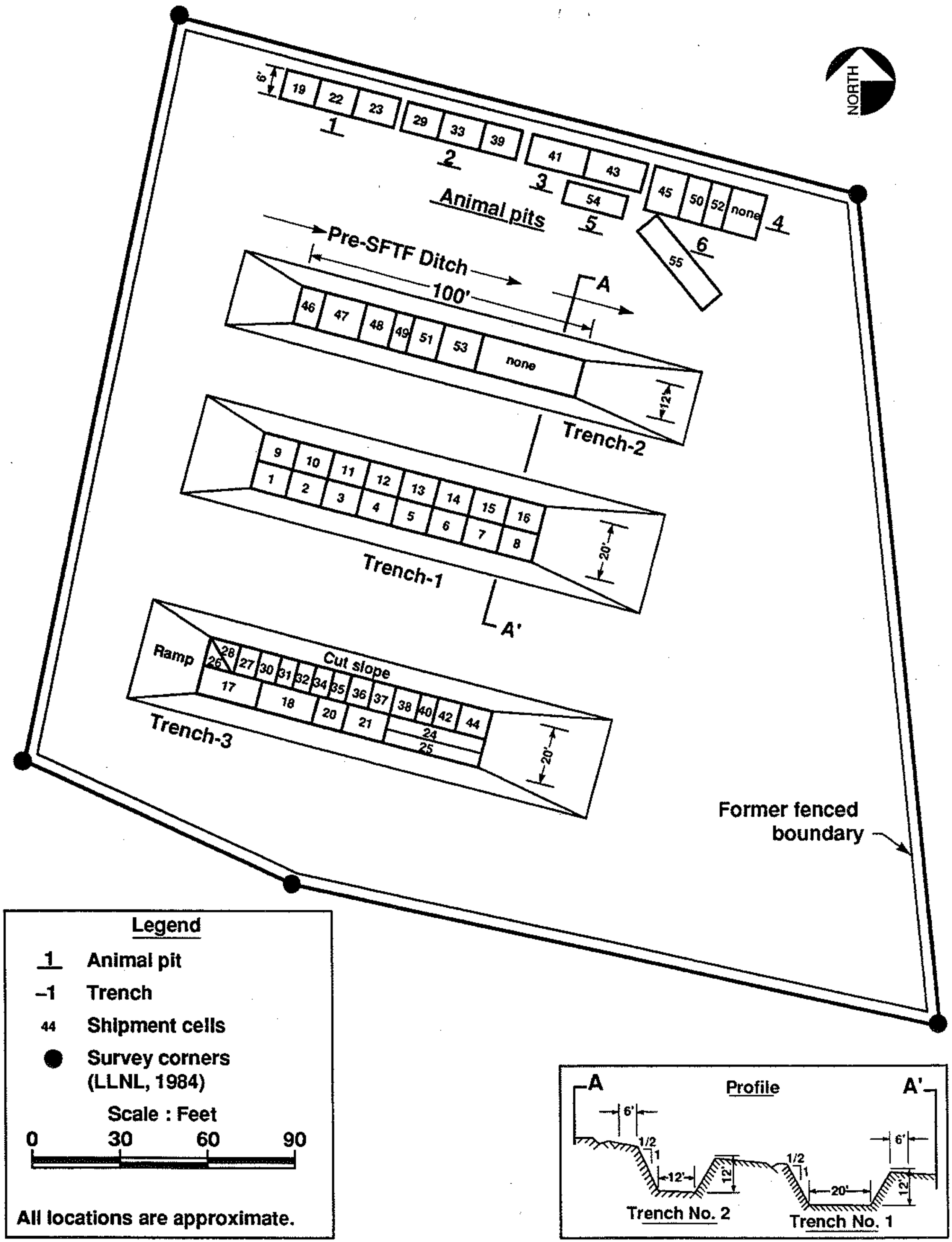
Figure 1-12. Potentiometric surface elevation map of major water-bearing units at Site 300.

This page intentionally left blank.



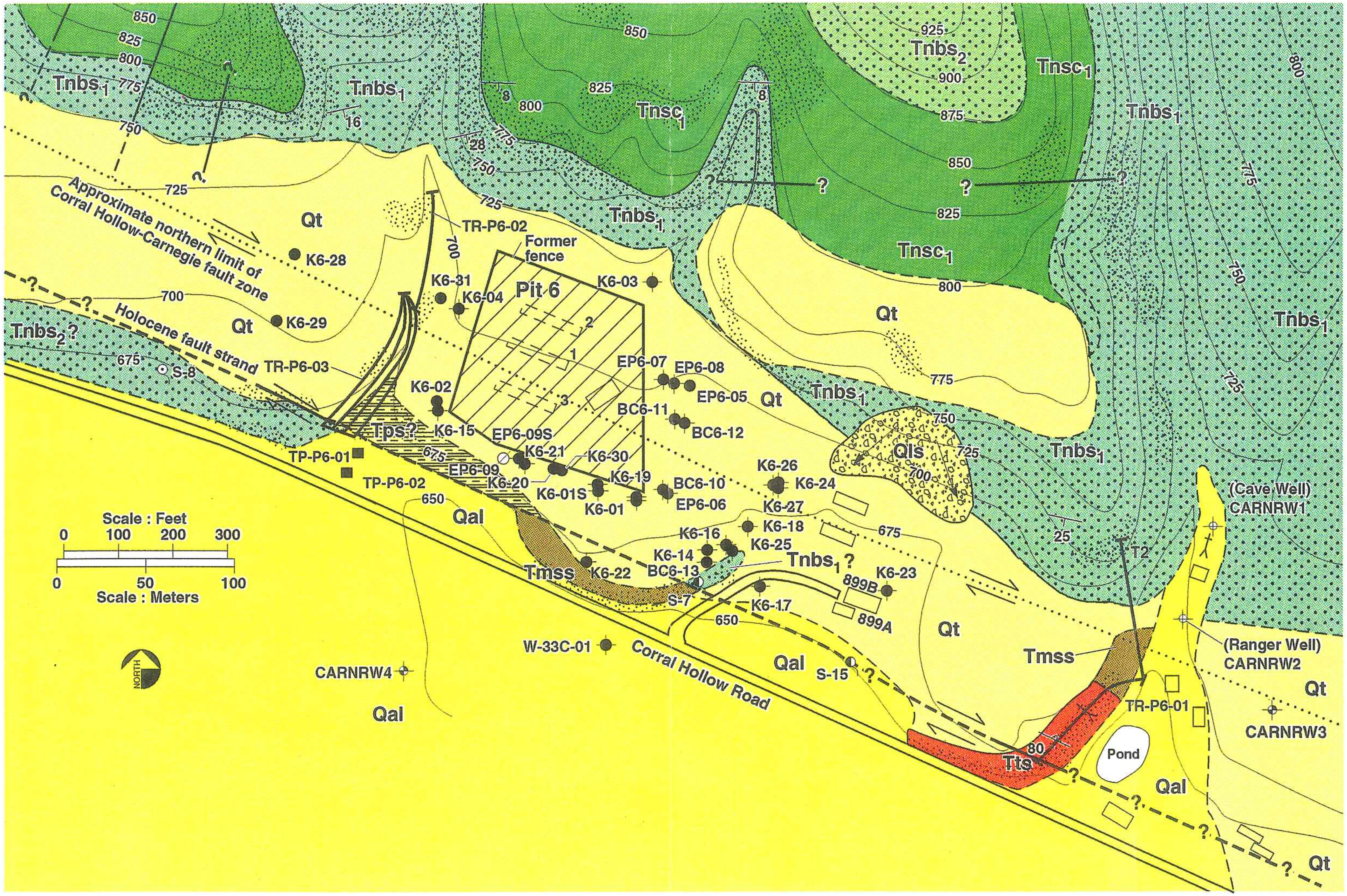
ERD-FS-PT6-3162

Figure 1-13. Water-supply wells at and within 0.5 mi of Site 300.



ERD-FS-PT6-3152

Figure 1-14. Pit 6 trench and animal pit locations showing shipment cells and profile A-A' across trenches 1 and 2.



ERD-FS-PT6-3138

Figure 1-15a. Geologic map of the Pit 6 operable unit and vicinity.

This page intentionally left blank.

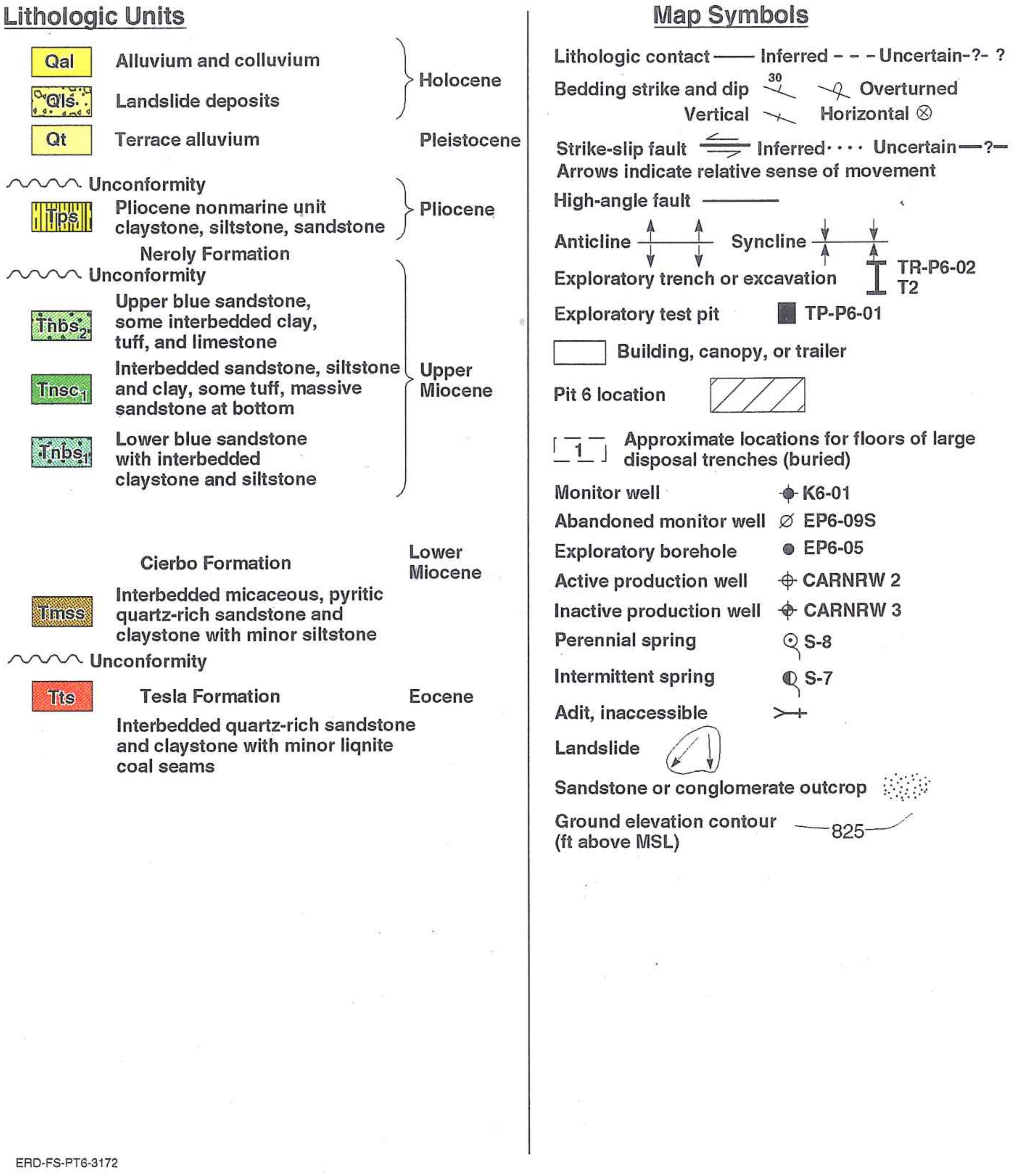
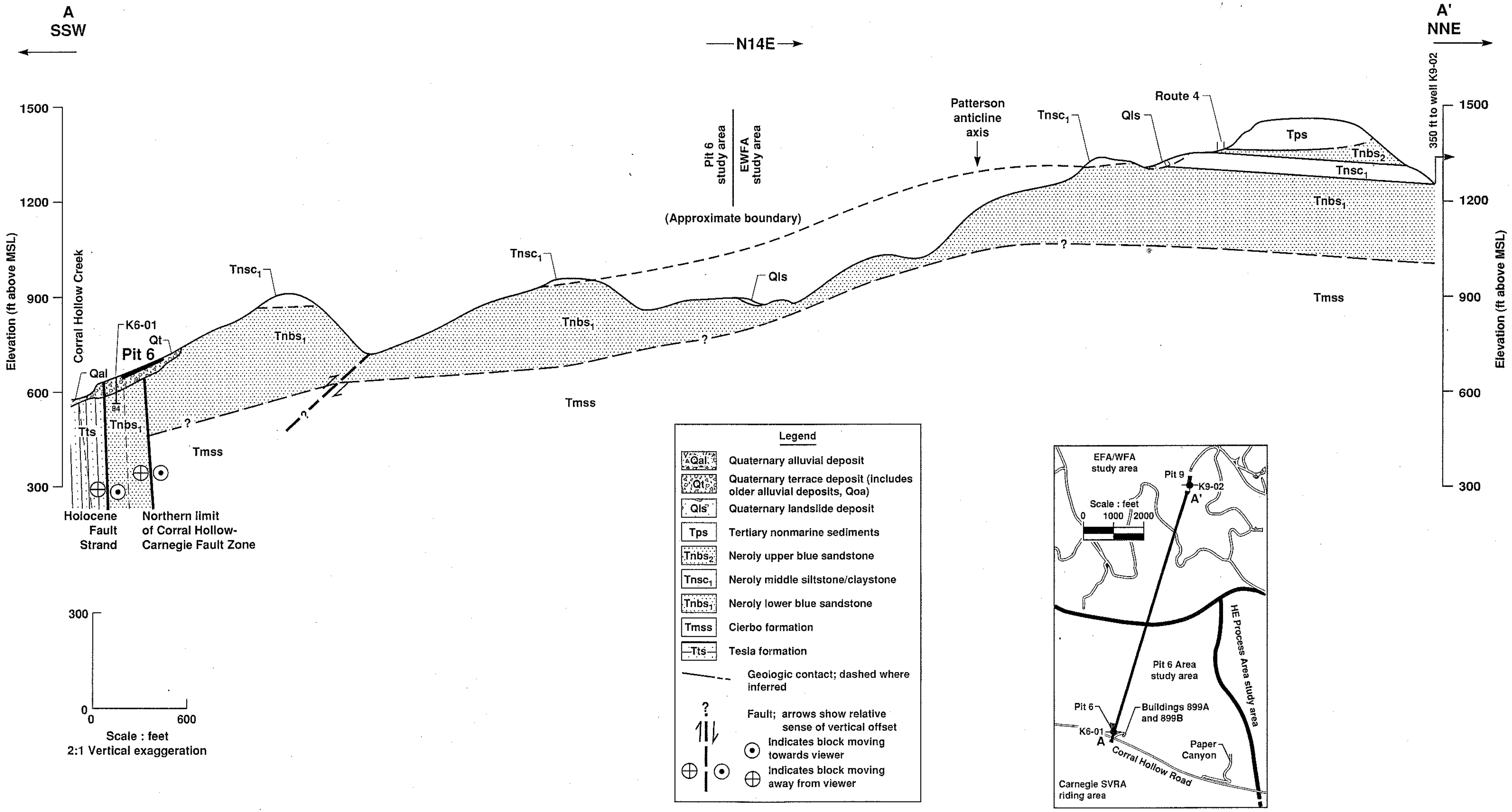


Figure 1-15b. Legend for Pit 6 operable unit geologic map, geologic cross sections, and hydrogeologic cross sections.



ERD-FS-PT6-3139

Figure 1-16. Geologic cross-section A-A' from Pit 6 Area study area to EFA/WFA study area.

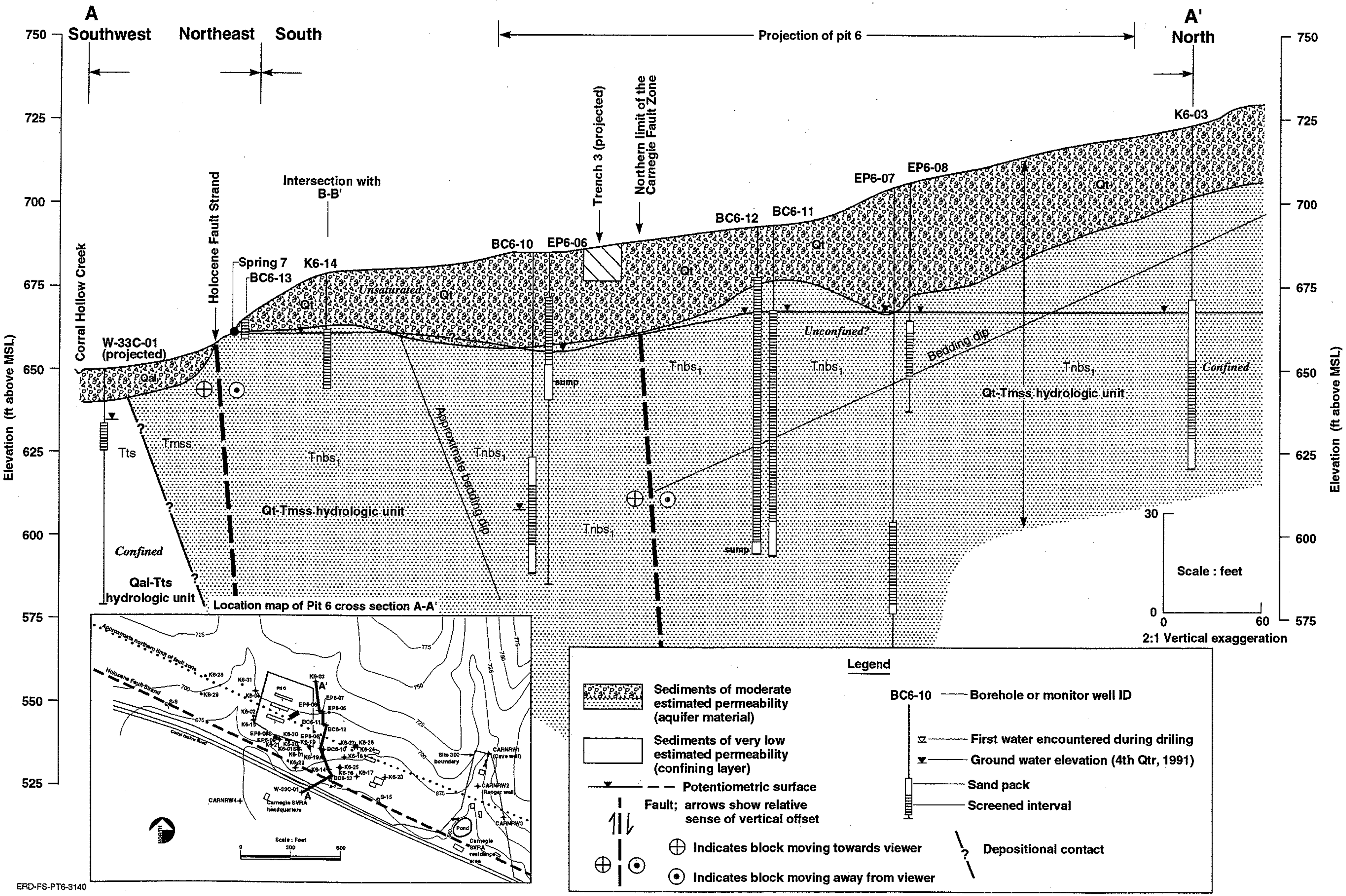
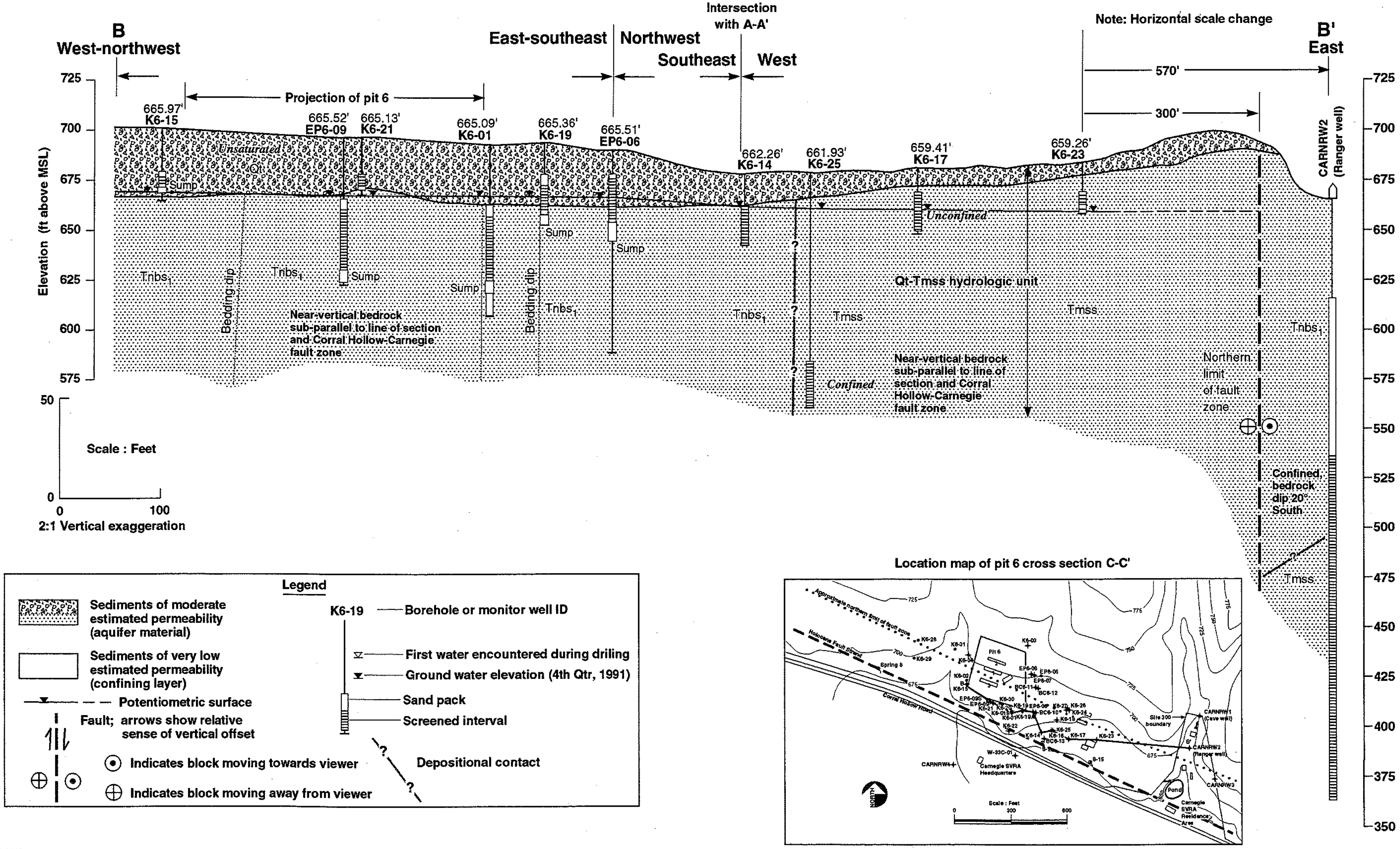


Figure 1-17. Hydrogeologic cross-section A-A', Pit 6 operable unit.



ERD-FS-PT6-3142

Figure 1-18. Hydrogeologic cross-section B-B', Pit 6 operable unit.

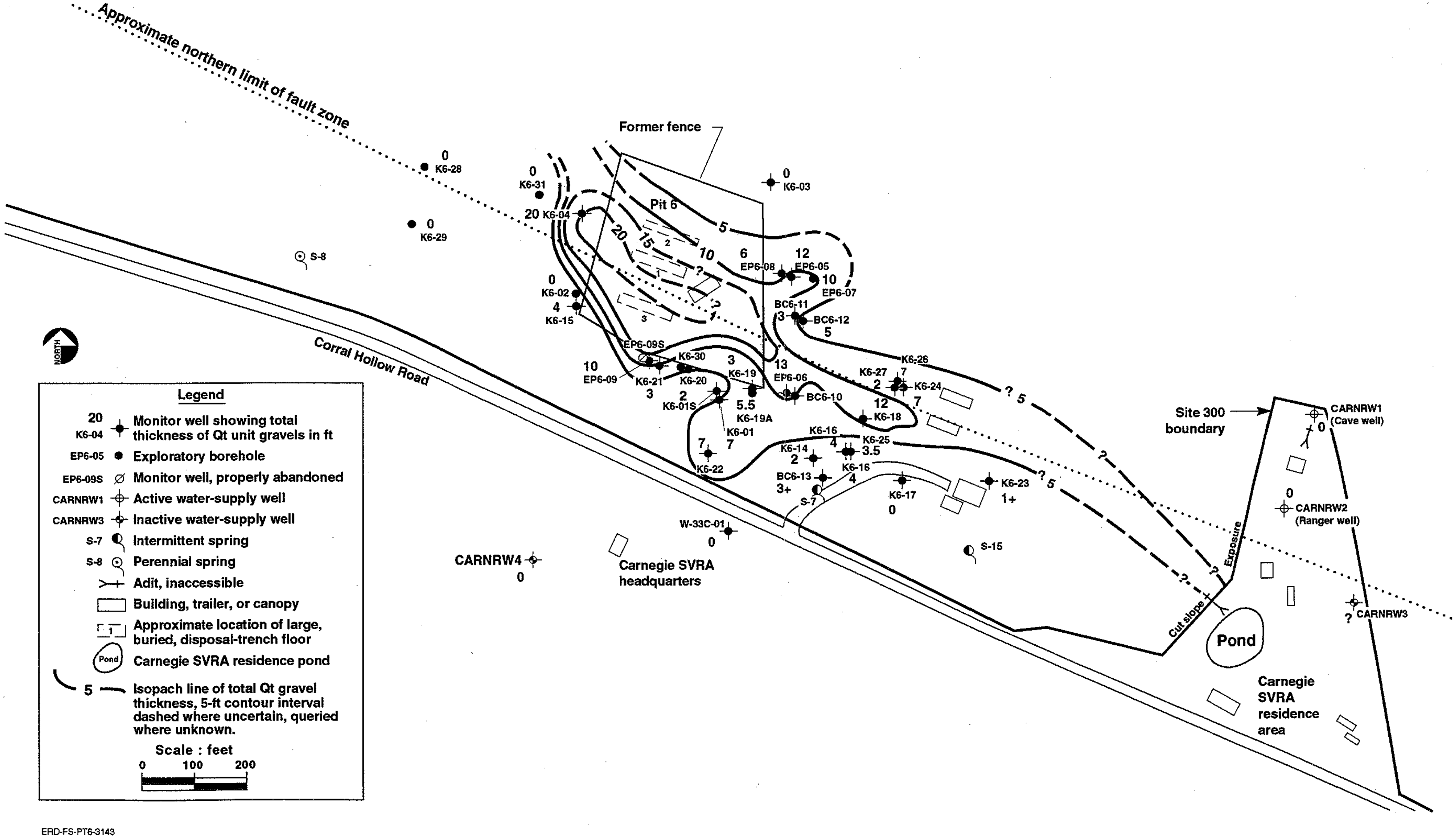
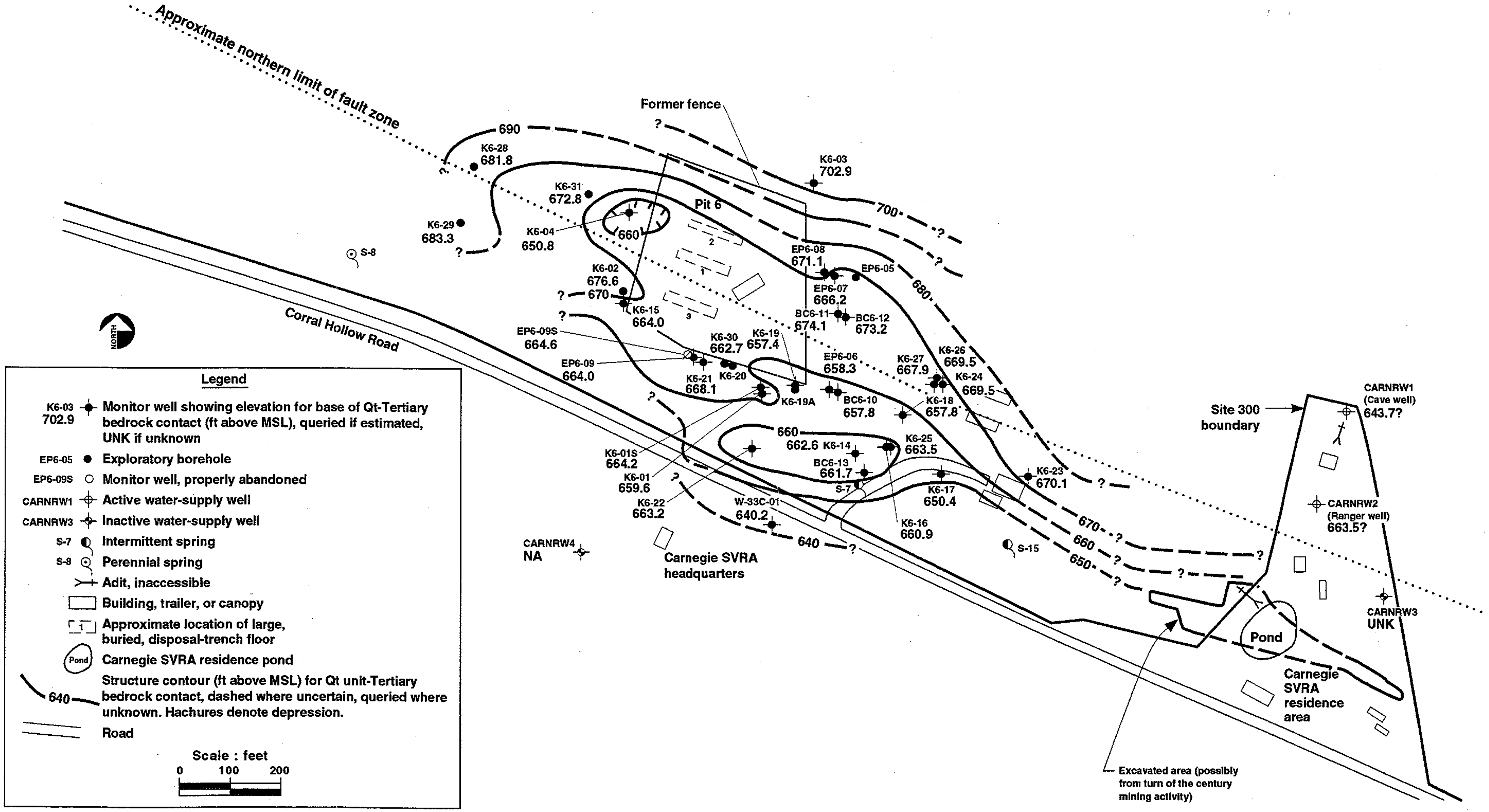


Figure 1-19. Isopach map of Quaternary terrace gravel (Qt) in the Pit 6 operable unit.



ERD-FS-PT6-3144

Figure 1-20. Elevation contour map for Qt unit-Tertiary bedrock contact in the Pit 6 operable unit.

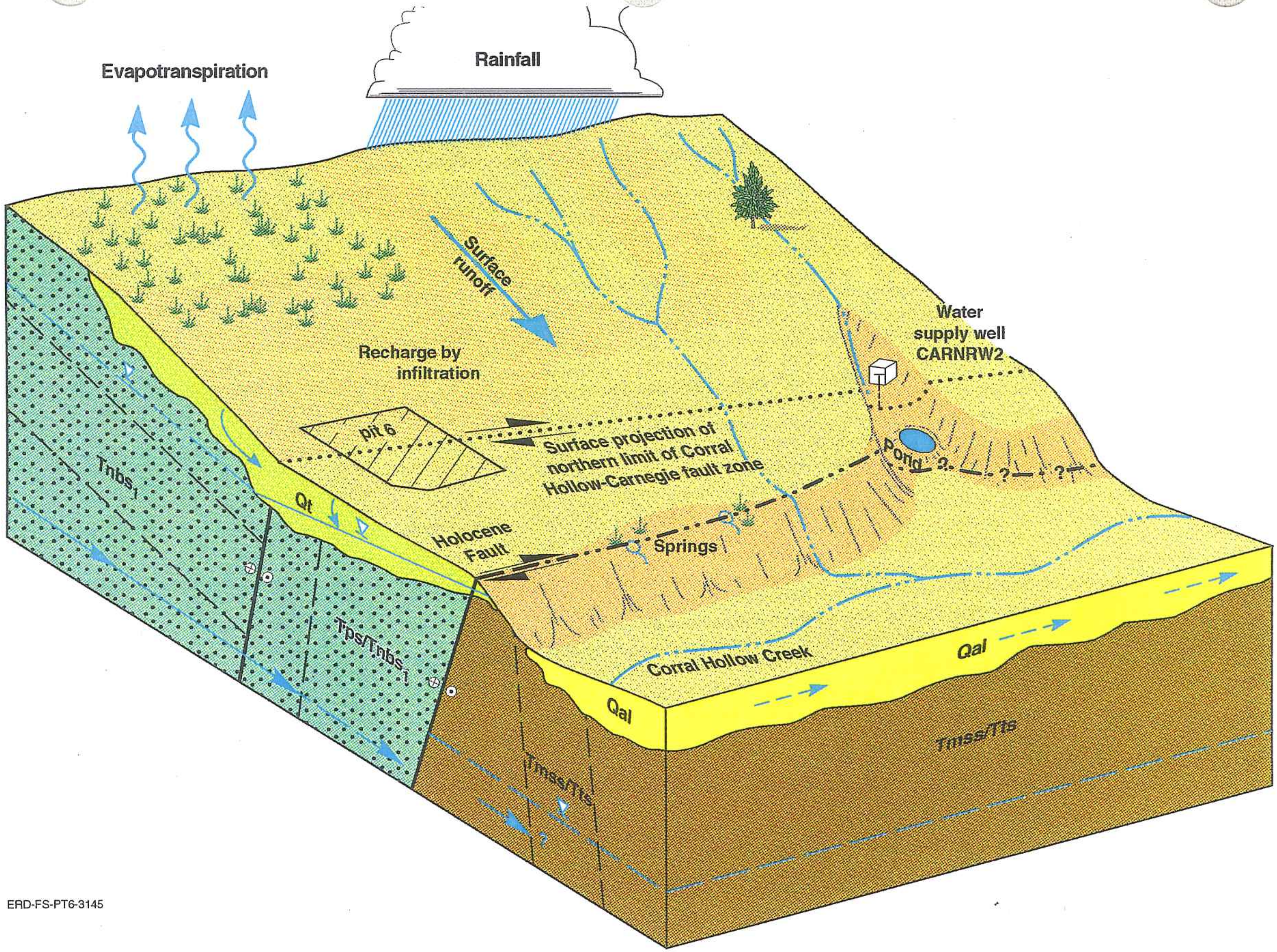
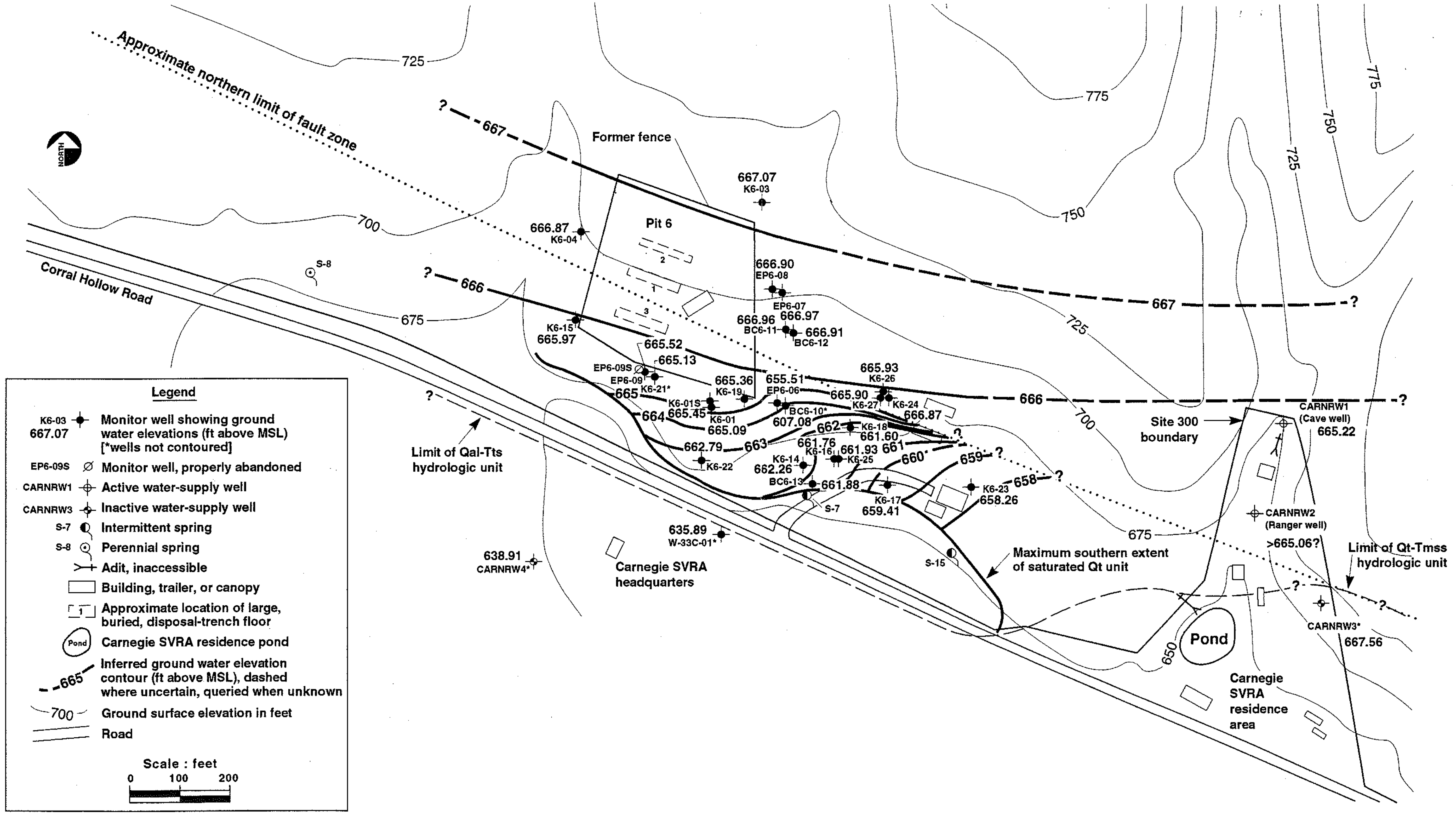
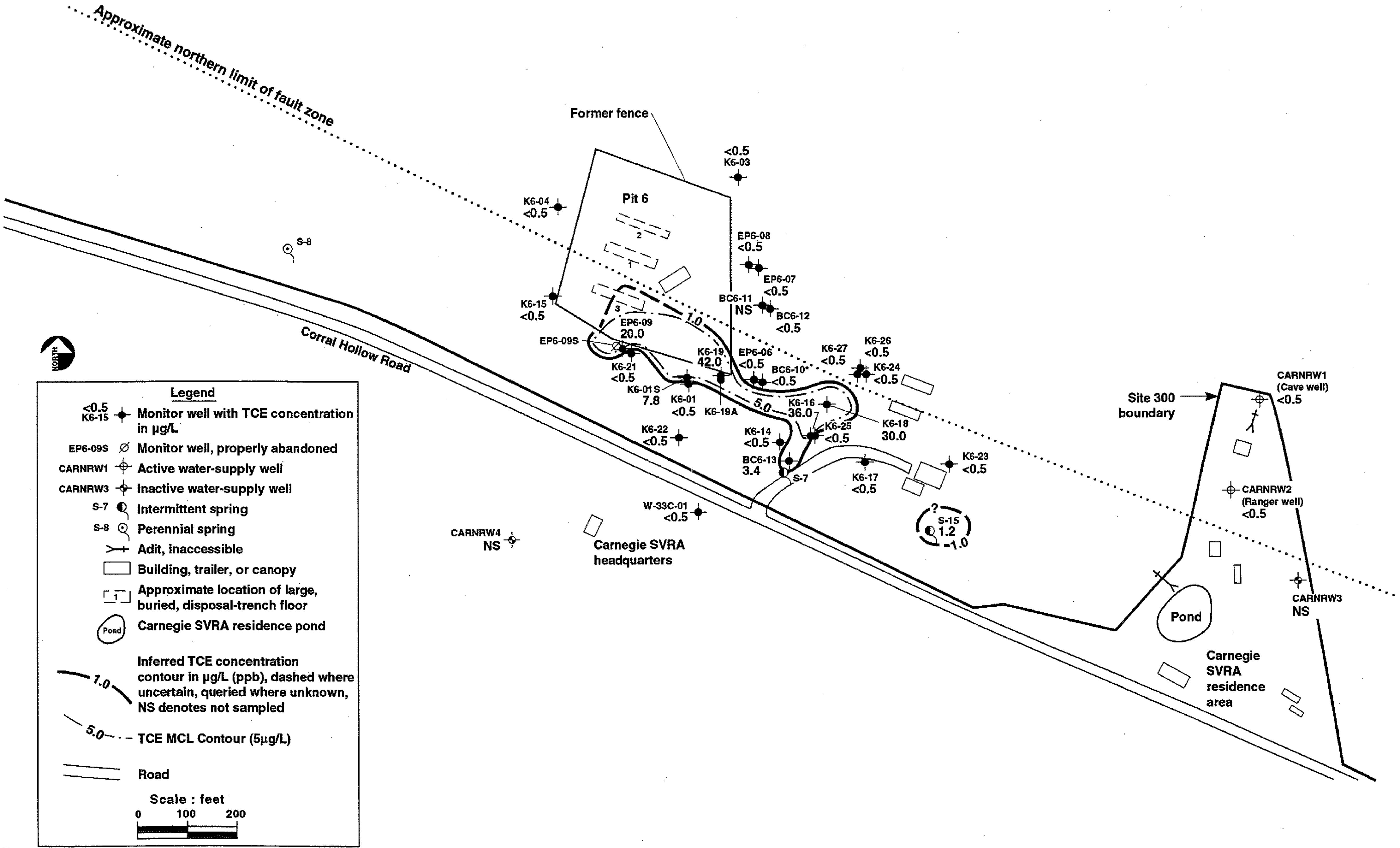


Figure 1-21. Conceptual hydrogeologic model for the Pit 6 operable unit.



ERD-FS-PT6-3146

Figure 1-22. Potentiometric surface map of the Qt-Tmss hydrologic unit in the Pit 6 operable unit, December 1991.



ERD-FS-PT6-3156

Figure 1-23. Distribution of TCE in ground water of the Qt-Tmss hydrologic unit for the Pit 6 operable unit, December 1991.

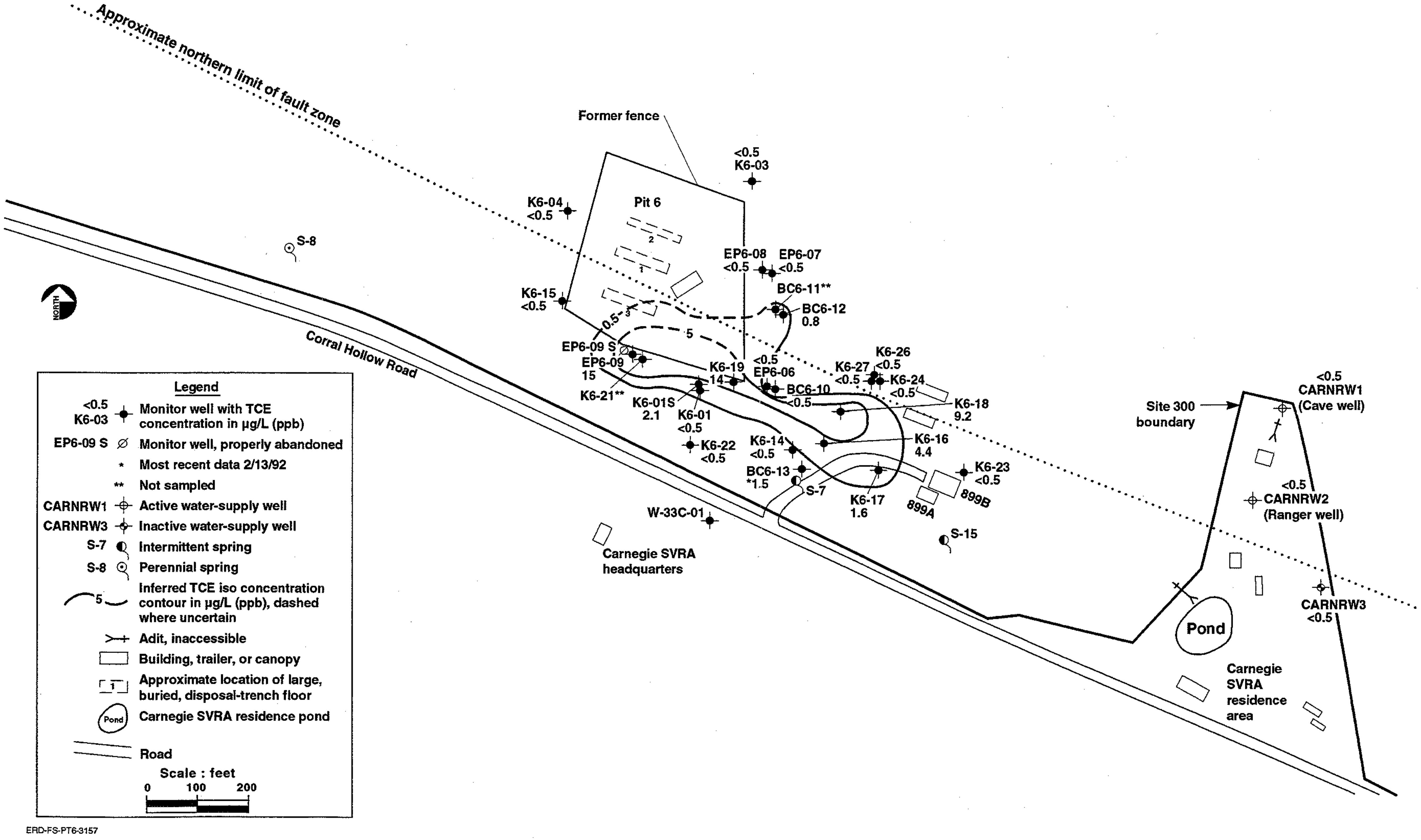
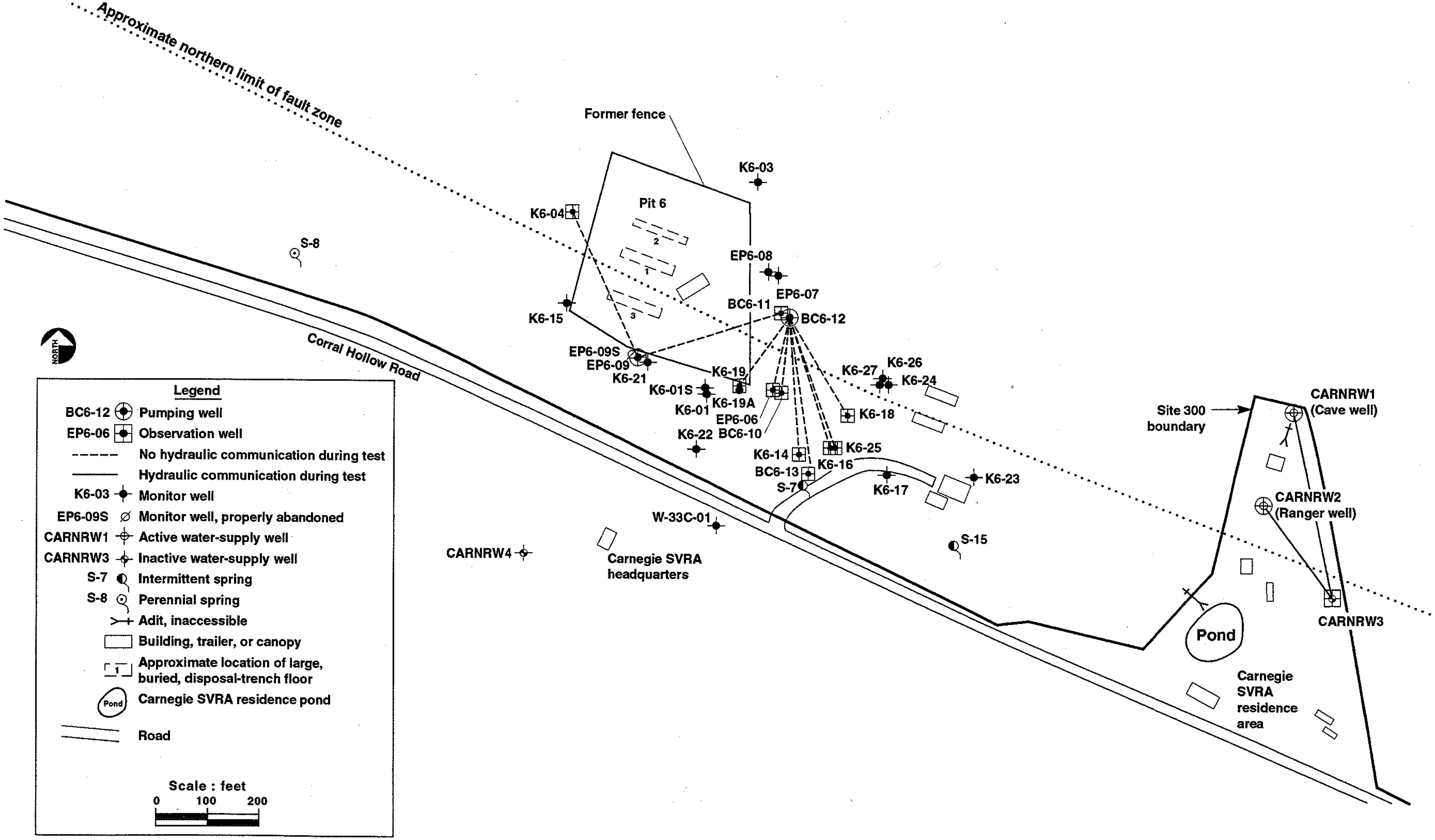


Figure 1-24. Distribution of TCE in ground water of the Qt-Tmss hydrologic unit, Pit 6 operable unit, May–July 1993.



ERD-FS-PT6-3148

Figure 1-25. Cross-fault hydraulic tests in the Pit 6 operable unit.

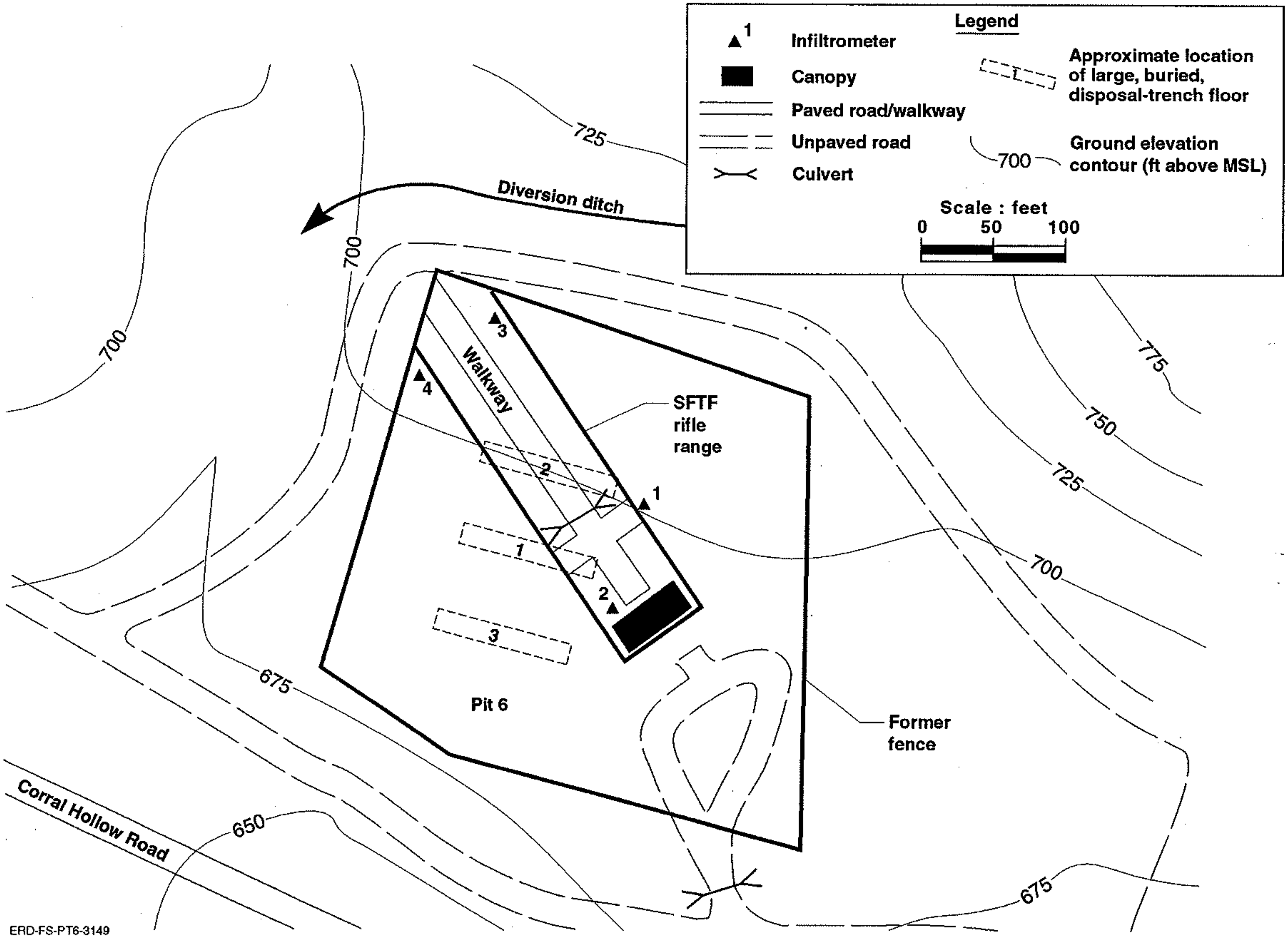
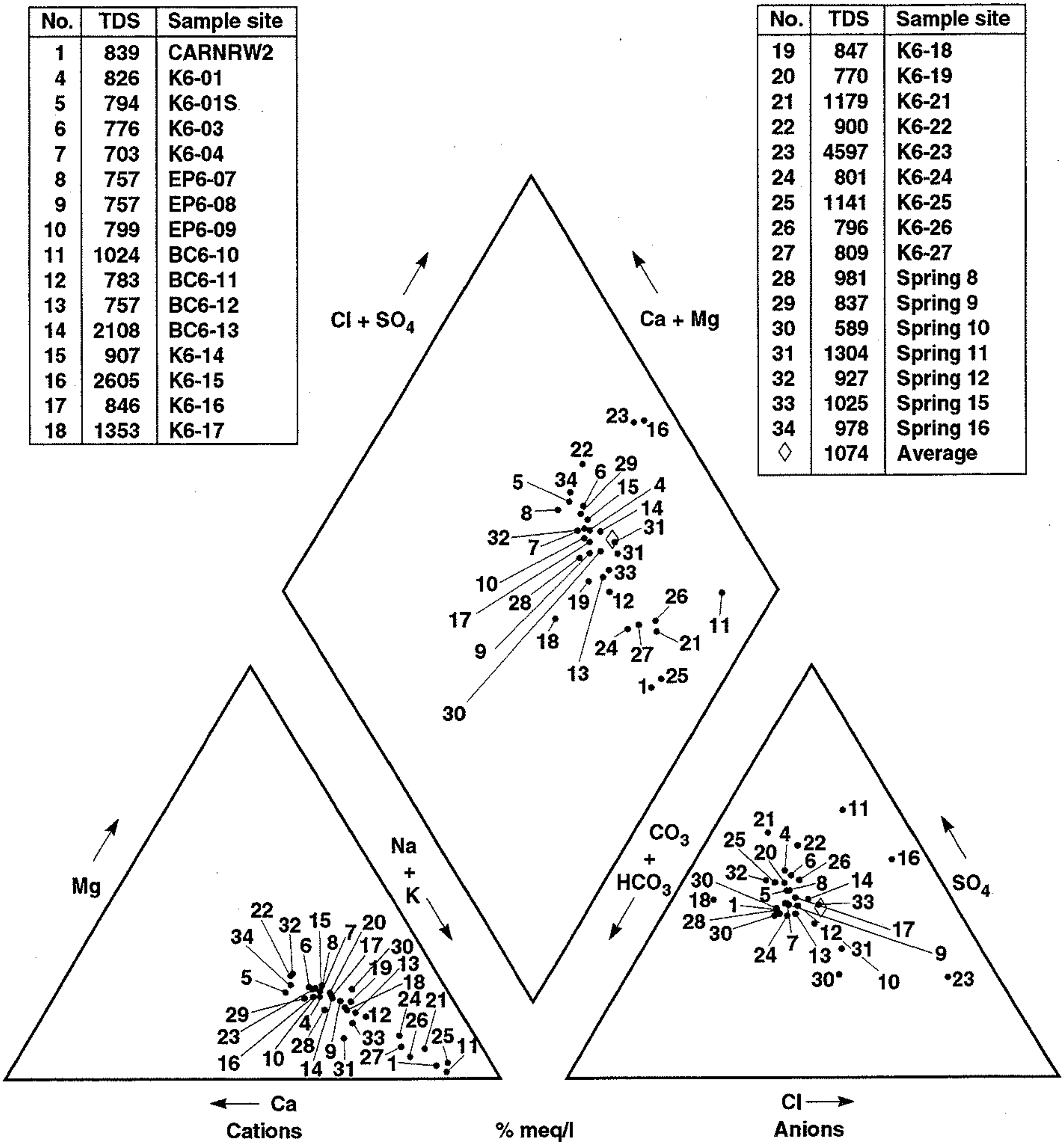


Figure 1-26. Infiltrometer test locations in the pit 6 soil cover.



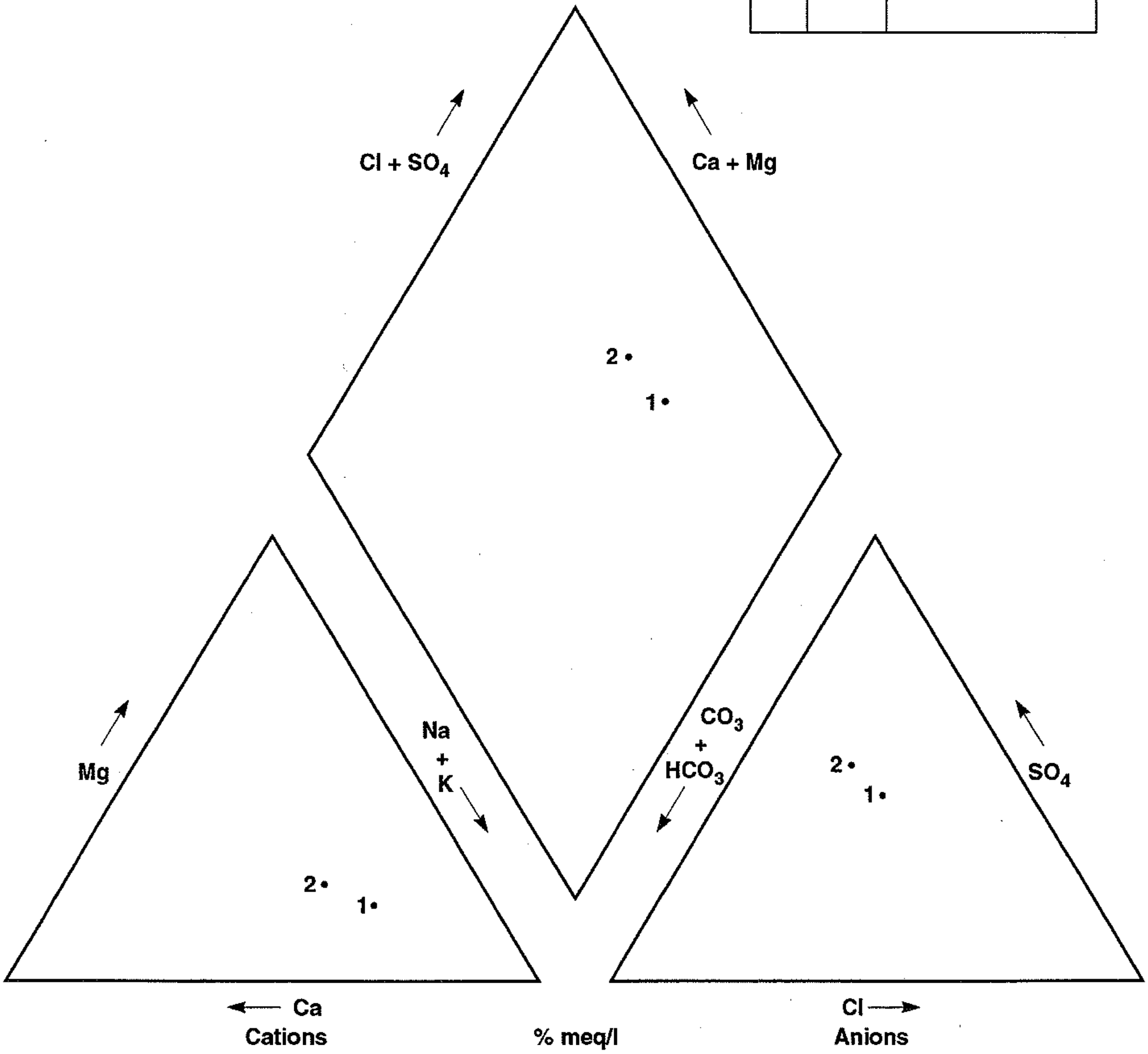
No.	TDS	Sample site
1	839	CARNRW2
4	826	K6-01
5	794	K6-01S
6	776	K6-03
7	703	K6-04
8	757	EP6-07
9	757	EP6-08
10	799	EP6-09
11	1024	BC6-10
12	783	BC6-11
13	757	BC6-12
14	2108	BC6-13
15	907	K6-14
16	2605	K6-15
17	846	K6-16
18	1353	K6-17

No.	TDS	Sample site
19	847	K6-18
20	770	K6-19
21	1179	K6-21
22	900	K6-22
23	4597	K6-23
24	801	K6-24
25	1141	K6-25
26	796	K6-26
27	809	K6-27
28	981	Spring 8
29	837	Spring 9
30	589	Spring 10
31	1304	Spring 11
32	927	Spring 12
33	1025	Spring 15
34	978	Spring 16
◇	1074	Average

ERD-FS-PT6-3150

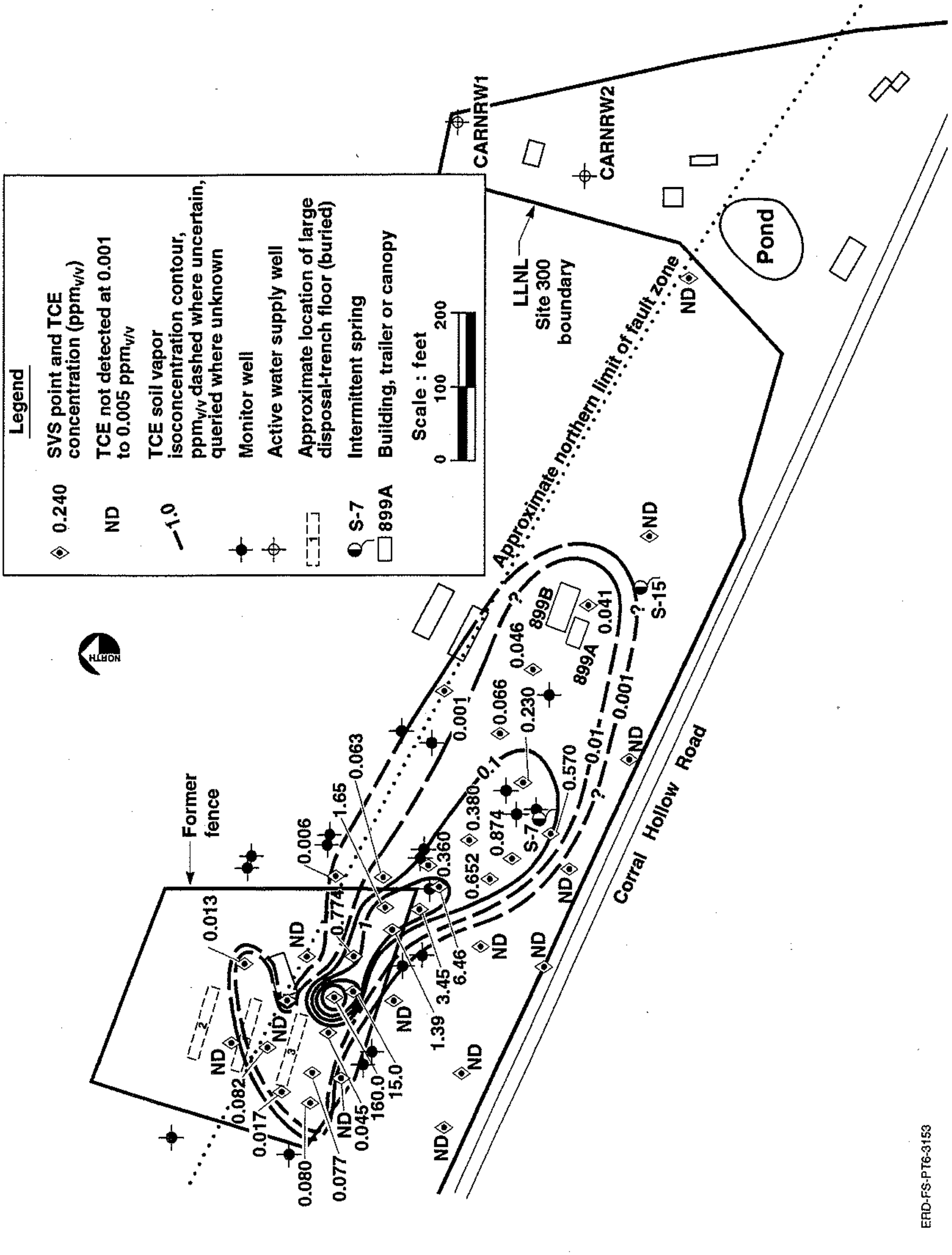
Figure 1-27. Piper diagrams of major ground water ions in the Qt-Tmss hydrologic unit, Pit 6 operable unit.

No.	TDS	Sample site
1	1074	Qt/Tmss (average of 27 wells and 7 springs)
2	1538	Qal/Tts (W-33C-01 screened in Tts)



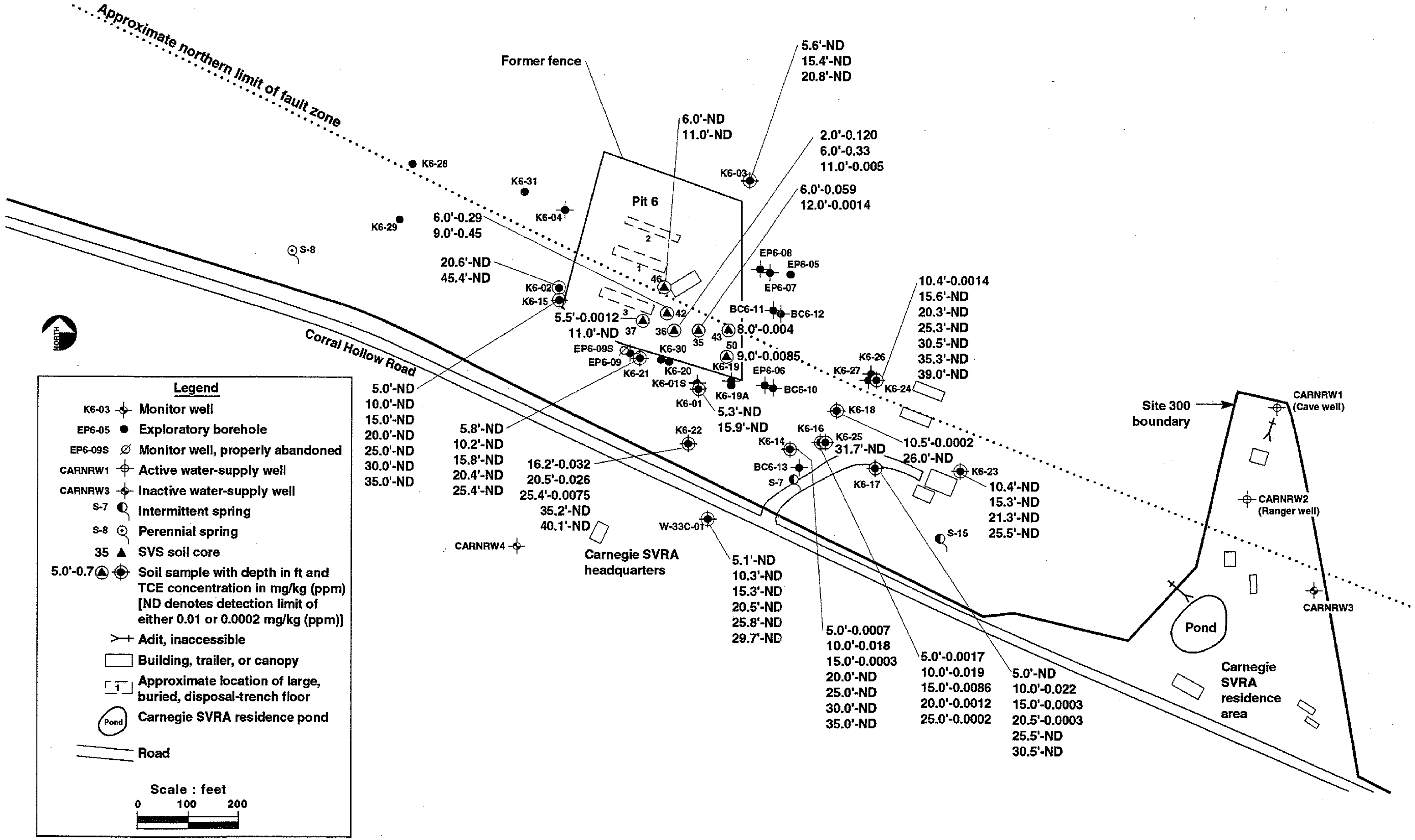
ERD-FS-PT6-3151

Figure 1-28. Piper diagram of the average major ground water ions in the Qt-Tmss and Qal-Tts hydrologic units, Pit 6 operable unit.



ERD-FS-PT6-3153

Figure 1-29. TCE soil vapor concentrations in the Pit 6 operable unit using active vacuum induced soil vapor survey (SVS) points.



ERD-FS-PT6-3154

Figure 1-30. Distribution of TCE in soil/rock for the Pit 6 operable unit.

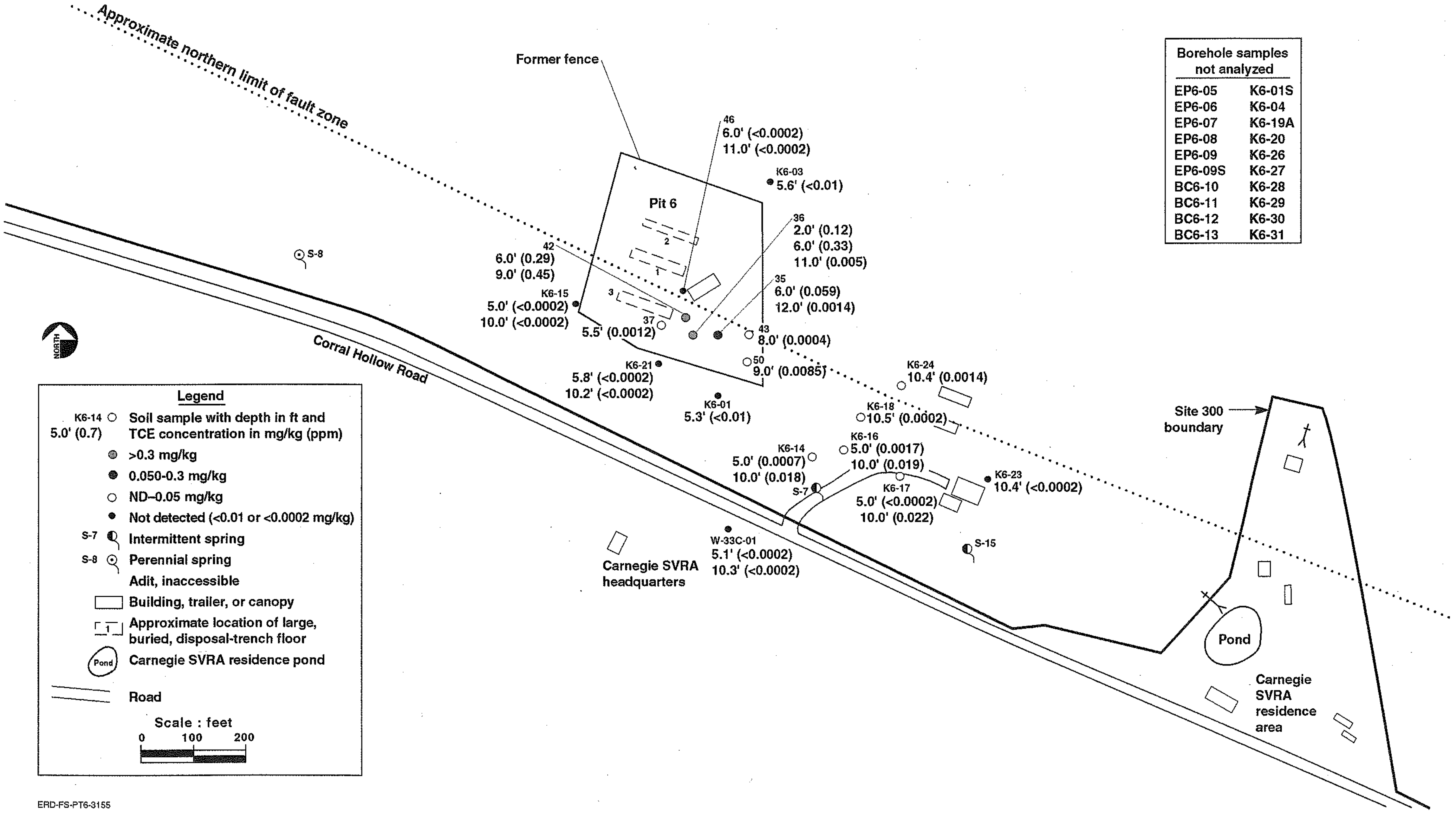
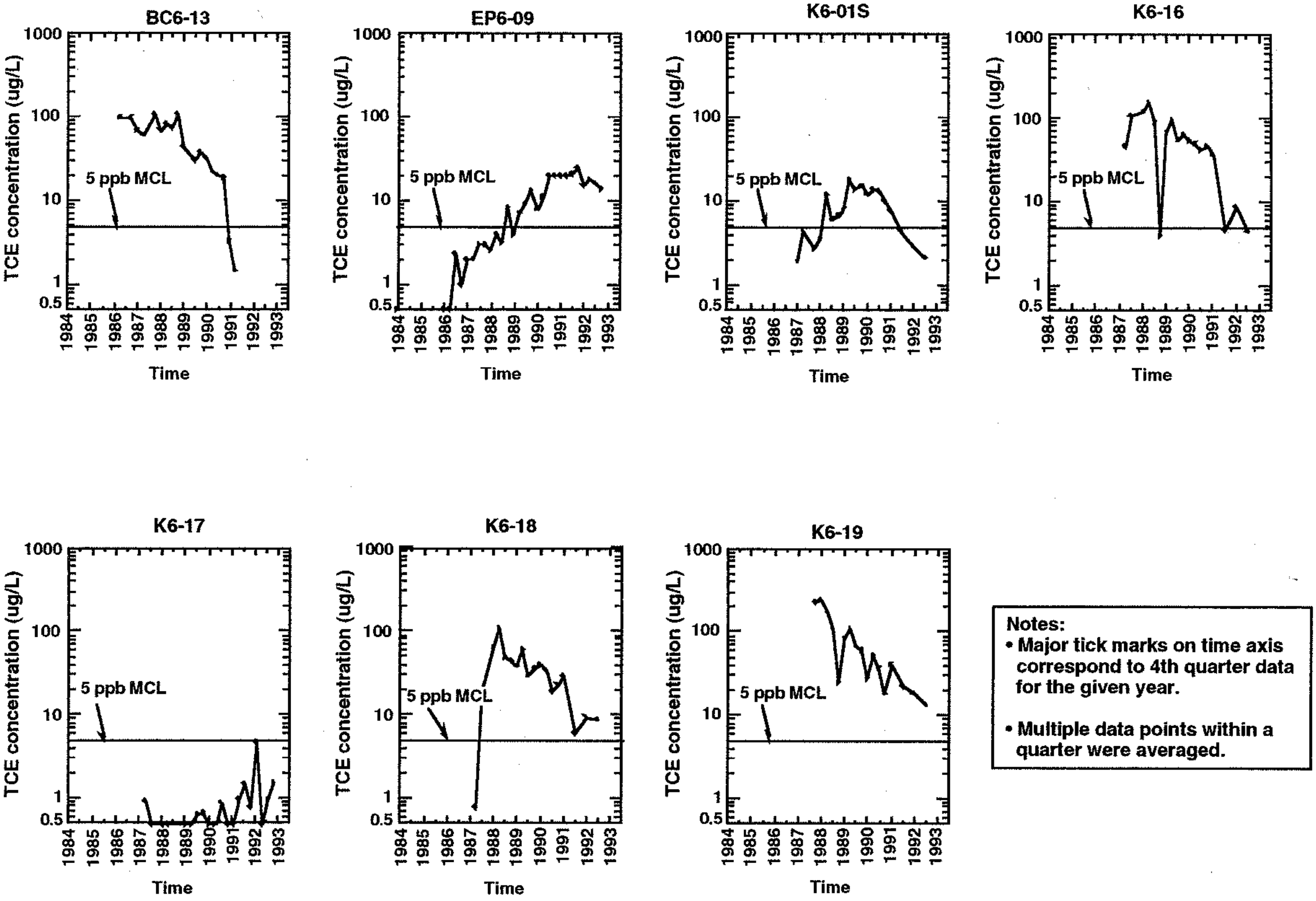


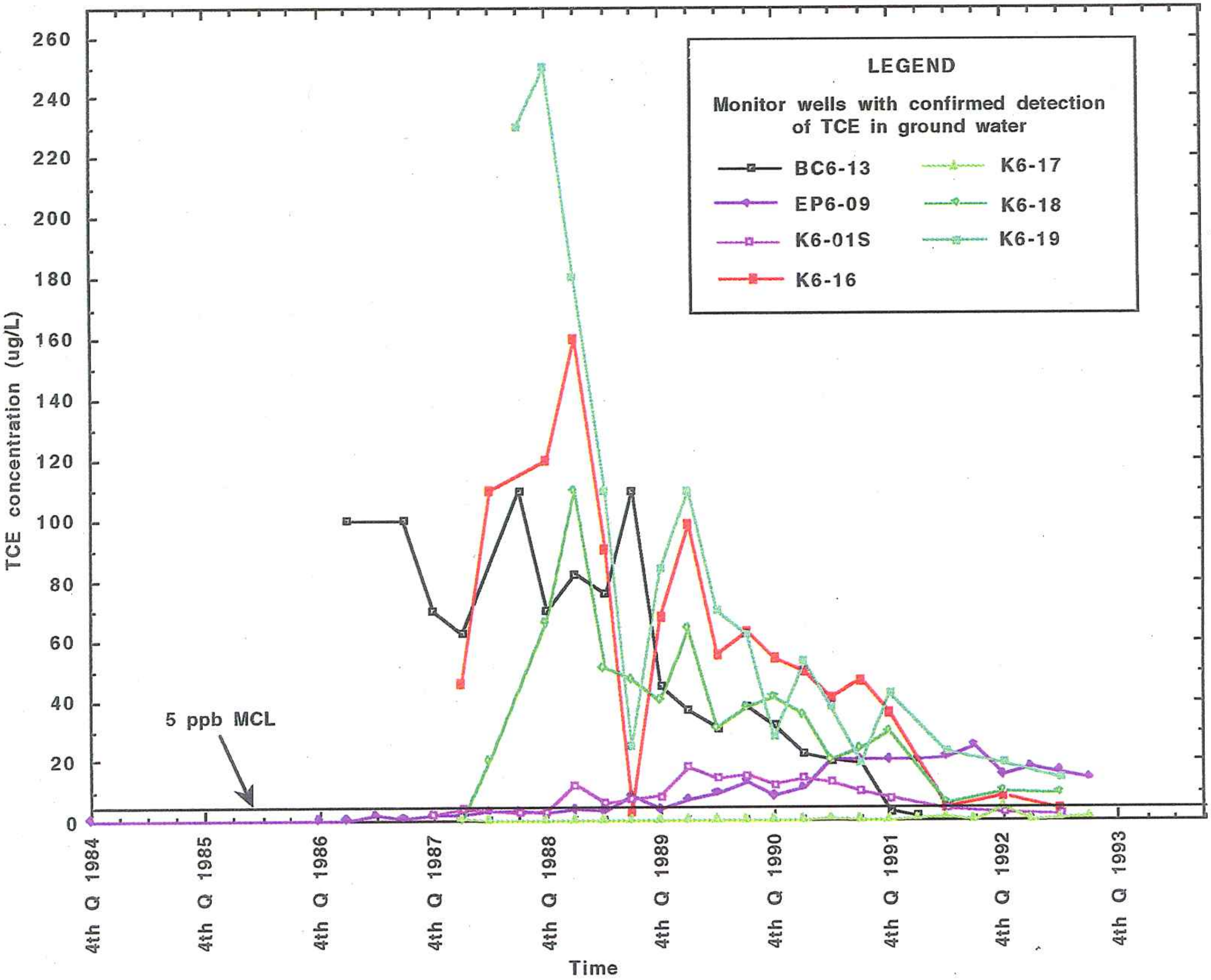
Figure 1-31. Maximum TCE concentration in mg/kg (ppm) for soil/bedrock core samples collected between 0 to 12 ft in the Pit 6 operable unit.



Notes:
- Major tick marks on time axis correspond to 4th quarter data for the given year.
- Multiple data points within a quarter were averaged.

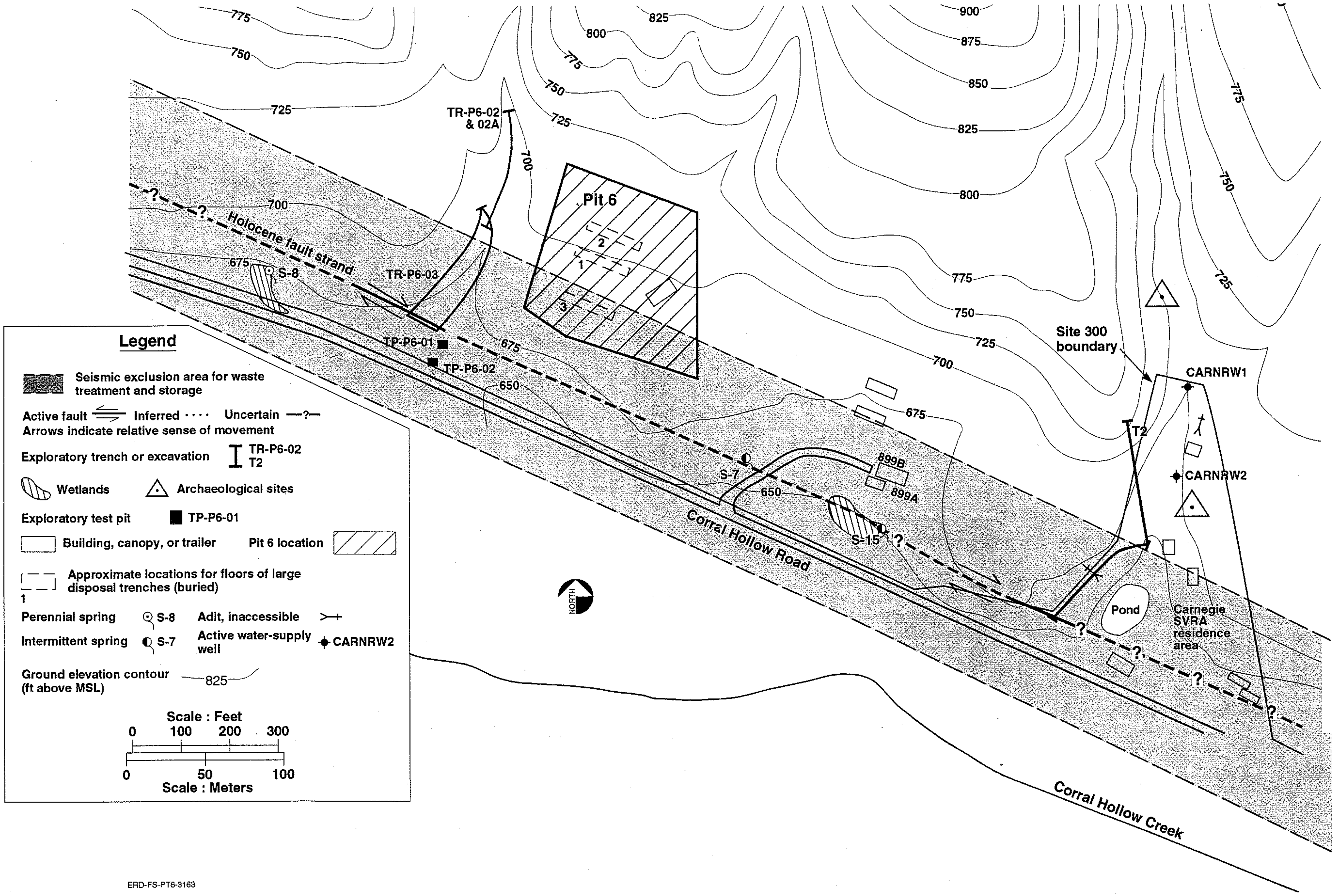
ERD-FS-PT6-3212

Figure 1-32. Log-linear plots of TCE concentration trends in ground water from Pit 6 operable unit monitor wells.



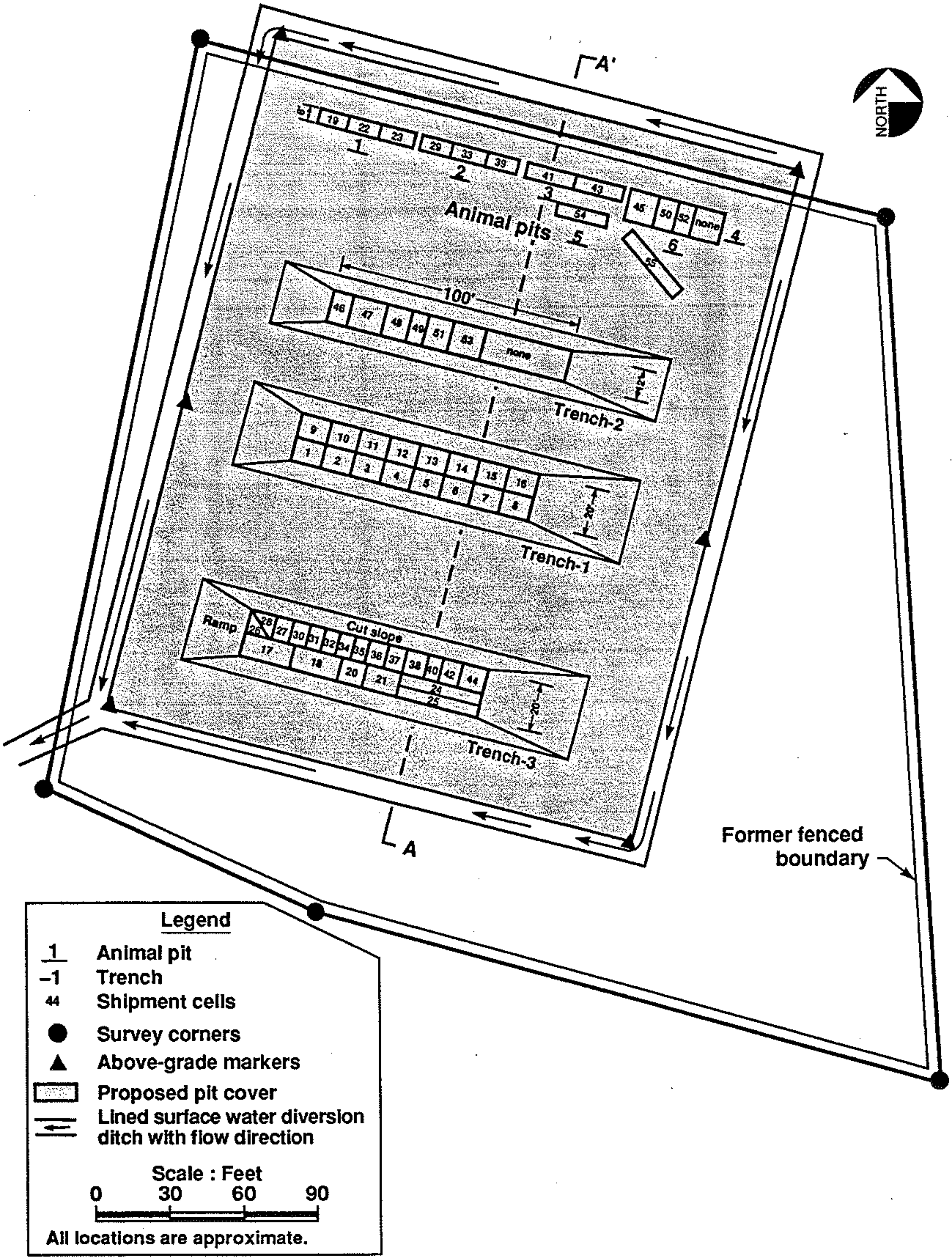
ERD-FS-PT6-3213

Figure 1-33. TCE concentration trends in ground water samples collected from Pit 6 operable unit monitor wells.



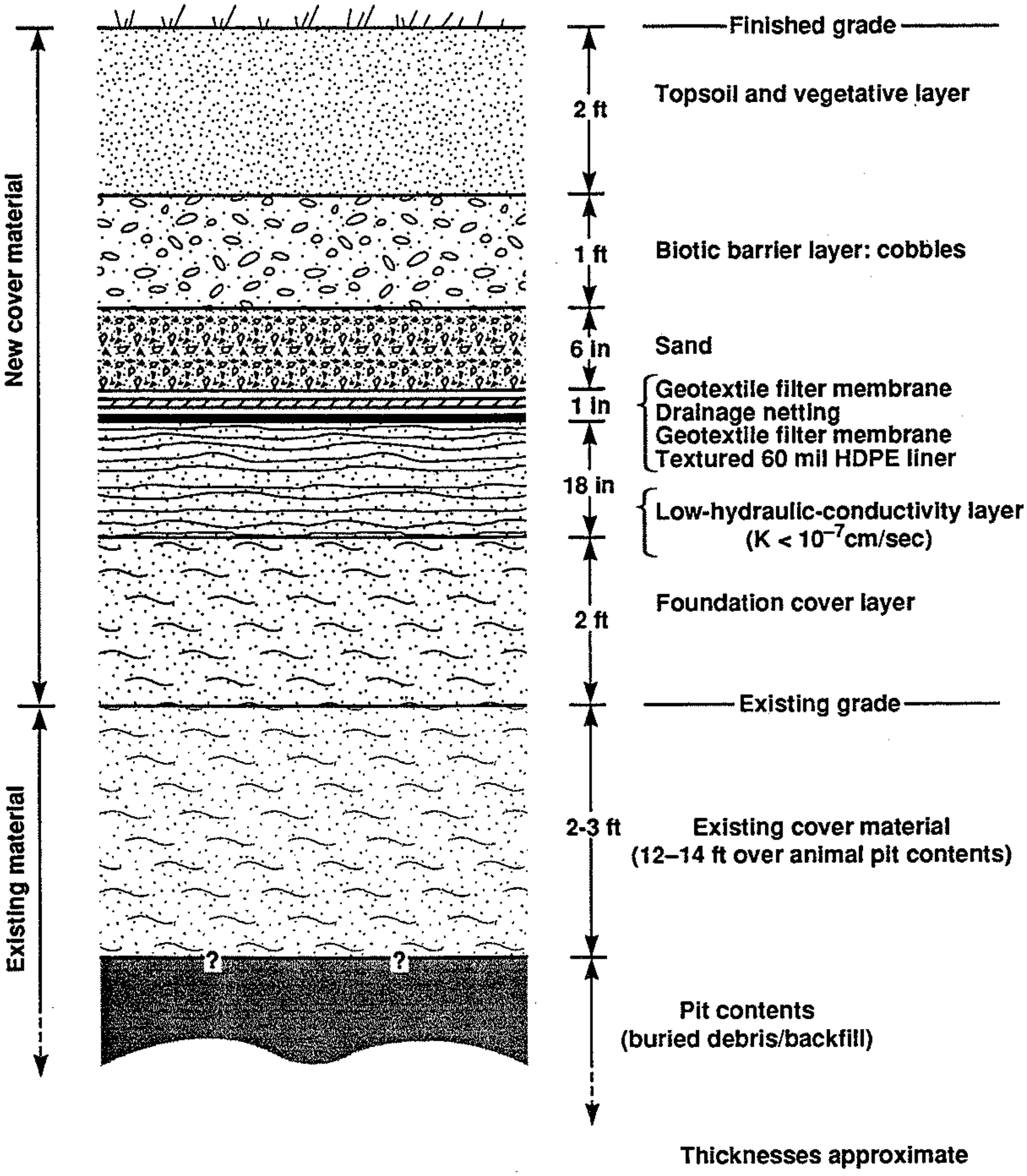
ERD-FS-PT6-3163

Figure 2-1. Location of wetland, archaeological sites, and seismic exclusion area for waste treatment and storage in the vicinity of the Pit 6 operable unit.



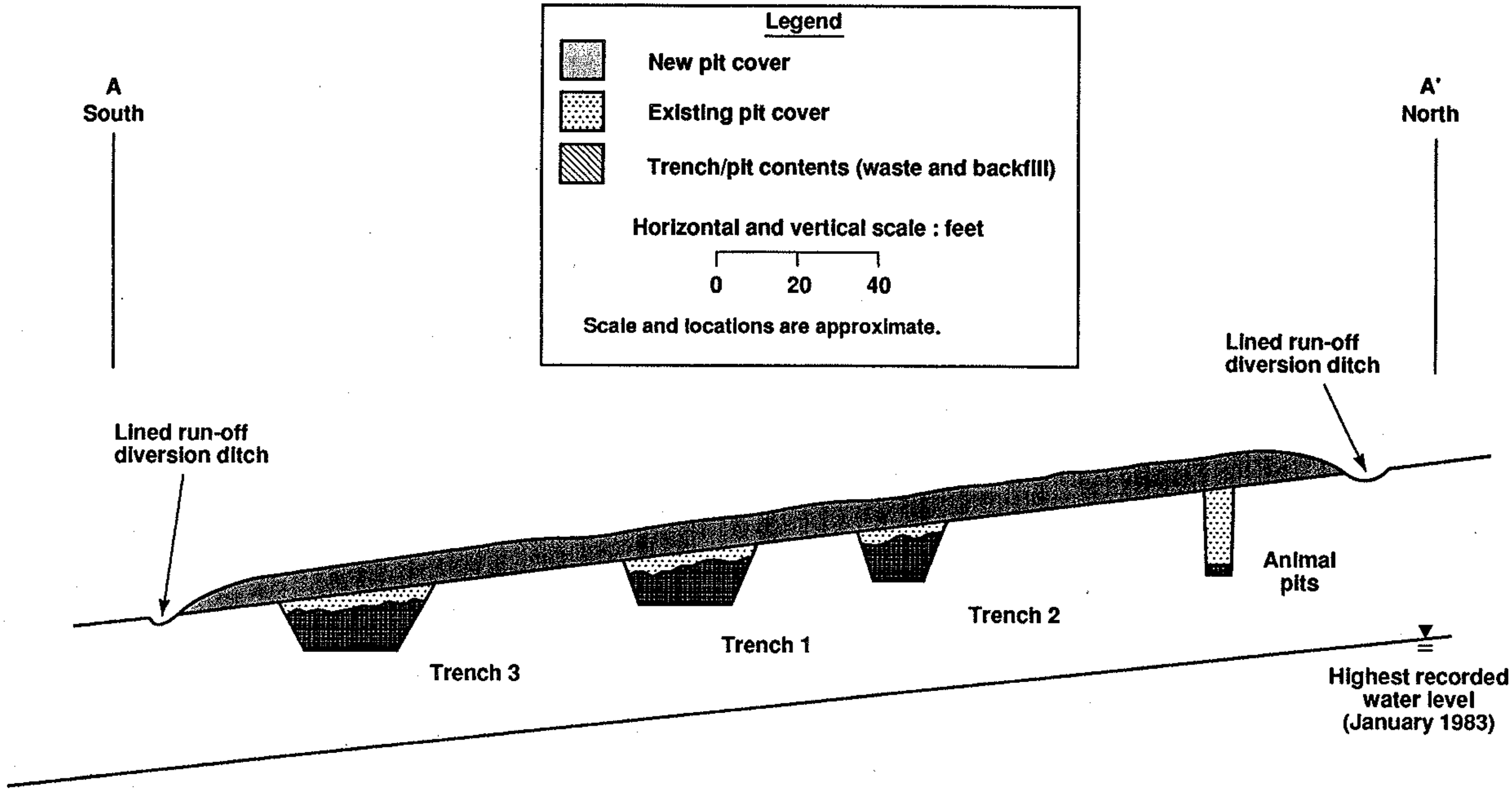
ERD-FS-PT6-3200

Figure 4-1. Proposed location of pit 6 cover—Alternatives 2, 3, and 4.



ERD-FS-PT6-3203

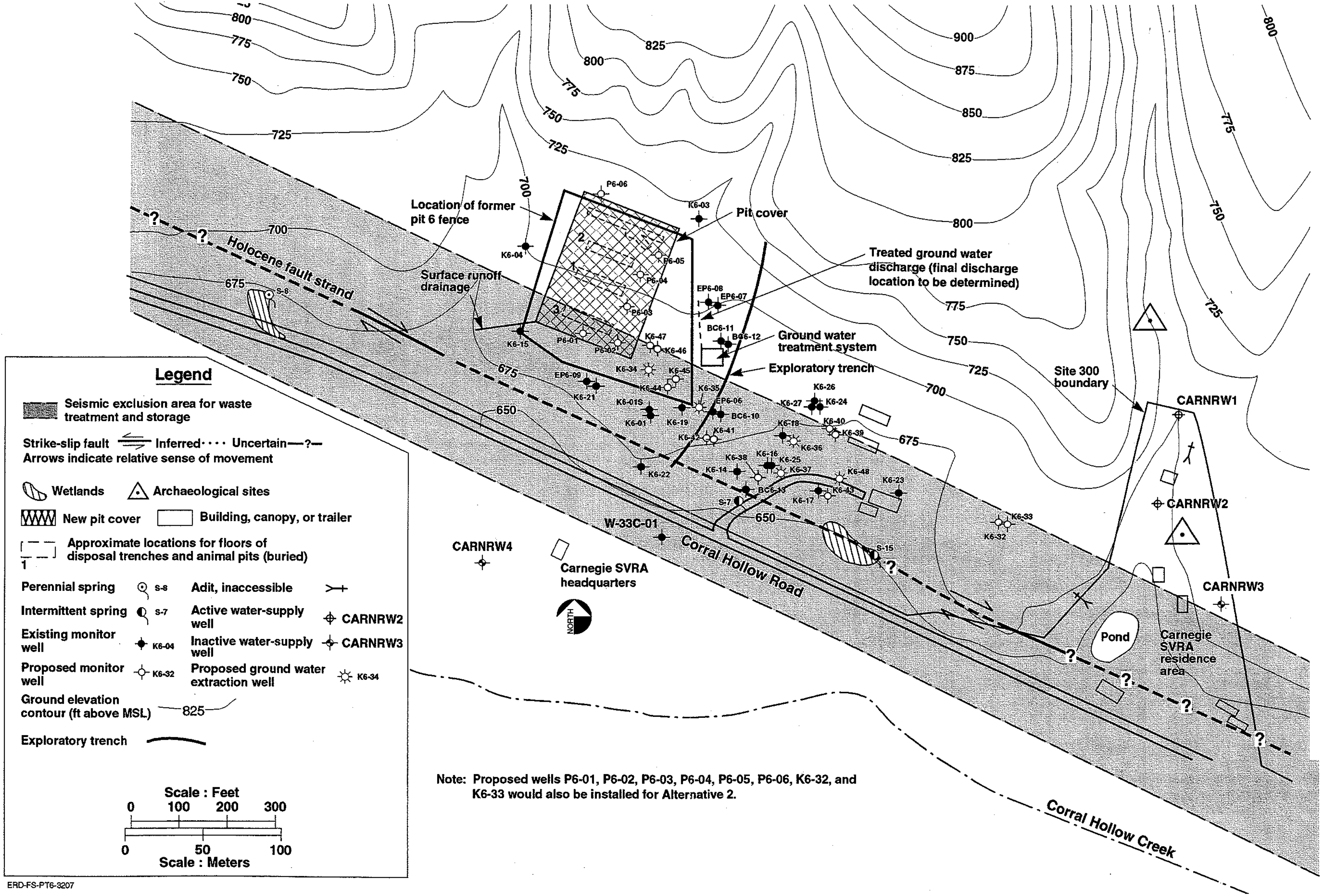
Figure 4-2. Typical section for the proposed pit 6 cover—Alternatives 2, 3, and 4.



Location of cross section shown on Figure 4-1.

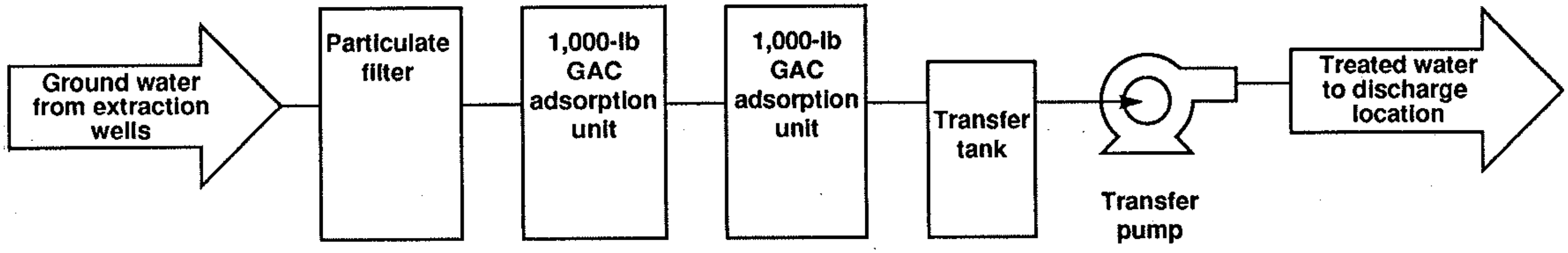
ERD-FS-PT6-3201

Figure 4-3. Conceptual south-north cross section showing proposed location of pit 6 cover—Alternatives 2 and 3.



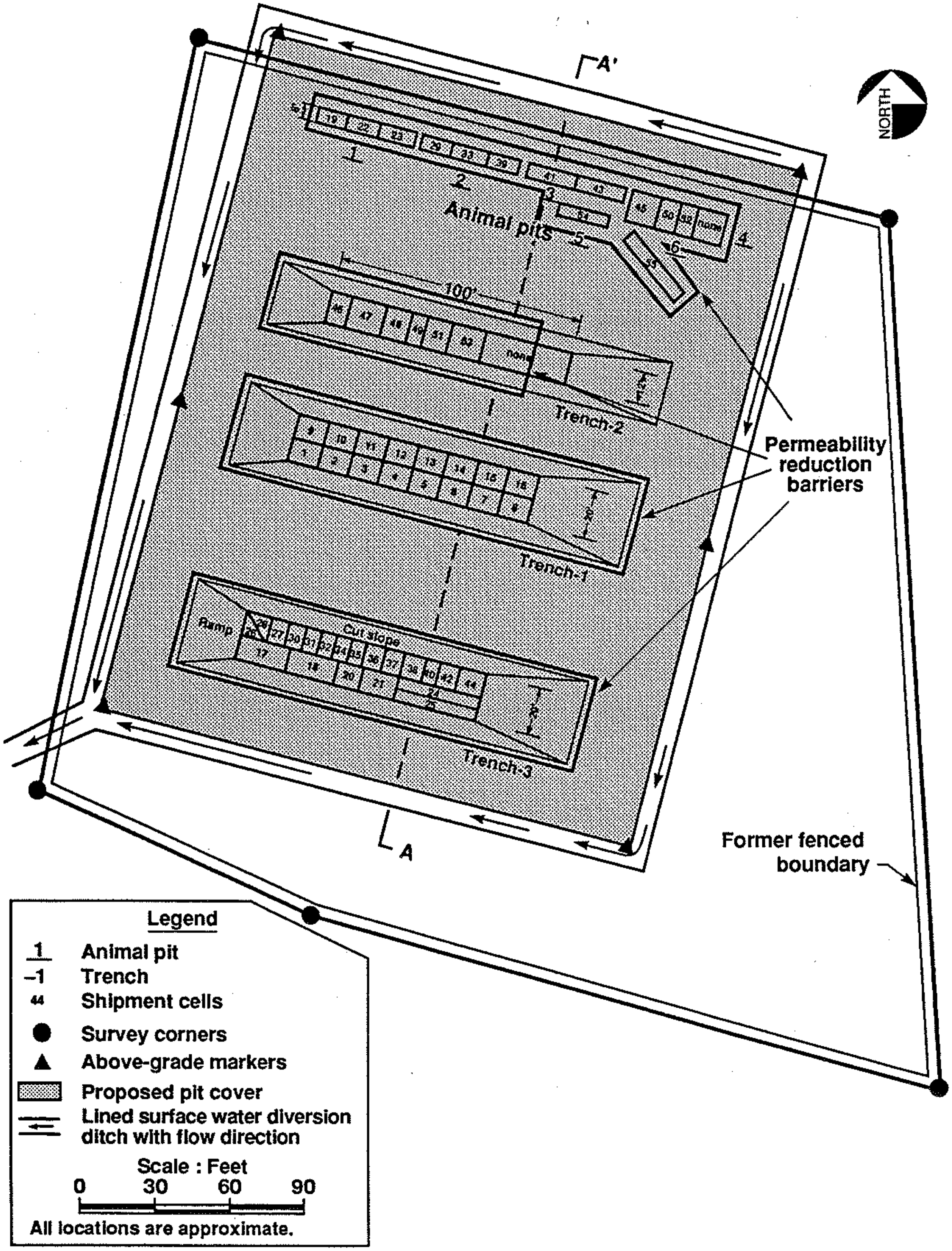
Note: Proposed wells P6-01, P6-02, P6-03, P6-04, P6-05, P6-06, K6-32, and K6-33 would also be installed for Alternative 2.

Figure 4-4. Proposed locations of ground water extraction and treatment system, extraction wells, and monitor wells—Alternatives 3 and 4.



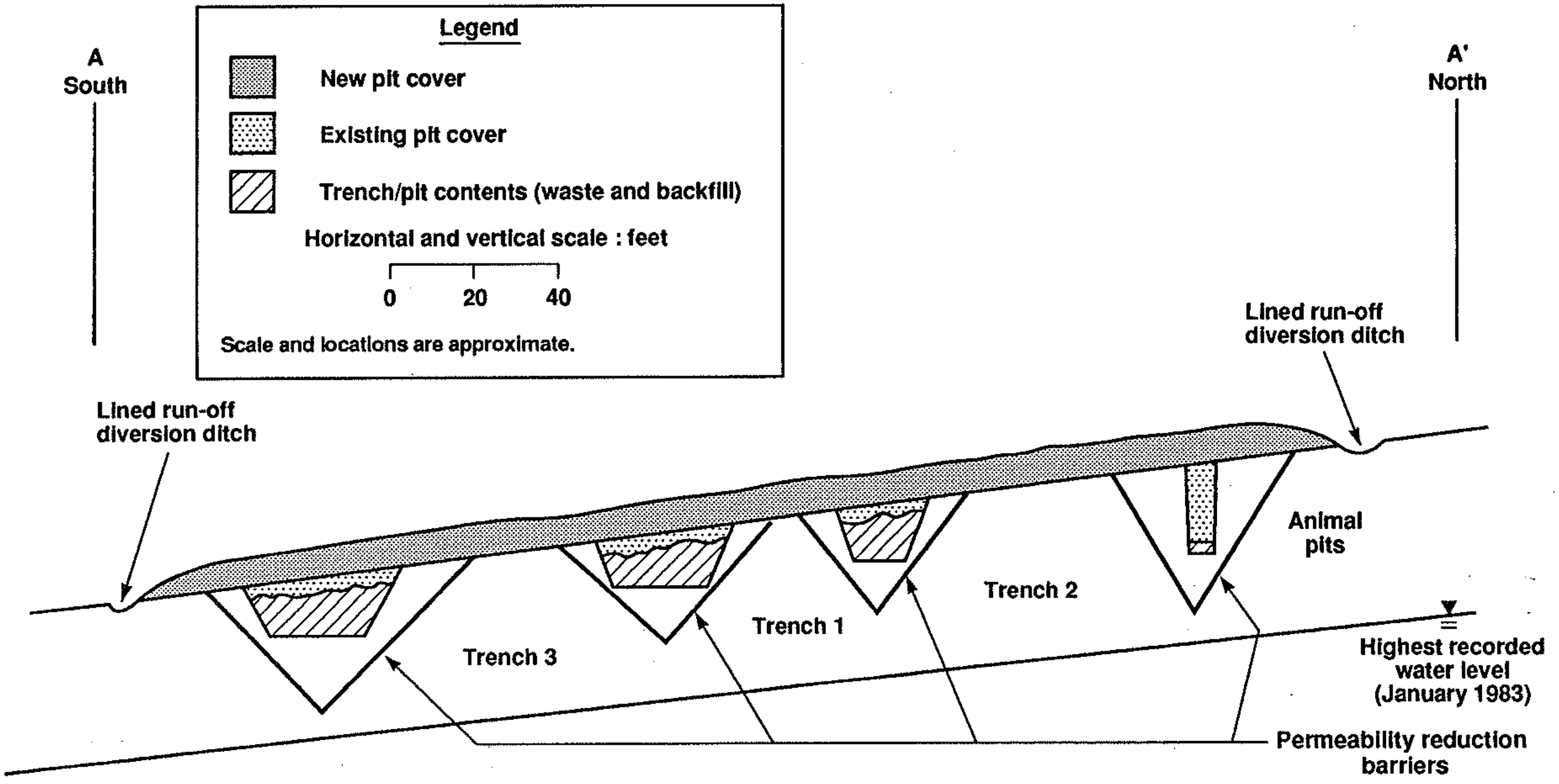
ERD-FS-PT6-3206

Figure 4-5. Proposed ground water extraction and treatment system—Alternatives 3 and 4.



ERD-FS-PT6-3210

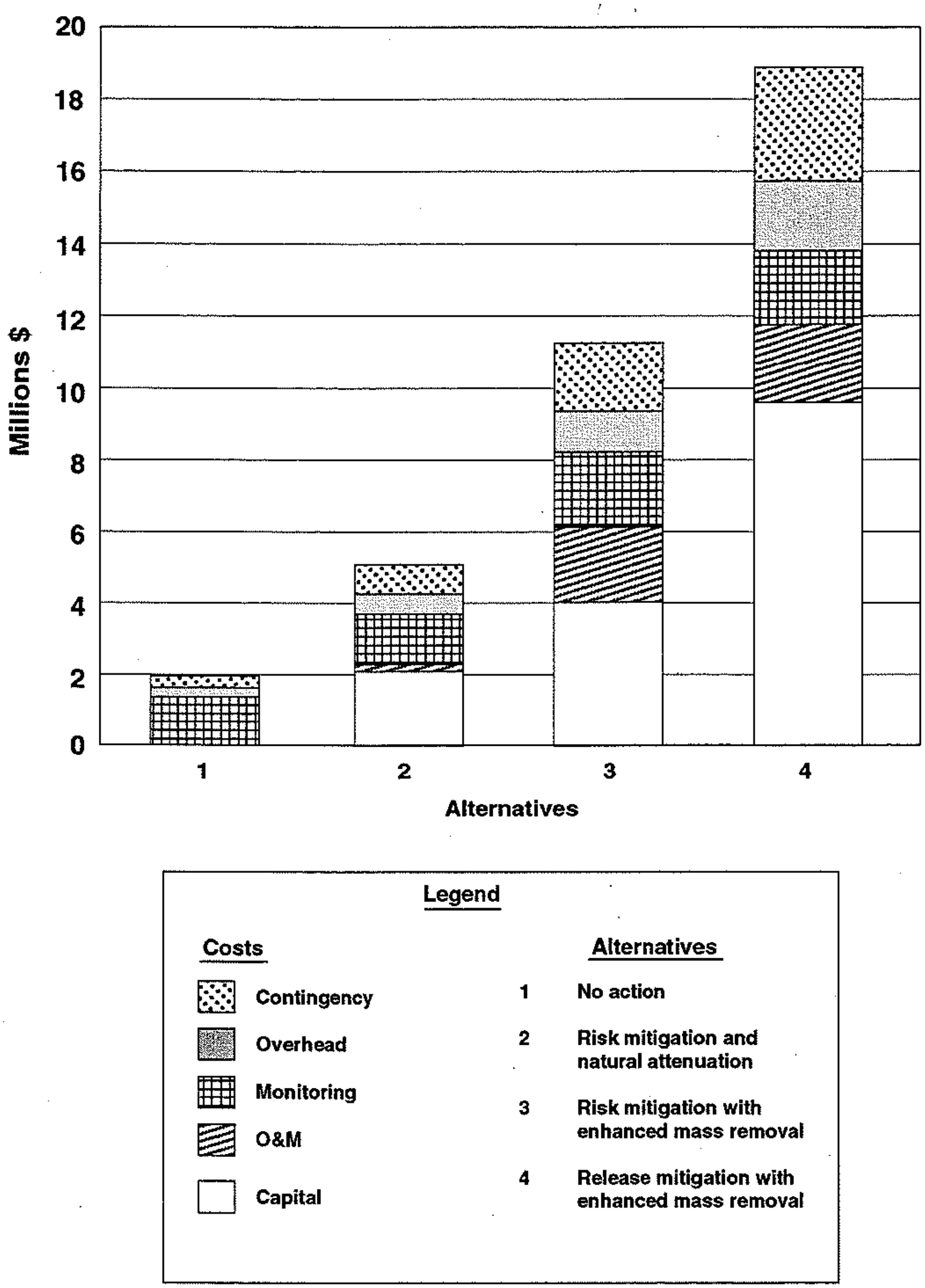
Figure 4-6. Proposed locations of subsurface permeability reduction barriers—Alternative 4.



Location of cross section shown on Figure 4-1.

ERD-FS-PT6-3202

Figure 4-7. Conceptual south-north cross section showing proposed locations of pit 6 cover and subsurface permeability reduction barriers—Alternative 4.



ERD-FS-PT6-3216

Figure 5-1. Cost summary for Pit 6 operable unit remedial alternatives.

Tables

Table 1-1. Stratigraphic characteristics of geologic units, LLNL Site 300.

Epoch	Geologic unit	Depositional environment	Lithologic characteristics
Holocene	Colluvium, alluvium and valley fills (Qal), landslides (Ls/Qls)	Continental, mass wasting, fluviatile	Silty clay, sand, gravel, landslides heterogeneous.
Pleistocene	Older alluvium (Qoa) and landslides (Qls), terrace deposits (Qt)	Continental, predominantly fluviatile	Silty clay, silt, sand, gravel, often partly cemented.
Pliocene	Pliocene nonmarine unit of Dibblee (1980) (Tps)	Continental fluviatile, lacustrine	Pebble conglomerate, greenish gray, brown and red clay, silty sand and some marl interbeds.
Late Miocene	Neroly Formation (Tn)	Continental, fluviatile, lacustrine	Volcanic source terrain; immature sandstone, conglomerate, tuffaceous shale and claystone, slightly to well-lithified, within Site 300 subdivided into following informal lithologic members: Tnbs$_2$ upper blue sandstone (predominantly fine-coarse grained, blue-gray and brown silty sandstone, conglomerate lenses, tuffaceous claystone interbeds; beds of claystone, sandstone, heterogeneous conglomerate (Tnsc$_2$) discontinuously present at top of sequence and mappable locally but not present in Pit 6 operable unit). Tnsc$_1$ middle claystone, siltstone (interbedded claystone, siltstone, fine sandstone). Tnbs$_1$ lower blue sandstone (predominantly fine to coarse-grained, blue-gray silty sandstone, tuffaceous claystone and siltstone interbeds, conglomerate lenses).
	Cierbo Formation (Tmss)	Littoral, varying from shallow marine to continental	Friable, yellow-gray quartz-rich sandstone, chert pebble conglomerate, gray claystone, locally tuffaceous.
Late Paleocene-Eocene	Tesla Formation (Tts)	Brackish water to marine	Quartz-mica sandstone and carbonaceous clay, subordinate chert pebble conglomerate and lignite coal.
Late Jurassic-Cretaceous	Great Valley Sequence (Kgv) (Panoche Formation)	Deep oceanic trough floor grading up to subsea fans, forearc basin setting	Arkosic sandstone with large concretions, micaceous clay interbeds. Present only very locally in northwestern portion of Pit 6 operable unit.

Table 1-2. Principal active and potentially active faults, San Francisco Bay Region, Altamont Hills and Central Valley margin areas.

			Slip rate (mm/yr)		Max. earthquake magnitude	
Fault	Distance (mi)[b] and direction	Max. historic earthquake magnitude (y)	Geodetic	Geologic	Probable	Credible
Corral Hollow-Carnegie	0[a]	None known[d]	—	0.7[e]	6.3–6.7[e]	7.1[e]
Midway	2 (NE)	3.5 (no date)[f]	—	0.05[g]	—	6.0[g]
Tesla	2.5 (S)	4.6 (1977)[f]	—	0.2[g]	—	6.25[g]
Patterson Pass	3 (W)	4.6 (after 1900)[f]	—	NA	—	5.9[h]
Black Butte	4 (NE)	None known[d]	—	0.2[g]	—	6.5[g]
Greenville	6 (SW)	5.8 (1980)[d]	—	0.5–0.75[i]	—	6.6 ± 0.2[i]
Las Positas	10 (SW)	5.5 (1903)[d]	—	0.4[i]	—	6.0 ± 0.5[i]
Ortigalita	17 (SSE)[j]	5± (1926) 3.7 (1981)[l]	—	0.1[k]	—	6.8[k]
Calaveras	20 (SW)	6± (1861)[m] 6.2 (1984)[p]	7[n]	5.3[o]	—	7.0 ± 0.25[h]
Hayward	25 (SW)	7± (1868)[q]	7[n]	3.5–9[r]	7.0[q]	7.5[q]
San Andreas	42 (SW)	8.25 (1906)[m] 7.1 (1989)[s]	12.2 ±3.9[n]	10–30[o]	—	8.3[m]
San Gregorio-Seal Cove-Hosgri	54 (SW)	6.1 (1926)[m]	—	6–13[o]	—	7.4[m]

[a] The Corral Hollow-Carnegie fault zone traverses the Pit 6 operable unit.

[b] Distances for more distant faults are from approximate center of Site 300.

[c] Reported microseismicity with general spatial correlation.

[d] Carpenter et al. (1991).

[e] CDWR (1979).

[f] Tera Advanced Services Corporation (1984).

[g] Calculated using total fault length method in Slemmons and Chung (1982).

[h] Carpenter et al. (1984).

[i] To northern tip, activity mainly farther south.

[j] Shedlock et al. (1980).

[k] Laforge and Lee (1982). M = 5 event was near southern end of mapped trace, but location accuracy uncertain.

[l] Wesson et al. (1975), for San Andreas Fault, North Coast segment; other faults not segmented.

[m] Prescott et al. (1981).

[n] Page (1982).

[o] Oppenheimer et al. (1990).

[p] Steinbrugge et al. (1987).

[q] Lienkaemper et al. (1991).

[r] Plafker and Galloway (1989), Santa Cruz Mountains segment.

— = Not available.

Table 1-3. Buildings located in the vicinity of the Pit 6 operable unit.

Building	Completion date	Function
On-site Buildings		
Small Firearms Training Facility	Construction began in 1970	
899A—Storage building	Construction began in 1970	Weapon cleaning, storage, and armorer work area
899—Classroom office	Construction began in 1970	Classroom, control center, and Rangemaster office
Five miscellaneous structures		
Three firing position metal canopies	Construction began in 1970	Protect shooters
Abandoned sheepherders' shack	Unknown	Ranching prior to 1955
Wooden shed (near Paper Canyon)	1969	PSO guard post in late 1960s and early 1970s
Off-site Buildings at Carnegie SVRA	State occupancy began in 1980	
Four trailers	Approx. 1980	Residence area for Carnegie SVRA personnel and families
Headquarters building	1990	Attendance control
Concession store	Approx. 1980	Visitor supplies
Maintenance complex	1990	Repair of state-owned vehicles and equipment

Table 1-4. Abandoned mining prospects in the vicinity of the Pit 6 operable unit.

Mining prospect	Distance and bearing from pit 6	Present condition	Length of tunnel or adit	Orientation	Reference
1. Residence pond adit	950 ft southeast	Opening blocked with soil	Unknown	East-west	Carpenter et al. (1991)
2. Cave well/ Carnegie townsite well adit	1,050 ft east	Opening blocked with wooden structure	80 ft	North-south	Carter (1991)
3. Spring 12 adit	6,500 ft northwest	Open	Caved at 30 ft, possibly 250 ft east-west and 100 ft north-south	East-west and north-south	U.S. DOE (1982)
4. County line tunnel	Possibly 4,100 ft west	Opening collapsed (caved), not visible[a]	140 ft	North-south	Anonymous (1890), Dietrich (1928)
5. Sixty-ft tunnel	Possibly 500 ft east	Opening caved, not visible[a]	60 ft	North-south	Anonymous (1890), Dietrich (1928)
6. Old people's mine	4,000 ft southwest	Converted into well CARNRW6, opening caved	Vertical shaft about 150 ft, horizontal shaft length unknown	Probably east-west	Mosier (1983), Carter (1991)

[a] Prospects 4 and 5 are not visible and therefore are not plotted in Figure 1-3.

Table 1-5. Summary of disposal dates, principal contents, surface areas, and estimated volumes of the nine trenches in pit 6.

Disposal location	Shipment numbers	Disposal dates	Principal contents	Surface area (ft^2)	Volume[a] (ft^3)
Trench 1	1–16	07/01/64–10/12-64	Empty waste and oil drums, empty retention tanks, glove boxes, ducting, lumber, capacitors, filters, shell furnaces, gas cylinders, piping, paper.	2,000	20,000
Trench 2	46–49, 51, 53	04/12/68–09/01/70	Empty waste and oil drums, capacitors, wood, empty retention tanks, mercury tubes, filters, scrap iron, gas cylinders.	780	7,800
Trench 3	17, 18, 20, 21, 24–28, 30–32, 34–38, 40, 42, 44	12/15/64–10/25/67	Empty waste and oil drums, empty carboys, empty retention tanks, glove boxes, ducting, filters, capacitors, mercury lights, piping, gas cylinders.	2,000	20,000
			Original volume of trenches 1, 2, 3		47,800
			Minus volume of exhumed D-38 drums		–229
			Present volume of trenches 1, 2, 3		47,571
Animal pit 1	19, 22, 23	03/22/65–06/18/65	Animal carcasses, animal wastes.	240	720
Animal pit 2	29, 33, 39	02/25/66–01/16/67	Animal carcasses, animal wastes.	240	720
Animal pit 3	41, 43	05/13/67–09/01/67	Animal carcasses, animal wastes.	240	720
Animal pit 4	45, 50, 52	11/01/67–09/24/69	Animal carcasses, animal wastes.	312	936
Animal pit 5	54	04/28/71	Animal carcasses, animal wastes.	120	360
Animal pit 6	55	02/20/73	Animal carcasses, animal wastes.	186	558
			Volume of animal pits 1-6		4,014
			Present volume of pit 6		51,585

[a] Volumes were calculated using a waste-layer thickness of 10 ft and 3 ft for the trenches and animal pits, respectively. Calculated volumes should be regarded as approximate.

Table 1-6. Summary of disposed waste material in trenches 1, 2, and 3 (after Rich, 1971).

Item	Amount	Description
Boxes	129	Various contents (capacitors, filters, soil, ducting, etc.)
Drums	1,127	Mostly empty rusted-out oil drums
Compressed drums	166	Smashed flat
Drums (30-gal.)	54	Contain D-38 (to be removed)[a]
Filters	151	Various sizes (Be and Tuballoy Shops)
Capacitors	2,022	Various sizes, mostly large
Furnaces	8	BeO contaminated
Glove boxes	36	Various sizes—BeO + U contaminated
Loaded pallets	72	Contain pipes, ducting, wood, styrofoam, trash, metal, coils, soil, general waste, etc.
Unloaded pallets	400	Empty/damaged
Miscellaneous	8	Hoods and vent covers, tables, stands, and benches
Enclosure	1	Enclosure

[a] The D-38 drums were removed after Rich wrote his memo in 1971.

Table 1-7. Description of stratigraphic units encountered in boreholes in the vicinity of the Pit 6 operable unit.

Stratigraphic unit	*Quaternary deposits: Alluvium deposits (Qal),Terrace deposits (Qt)*
Range of thickness	Qal: 9 ft thick in well W-33C-01; this well is the only one (with well logs available) that encounters this unit in the study area. Deposits are variable in thickness throughout Corral Hollow Creek floodplain. Qal deposits are more than 48 ft thick in the eastern GSA study area (McIlvride et al., 1990). Qt: The thickness from well log data varies from 3 ft in well BC6-13 up to 55 ft in well K6-04. The calculated average thickness around pit 6 is about 23 ft. The unit probably thins to a few inches thick at the base of the hillslopes immediately north of pit 6. A gravel unit within portions of the Qt varies in thickness, up to 20 ft in well K6-04. Figure 1-19 presents an isopach map of this gravel unit in the Pit 6 Area. The thickest gravel deposits generally follow a northwest to southeast trend across pit 6.
Lithology	Qal: Alluvial deposits consist of brown to light-brown gravelly silt and sandy gravel dominantly of Franciscan origin. Gravel deposits locally contain cobbles and boulders. Qt: Terrace deposits consist of unconsolidated to semiconsolidated brown, yellow-brown, blue-gray, and gray sediments ranging from clay to gravel. In general, the sediments coarsen with depth and commonly grade to a basal gravel. The fine-grained deposits are soft to stiff with low to moderate plasticity and contain minor and localized carbonate stringers, roots, and iron oxide staining. The sand deposits are loose to very dense, and in general are very fine to medium grained, although they are commonly coarse grained in the gravelly sand and gravel deposits. The sand deposits are moderately to well sorted and may contain minor caliche and organic fragments. Gravel clasts range from angular to rounded, but are predominantly subrounded. Gravel and sporadic boulders are derived primarily from Franciscan Complex sources and are composed of chert, graywacke, and volcanics, with lesser quartz and sandstone. Gravel size ranges from less than 1-in. diam to about 8-in. diam, with an average diam of 2 in. The coarser gravel vaguely defines an east-to-west trend through boreholes and wells K6-15, K6-30, K6-19, BC6-13, K6-18, K6-27, and K6-24. The gravel may be stained or coated with iron oxide or carbonate.
Extent of unit	Qal: Alluvial deposits extend northwest to southeast along the Corral Hollow Creek floodplain immediately south of pit 6. Qt: Terrace deposits are most extensive in the immediate vicinity of pit 6 where they comprise a relatively level area about 500 ft wide (Fig. 1-15a). The surface of these older terrace deposits is typically about 50 ft above the surface of the Corral Hollow Creek floodplain to the south (Taffet, 1990), although one exposure of an older Qt remnant is nearly 100 ft above the surface of pit 6 (Fig. 1-15a). For discussion of ages of different terrace remnants, see Carpenter et al. (1991). Qt material crops out along the terrace face south of pit 6, and in ravines east and west of the landfill.

Table 1-7. (Continued)

Stratigraphic Unit	*Miocene Neroly Formation: Lower Blue Sandstone (Tnbs$_1$)*
Range of thickness	The Neroly lower blue sandstone was not fully penetrated at pit 6 by any borehole, except possibly well CARNRW1, where the lithology is poorly documented. Up to 295.5 ft of sandstone was penetrated in well K6-26.
Lithology	The Neroly lower blue sandstone consists of massive blue sandstone with interbedded claystone, siltstone, and minor tuff. The sandstone is gray, brown, purple brown, or green gray, and commonly dries to a blue or bluish-gray color. This unit is moderately to well indurated with up to 40% fines. This sandstone is composed generally of plagioclase, clay, and quartz. Fine-grained potassium feldspar is also present. Rock fragments, biotite, clinopyroxene, apatite, hornblende, and zircon occur as accessory minerals. Much of the clay is diagenetic and smectitic. Plagioclase is altered to kaolinitic clay, which often forms crusts on the quartz grains, giving the sandstone its blue color (Lerbekmo, 1961). Minor gravel is rounded to subrounded, up to 1.5-in. diam. The sandstone commonly displays cross-bedding, rip up clasts, and local carbonaceous material, carbonate cement, mica, iron oxide stains, and silica veins. Soft sedimentary deformation such as slump structures and convolute bedding have also been noted in the Tnbs$_1$ (Taffet, 1990). The finer grained interbeds are gray, brown, to green, moderately to well indurated claystone to sandy siltstone containing thin lenses of gravel, conglomerate, and sandstone. Locally these interbeds are laminated and contain rip-up clasts, pyrite, leaf fossils, carbonaceous material, and rare crystalline calcite. North of the Carnegie Fault, the beds of this unit strike an average of N70°E and dip an average of 15° to the southeast. This unit occurs sporadically in the pit 6 area south of the Carnegie Fault. Where present south of the fault, the unit dips nearly vertical to steeply south. Fractured surfaces are commonly healed with clay, open with slickensides, or coated with carbonate, manganese oxide, iron oxide, pyrite, gypsum, or possibly epidote.
Extent of unit	The Neroly lower blue sandstone is exposed along the hillslopes north of the Carnegie Fault. Adjacent to pit 6, this unit also directly underlies the Qt strata north of the Carnegie Fault and, thus, all the monitor wells in this area encounter this sandstone unit. South of the fault, this unit is discontinuous.
Stratigraphic Unit	*Miocene Cierbo Formation (Tmss)*
Range of thickness	The thickness of the Cierbo Formation at pit 6 is unknown, as it is not fully penetrated by any boreholes; up to 117 ft was penetrated in borehole K6-25. However, assuming the unit is overturned up to 10–30°, about 38 ft of section was penetrated. The Cierbo Formation has a maximum thickness of about 285 ft in the northern part of Site 300.

Table 1-7. (Continued)

Lithology	The Cierbo Formation consists of a silty sandstone to sandstone unit interbedded with finer grained claystone to siltstone and minor tuffs. The finer grained sediments are absent in wells K6-23 and K6-17, but represent up to 81 ft of section in well K6-25. The claystone and siltstone are blue gray, green, brown and gray, moderately to well indurated, and contain minor biotite flakes, quartz grains, pebbles, iron oxide stains, laminations, and rare coal. The borehole for well K6-25 encountered a gravelly sandstone interbed with subangular to subrounded chert and siltstone gravel to 1.5-in. diam. A brackish water pelecypod (*Ostrea bourgeosii*) suggests a shallow marine origin for these rocks (Raber and Carpenter, 1983). Horizontal to subvertical fractures may have slickensides, pyrite, or may be coated with carbonate, gypsum, or epidote. The silty sandstone to sandstone is blue gray to green gray, and less commonly brown, yellow gray, and yellow brown. These rocks are typically light gray to white in outcrop. The sandstone is massive, friable, poorly to moderately indurated, contains fine- to medium-grain quartz-rich sand, and contains up to 25% silt. In addition to abundant quartz, the sandstone contains potash and plagioclase feldspar, and smectite within pores. Scanning electron microscopy indicates that many of the pores are lined with smectite clay. Accessory minerals include biotite with lesser pyrite, apatite, zircon, hornblende, clinopyroxene, and ilmenite. Gypsum and calcite form as authigenic phases in addition to clay (Taffet, 1990). The sandstone may have iron oxide or manganese oxide stains.
Extent of unit	The Cierbo Formation has not been encountered in deep wells completed north of the Carnegie Fault near pit 6. However, it has been encountered within the fault zone. Where exposed south of the fault, beds strike about east-west and are overturned 10–30°. The Cierbo Formation crops out south of pit 6 adjacent to Corral Hollow Road, and on a cut slope in the Carnegie SVRA residence area east of pit 6 (Fig. 1-15a).
Stratigraphic Unit	*Late Paleocene-Early Eocene Tesla Formation (Tts)*
Range of thickness	The thickness of the Tesla Formation is highly variable, as it was deposited upon an erosional surface within the underlying Great Valley Sequence (Taffet, 1990). The Tesla Formation is encountered in wells W-33C-01, CARNRW4, and CARNRW5. Detailed lithologic descriptions are from well W-33C-01 and local outcrops. Where the Tesla Formation is exposed east of pit 6 in a cut slope (on SVRA property), the thickness is about 130 ft, and beds are overturned and steeply dipping. On a regional scale, this unit may be from 1,200 to 1,500 ft thick (Huey, 1948).

Table 1-7. (Continued)

Lithology	The Tesla Formation is a heterogeneous sequence of brackish water and marine sedimentary rocks of late Paleocene to early Eocene age, unconformably underlying the Cierbo Formation (Carpenter et al., 1991). These rocks are composed of fine- to very fine-grained, white to buff, quartz-rich sandstone, and olive green, olive brown, dark green, and less commonly yellow and gray blue, well-indurated claystone to silty claystone containing 10–15% silt, and 5–10% fine-grained to medium-grained sand. The unit contains minor biotite flakes, organic fragments, pyrite, and thin (up to 2 in. thick where exposed east of pit 6) seams of lignite and subbituminous coal This unit is similar to the Cierbo Formation, but is distinguished by the presence of more coal. Gypsum frequently occurs as a secondary fracture and pore filling. Fractures may have slickensides, sulfide, iron oxide stains, and black organic coatings.
Extent of unit	The Tesla Formation probably underlies much of the Qal along Corral Hollow Creek floodplain, and is discontinuous across the pit 6 area. The unit crops out south and east of pit 6. Within the northwest portion of Site 300, Cierbo Formation rocks overlie Great Valley Sequence rocks and, thus, the Tesla Formation pinches out rapidly northward from Corral Hollow Creek (Taffet, 1990).

Table 1-8. Characteristics of soil types in the vicinity of the Pit 6 operable unit.[a]

Characteristic	Carbona clay loam (GAC)	Zacharias gravelly clay loam (LRC)	Wisflat–Arburua–San Timoteo Complex (GAF/GAG)
Soil classification	Clay loam grading to clay, gravelly clay, or gravelly clay loam	Gravelly clay loam, sandy loam, or gravelly loam	Sandy loam, clay loam, loam, local gravels
Drainage type	Well drained	Well drained	Well drained
Permeability	Slow	Moderately slow	Moderate to moderately rapid
Water-holding capacity	High	Moderate	Low to very low
Runoff potential	Slow	Slow	Rapid
Erosion hazard	Slight	Slight	Severe to very severe
Shrink-swell potential	High	High	High

[a] USDA, 1990.

Table 1-9. Well completion and water elevation data for monitor wells in the vicinity of the Pit 6 operable unit.[a]

Completion zone	Well	Ground water elevation	Top bedrock elevation	Elevation range of completion	Completion length[b]	Near-vertical bedrock
Qt-Tmss Hydrologic Unit						
Qt	EP6-09S	NM[c]	664.6	672.6–665.6	7.0	NA[d]
	K6-15	666.0	664.0	676.5–666.0	10.5	NA
	K6-21	665.1[e]	668.1	677.1–667.7	9.4	NA
Qt/Tnbs$_1$	K6-01S	665.5	664.2	669.7–662.2	7.5	NA-yes
	K6-04	666.9	650.8	667.8–637.8	30.0	NA-no
	EP6-06	655.5	658.3	672.8–640.8	32.0	NA-yes
	BC6-12	666.9	673.2	677.7–592.7	85.0	NA-no
	BC6-13	661.9	661.7	664.7–659.7	5.0	NA-yes
	K6-16	661.8	660.9	665.7–658.2	7.5	NA-yes
	K6-17	659.4	650.4	666.4–643.4	23.0	NA-yes
	K6-18	661.6	657.8	666.3–653.3	13.0	NA-yes
	K6-19	665.4	657.4	673.6–649.1	24.5	NA-yes
Tnbs$_1$	K6-01	665.1	659.6	659.6–617.6	42.0	Yes
	K6-03	667.1	702.9	672.7–619.7	53.0	No
	EP6-07	667.0	666.2	607.2–579.2	28.0	No
	EP6-08	666.9	671.1	665.1–644.1	21.0	No
	EP6-09	665.5	664.0	661.0–622.0	39.0	Yes
	BC6-10	607.1	657.8	623.3–586.3	37.0	Yes
	BC6-11	667.0	674.1	668.6–591.6	77.0	No
	K6-14	662.3	662.6	660.6–642.6	18.0	Yes
	K6-22	662.8	663.2	656.0–639.0	17.0	Yes
	K6-24	666.9	669.5	650.9–644.1	6.8	No
	K6-26	665.9	669.5	467.0–439.5	27.5	No
	K6-27	665.9	667.9	537.9–513.9	24.0	No
	CARNRW1	665.2	643.7	628.7–178.7	450.0	No
	CARNRW2	>665.1[f]	663.5	613.2–363.2	250.0	No
Tmss	K6-23	658.3	670.1	664.1–653.8	10.3	Yes
	K6-25	661.9	663.5	582.5–553.5	29.0	Yes
	CARNRW3	677.9	—[g]	652.4–465.7	186.7	Yes
Qal-Tts Hydrologic Unit						
Qal/Tts	CARNRW4	638.9	—[g]	650.8–547.1	103.7	NA-yes
Tts	W-33C-01	635.9	640.2	633.2–625.9	7.3	NA-yes

Note: Footnotes to appear on the following page.

Table 1-9. (Continued)

---

[a] Elevations are in feet above mean sea level. Ground water elevations were measured during December 1991. All elevations are rounded to nearest 0.1 ft.

[b] Well completion length includes sandpack along the screen and sloughed material, if any, below casing that was not sealed with bentonite or grout.

[c] Not measured. Monitor well EP6-09S was sealed in May 1989.

[d] Not applicable. Qt unit deposits are not significantly tilted by faulting.

[e] Well K6-21 has a sump that extends down to an elevation of 665.07 ft.

[f] Water-supply well may be flowing artesian between pumping cycles.

[g] Unknown. Well completion logs are not available.

Table 1-10. Evaluation of vertical gradients in the vicinity of the Pit 6 operable unit.

Well pair	Lateral distance between wells (ft)	Depth of completion interval (ft)	Vertical separation of completion intervals (ft)	Difference in ground water elevation (ft), December 1991	Gradient	
					Direction	Magnitude (ft/ft)
EP6-07	19	99.0–128.0	37	0.07	Up	0.002
EP6-08		41.0–62.0				
K6-24	8	33.9–40.7	177.1	0.94	Down	0.005
K6-26		217.0–244.5				
K6-24	8	33.9–40.7	106.2	0.97	Down	0.009
K6-27		146.0–70.3				
K6-26	8	217.0–244.5	46.9	0.03	Up	0.001
K6-27		146.0–170.3				

Table 1-11. Summary of hydraulic tests in the Pit 6 operable unit.

								Hydraulic conductivity						Obs	Well Test	Obs		
Test well	Screened unit	Aquifer thickness [screen length] (ft)	Test type	Analytical method	Obs well	Screened unit	Transmissivity (gpd/ft)	(gpd/ft^2)	(cm/sec)	Storativity	Data quality	Date of test	Maximum pumping rate (gpm)	Distance from test well (ft)	Near-vertical strata	Near-vertical strata	Test duration (hr)	Reference
K6-01S	Qt/Tnbs$_1$	[4.75]	DD3&R	Theis (1935)	None	NR	380	70	3.3×10^{-3}	NC	F	5/09/88	2.0	NR	No	NR	2.0	Taffet (1990)
			DD3&R	Cooper and Jacob (1946)	None	NR	400	80	3.8×10^{-3}	NC	F		2.0	NR	No	NR	2.0	
EP6-06	Qt/Tnbs$_1$	11 [20.0]	DD	Jacob and Lohman (1952)	None	NR	0.35	0.032	1.5×10^{-6}	0.0063	F	12/04–08/86	4.6	NR	No/Yes	NR	1.7	Brown and Caldwell (1987)
			Slug	Ferris and Knowles (1963)	None	NR	0.1	0.01	4.7×10^{-7}	NR	F		NR	NR	No/Yes	NR	96.0	
EP6-07	Tnbs$_1$	28 [20]	DD	Jacob (Lohman, 1979)	K6-03	Tnbs$_1$	10,758	384	1.8×10^{-2}	0.001	G	10/17/84	20.0	188	No	No	4.0	CH2M HILL (1985)
			DD	Theis (1935)	K6-03	Tnbs$_1$	9,172	327	1.5×10^{-2}	0.003	F			188	No	No	4.0	
			DD	Jacob (Lohman, 1979)	EP6-07	Tnbs$_1$	1,549[a]	55	2.6×10^{-3}	0.060[a]	G			0	No	No	4.0	
			R	Theis (1935)	EP6-07	Tnbs$_1$	12,867	460	2.2×10^{-2}	NR	G			0	No	No	1.5	
			DD	Jacob (Lohman, 1979)	EP6-08	Tnbs$_1$	9,411	336	1.6×10^{-2}	0.040[a]	F			19	No	No	4.0	
			DD	Theis (1935)	EP6-08	Tnbs$_1$	5,207[a]	186	8.8×10^{-3}	0.060[a]	F			19	No	No	4.0	
EP6-08	Tnbs$_1$	80 [15]	Slug	Bouwer and Rice (1976)	NR	NR	7,779	97	4.6×10^{-3}	NC	G	10/29/84	NR	NR	No	NR	37.0	CH2M HILL (1985)
EP6-09	Tnbs$_1$	39 [30]	DD	Theis (1935)	K6-01	Tnbs$_1$	1,730	40	2.0×10^{-3}	0.0002	G	10/19/84	15.0	147	Yes	Yes	2.5	CH2M HILL (1985)
			DD	Theis (1935)	K6-01	Tnbs$_1$	1,713	41	2.0×10^{-3}	0.0003	G			147	Yes	Yes	2.5	
			R	Jacob (Lohman, 1979)	EP6-08	Tnbs$_1$	12,260	314	1.5×10^{-2}	NC	G			20	No	No	1.0	
			DD	NWLC	K6-04	Qt/Tnbs$_1$	NR	NR	NR	NR	NR			315	Yes	No	2.5	
			DD	Cooper and Jacob (1946)	K6-01	Tnbs$_1$	1,780	44	2.1×10^{-3}	0.0002	G			147	Yes	Yes	3.0	
			DD	NWLC	BC6-11	Tnbs$_1$	NC	NC	NC	NC	NR			300	Yes	No	3.0	
			R	Theis (1935)	EP6-09	Tnbs$_1$	1,414	37	1.7×10^{-3}	NC	G			0	Yes	NR	1.0	
BC6-10	Tnbs$_1$	[20.0]	Slug	Ferris and Knowles (1963)	None	NR	0.001	0.00001	4.7×10^{-10}	NR	G	12/17/86-3/16/87	NR	0	Yes	NR	2,136.0	Brown and Caldwell (1987)
BC6-12	Qt/Tnbs$_1$	[80.0]	DD	Theis (1935)	BC6-11	Tnbs$_1$	18,700	275	1.3×10^{-2}	0.0020	G	2/09-11/87	74.1	20	No	No	44.0	Brown and Caldwell (1987)
			DD	Theis (1935)	EP6-07	Tnbs$_1$	14,300	157	7.0×10^{-3}	0.0011	G			77	No	No	44.0	
			DD	Distance-Drawdown	BC6-11	Tnbs$_1$	18,800	207	1.0×10^{-2}	0.0019	G			77	No	No	44.0	
					EP6-07	Tnbs$_1$					G			15	No	No	44.0	
					EP6-08	Tnbs$_1$					G			100	No	No	44.0	
			DD	Cooper and Jacob (1946)	BC6-12	Qt/Tnbs$_1$	9,200	120	5.8×10^{-3}	NR	G	3/27/90	33.7	NR	No	NR	3.0	Taffet (1990)
			DD	Cooper and Jacob (1946)	BC6-11	Tnbs$_1$	8,700	116	5.4×10^{-3}	NC	F			20	No	No	3.0	
				Hantush and Jacob (1955)	BC6-12	Qt/Tnbs$_1$	2,900	39	1.8×10^{-3}	NR	G			0	No	NR	3.0	

Table 1-11. (Continued)

Test well	Screened unit	Aquifer thickness [screen length] (ft)	Test type	Analytical method	Obs well	Screened unit	Transmissivity (gpd/ft)	Hydraulic conductivity (gpd/ft^2)	(cm/sec)	Storativity	Data quality	Date of test	Maximum pumping rate (gpm)	Obs Distance from test well (ft)	Well Test Near-vertical strata	Obs Near-vertical strata	Test duration (hr)	Reference
			DD	NWLC	EP6-06	Qt/Tnbs$_1$	NC	NC	NC	NC	G			145	No	No/Yes	3.0	
			DD	NWLC	BC6-10	Tnbs$_1$	NC	NC	NC	NC	G			145	No	Yes	3.0	
			DD	NWLC	K6-14	Tnbs$_1$	NC	NC	NC	NC	G			265	No	Yes	3.0	
			DD	NWLC	K6-16	Qt/Tnbs$_1$	NC	NC	NC	NC	G			265	No	No/Yes	3.0	
			DD	NWLC	K6-18	Qt/Tnbs$_1$	NC	NC	NC	NC	G			220	No	No/Yes	3.0	
			DD	NWLC	K6-19	Qt/Tnbs$_1$	NC	NC	NC	NC	G			165	No	No/Yes	3.0	
			HP	GZA (1990)	None	Qt/Tnbs$_1$	NR	NR	NR	NC	G	4/25/90	1.5	0	No	NR	3.4	GZA (1990)
K6-16	Qt/Tnbs$_1$	[5]	Slug	Papadopulos (1973)	NR	NR	210	43	2.0×10^{-3}	NR	G	2/16/90	NR	0	No/Yes	NR	1.0	Taffet (1990)
			Bail	Papadopulos (1973)	NR	NR	240	48	2.2×10^{-3}	NR	G		NR	0	No/Yes	NR	1.0	
K6-17	Qt/Tnbs$_1$	15	Slug	Papadopulos (1973)	NR	NR	4.7	0.3	1.4×10^{-5}	NR	P	2/9/90	NR	0	Yes	NR	1.7	Taffet (1990)
		[20]	Bail	Papadopulos (1973)	NR	NR	15.0	1.0	4.7×10^{-5}	NR	F			0	Yes	NR	1.7	
			DD&R	Cooper and Jacob (1946)	NR	NR	6.7	0.3	1.4×10^{-5}	NR	G	5/13/88	5.0	0	Yes	NR	1.0	Ferry (1988)
K6-18	Qt/Tnbs$_1$	1	Slug	Papadopulos (1973)	NR	NR	130	130	6.1×10^{-3}	NR	G	2/09/90-2/12/90	NR	0	No	NR	70.3	
		[5]	Bail	Papadopulos (1973)	NR	NR	95	95	4.5×10^{-3}	NR	P		NR	0	No	NR	48.1	Taffet (1990)
			DD&R	Theis (1935)	NR	NR	5	5	2.4×10^{-4}	NR	F	5/12/88	0.1	0	No	NR	16.5	Ferry (1988)
			DD&R	Cooper and Jacob (1946)	NR	NR	6	6	2.8×10^{-4}	NR	G		0.1	0	No	NR	16.5	
K6-19	Qt/Tnbs$_1$	[14.5]	DD&R	No unique curve	NR	NR	NC	NC	NC	NC	NR	5/11/88	1.3	0	No/Yes	No	2.0	Ferry (1988)
K6-22	Tnbs$_1$	[10.2]	Bail	Papadopulos (1973)	NR	NR	12	1.2	5.7×10^{-5}	NR	G	2/14/90-2/22/90	NR	0	Yes	NR	45.5	Taffet (1990)
K6-24	Tnbs$_1$	8.2	DD	Cooper and Jacob (1946)	NR	NR	9.6	1.2	5.5×10^{-5}	NR	F/G	2/23/90-2/27/90	1.0	0	No	NR	0.4	Landgraf (1990)
		[4.8]	R	Cooper and Jacob (1946)	NR	NR	7.9	1.0	4.5×10^{-5}	NR	G		NR	0	No	NR	96.2	
K6-25	Tmss	[20.0]	DD	Qualitative	NR	NR	s > 100 ft	NC	NC	NC	NR	4/5/90	1.0	0	Yes	NR	2.8	Ferry (1990)
					K6-14	Tnbs$_1$	NWLC	NC	NC	NC	NR			70	Yes	Yes	2.8	
					K6-16	Qt/Tnbs$_1$	s = 0.015 ft	NC	NC	NC	NR			10	Yes	No/Yes	2.8	
					K6-18	Qt/Tnbs$_1$	NWLC	NC	NC	NC	NR			70	Yes	No	2.8	
					K6-19	Qt/Tnbs$_1$	NWLC	NC	NC	NC	NR			225	Yes	No/Yes	2.8	
					K6-22	Tnbs$_1$	s = 0.05 ft	NC	NC	NC	NR			275	Yes	Yes	2.8	
K6-26	Tnbs$_1$	[20.0]	HP	GZA (1990)	None	Tnbs$_1$	NR	NR	NR	NC	G	4/23/90	4.5	0	No	NR	8.9	GZA (1990)
CARNR W1	Tnbs$_1$	[440.0]	DD	Qualitative	CARNRW3	Tmss	NC	NC	NC	NC	NR	01/03/92–1/6/92	34.0	390	No	Yes	648.0	Copland (1992)
CARNR W2	Tnbs$_1$	[150.0]	DD	Qualitative	CARNRW3	Tmss	NC	NC	NC	NC	NR	12/10/91–1/6/92	35.0	240	No	Yes	648.0	Copland (1992)

a = Value not representative (CH2M HILL, 1985).
DD = Drawdown test using a pumping well.
DD3 = Three step drawdown test.
F = Fair data distribution.
G = Good data distribution.
HP = Hydrophysical technique of GZA (1990).
NC = Not calculated.
NR = Not relevant.
NWLC = No water level change.
P = Poor data distribution.
Obs = Observation well.
R = Recovery test.
s = Drawdown.

Table 1-12. Estimated well yields for monitor wells completed exclusively in the $Tnbs_1$ unit.[a]

Well	Estimated yield (gpm)	Completion length (ft)[b]	Completion depth (ft)[c]
EP6-07	>100.0	29.0	99.0–128.0
EP6-09	>6.8	39.0	32.0–71.0
BC6-11	70.0	77.0	23.0–90.0
K6-22	0.5	17.0	23.4–40.5
K6-24	<1.0	6.8	33.9–40.7
K6-26	180.0	27.5	217.0–244.5
K6-27	80.0	24.0	146.0–170.3
CARNRW1	>34.0	453.0	50.0–503.0
CARNRW2	>35.0	250.0	50.0–300.0

[a] Brown and Caldwell, 1987; Lamarre, 1990a; Lamarre, 1990b; and Wade, 1992.

[b] Well completion length includes sandpack along the screen and sloughed material, if any, below casing that was not sealed with bentonite or grout.

[c] Completion depth measured from ground surface.

Table 1-13. Summary of hydraulic conductivities for wells completed in near-vertical bedrock in the vicinity of the Pit 6 operable unit.

Well	Completion zone	Average hydraulic conductivity, K (cm/sec)
K6-01S	$Qt/Tnbs_1$	3.6×10^{-3}
EP6-06	$Qt/Tnbs_1$	9.9×10^{-7}
K6-16	$Qt/Tnbs_1$	2.1×10^{-3}
K6-17	$Qt/Tnbs_1$	2.5×10^{-5}
K6-18	$Qt/Tnbs_1$	2.8×10^{-3}
K6-19	$Qt/Tnbs_1$	not calculated[a]
BC6-10	$Tnbs_1$	4.7×10^{-10}
K6-22	$Tnbs_1$	5.7×10^{-5}
K6-25	Tmss	not calculated
Average K (all wells)	near-vertical bedrock	1.2×10^{-3}[b]

[a] Poor test data quality (Ferry, 1992).

[b] Approximately 25 gpd/ft^2.

Table 1-14. Summary of hydraulic conductivities for wells completed in shallow-dipping bedrock in the vicinity of the Pit 6 operable unit.

Well	Completion zone	Average hydraulic conductivity, K (cm/sec)
BC6-12	Qt/Tnbs$_1$	7.2×10^{-3}
EP6-07	Tnbs$_1$	1.8×10^{-2}[a]
EP6-08	Tnbs$_1$	4.6×10^{-3}
K6-24	Tnbs$_1$	5.0×10^{-5}
Average K (all wells)	Shallow-dipping bedrock	7.5×10^{-3}[b]

[a] Where not considered representative by CH2M HILL (1985), some values are not used in calculating the average hydraulic conductivity for well EP6-07.

[b] Approximately 159 gpd/ft^2.

Table 1-15. Hydraulic conductivities of the pit 6 soil cover.[a]

Location	Hydraulic conductivity, K (cm/s)	Hydraulic conductivity, K (in./hr)
1	1.1×10^{-4}	0.156
2	9.6×10^{-5}	0.136
3	8.0×10^{-5}	0.113
4	7.0×10^{-4}	0.993
K average	2.5×10^{-4}	0.350

[a] Taffet, 1990.

Table 1-16. Estimated vertical distances separating buried debris from ground water at pit 6.

Disposal location	Ground surface elevation (ft above MSL)	Estimated depth from ground surface to base of waste[a] (ft)	Estimated elevation at base of waste (ft above MSL)	Ground water elevation[b] (ft above MSL)	Vertical distance from waste to ground water (ft)
Trench 1	700	12	688	666	22
Trench 2	705	12	693	667	26
Trench 3	695	12	683	666	17
Animal pits 1–6	710	16	694	667	27

[a] Sutton, 1992.

[b] Ground water elevation data collected December 1991.

Table 1-17. Inferred recharge and discharge mechanisms of the Qal, Qt, $Tnbs_1$, Tmss, and Tts stratigraphic units in the vicinity of the Pit 6 operable unit.

Stratigraphic unit	Recharge	Discharge
Qt-Tmss hydrologic unit		
Qt	Direct infiltration of precipitation on terrace surface	Discharge at springs 7, 8, and 15 along terrace face
	Surface water overland flow from hill slopes north of pit 6	Aquifer throughflow into underlying bedrock ($Tnbs_1$ unit and Tmss)
		Evapotranspiration at ground surface
$Tnbs_1$	Infiltration on hill slopes and gullies north of pit 6	Downgradient aquifer throughflow
	Downward migration from Qt unit	Possible discharge at springs 7, 8, and 15 along terrace face
		Evapotranspiration at ground surface
Tmss	Direct infiltration of precipitation along terrace face	Downgradient aquifer throughflow
	Aquifer throughflow from $Tnbs_1$ unit	Evapotranspiration at ground surface
Qal-Tts hydrologic unit		
Qal	Direct infiltration of precipitation along ravines and Corral Hollow Creek	Evapotranspiration at ground surface along ravines and Corral Hollow Creek
	Possible upward infiltration from Tts	Aquifer throughflow eastward to the GSA
Tts	Direct infiltration of precipitation along terrace face	Downgradient aquifer throughflow
	Possible infiltration from Qal	Evapotranspiration at ground surface

Table 1-18. Natural ground water geochemical characteristics of the hydrologic units in the vicinity of the Pit 6 operable unit.

Area	Hydrologic or geologic unit	Sampling location	pH	TDS (mg/L)	Specific conductivity (µmhos/cm)	Arsenic (mg/L)	Selenium (mg/L)
Pit 6 operable unit							
	Qt-Tmss	Monitor wells (Total of 27)	7.4–8.6	600–4,500	920–3,850	0.003–0.023	<0.002–0.003
	Qt-Tmss	Springs 7, 8, 15	7.4–8.0	890–1,800	1,260–2,470	0.015–0.036	<0.005–0.002
	Qt-Tmss	Wells CARNRW1 and CARNRW2	8.2	676–780	1,040–1,200	<0.001–0.002	<0.001
	Tts	Well W-33C-01	8.0	1,400	1,920	—	—
Outside the Pit 6 operable unit							
Paper Canyon	Tnsc$_1$	Wells W-34-01 and W-34-02	8.2–8.6	460–660	810–1,150	—	—
Scattered across study area	Qt or Tnbs$_1$	Springs 9, 10, 11, 12, 16	8.0–8.1	580–1,200	800–1,770	0.004 –0.059	<0.002–0.014
Corral Hollow Creek floodplain	Tts, possibly Qal	Well STONEHAM1	7.0	1,900	2,280	<0.002	<0.002

Note: Values are most recent for each location. No analyses are available for floodplain alluvium (Qal) or spring 18.

— No data available.

Table 1-19. Historical summary of water-supply wells in the vicinity of the Pit 6 operable unit.

Well	Well history	Reference
CARNRW1	The well CARNRW1 is also known as the Cave well and was formerly known as Carnegie Cycle Park #1 (CCP1). It was named for the abandoned mine working (adit) that intercepts the well casing. The well is located at the former location of the Carnegie town site well (circa 1900) in the Carnegie SVRA residence area and is used for filling the residence pond. It is pumped occasionally at 34 gpm to provide fire-fighting water. The well was installed in February 1972 to a depth of 503 ft with 6.25-in. PVC casing and is screened from 63 to 503 ft. The gravel pack extends from 50 to 503 ft. It was completed in the $Tnbs_1$ aquifer and also, perhaps, in the Cierbo Formation. The static depth to water in December 1991 was 13.5 ft.	Dietrich, 1928; Caldera, 1991; Carter, 1991; drillers' logs
CARNRW2	The well CARNRW2 is also known as the Ranger well and was formerly known as CCP2. It is located in the Carnegie SVRA residence area and is used for watering motorcycle riding tracks, irrigating trees, washing vehicles, and filling the residence pond. The water is chlorinated but is used rarely as drinking water because of its sulfurous odor and bad taste. It was installed in May 1983 to a depth of 300 ft with 6.0-in. PVC casing; it is screened from 150 to 300 ft, and the gravel pack extends from 50 to 300 ft. It was completed in the $Tnbs_1$ aquifer. Immediately after drilling, the well was flowing artesian at 30 gpm. The well may still be artesian between daily pumping cycles. The well is pumped automatically at about 35 gpm.	Caldera, 1991; Carter, 1991; drillers' logs
CARNRW3	The well CARNRW3 is located in the Carnegie SVRA residence area and has not been used as a drinking-water source since the pump was pulled in 1982. Park rangers do not plan to use the well again because the water is of very poor natural quality. No drilling log exists. The well might have been installed in 1975. A video log, taken in 1991, showed that the 6.0-in. steel casing is screened from at least 76 ft to the total depth of 236.7 ft. The gravel pack may extend from 50 ft downward. The well was probably completed in the highly fractured Cierbo Formation. The static depth to water in December 1991 was 25.1 ft. The well had been left open until 1991, when LLNL installed a submersible sampling pump.	Caldera, 1991; Carter, 1991; Fuller, 1991; video log, geophysical logs
CARNRW4	The well CARNRW4 is located in the Carnegie SVRA riding area but has probably never been used because of its low production and recharge. No drilling log exists. The well may have been installed about 1965. A video log was taken by LLNL in 1991. The 8.0-in.-steel-surface casing extends to a depth of 21 ft. At 11 ft, the uppermost section of casing is offset from the lower section by about 1 in. The well is completed as an open hole in the Tesla Formation to a depth of 103.7 ft. It probably does not have an annular seal through the floodplain alluvium. The static depth to water in December 1991 was 12.8 ft. At that time, trash was visible floating on the water. The well had been left partially open until 1991, when LLNL installed a locking cover.	Caldera, 1991; Carter, 1991; Fuller, 1991; video log

Table 1-19. (Continued)

Well	Well history	Reference
CARNRW5	The well CARNRW5 is located in the Carnegie SVRA riding area, but has probably never been used because of its black (coal-rich) water. No drilling log exists. The well may have been installed about 1965. A video log was taken by LLNL in 1991, but visibility was poor in the black water. The 10.0-in. steel surface casing may extend to the total depth of 31 ft. It probably does not have an annular seal and may be completed in both alluvium and the Tesla Formation. The static depth to water in December 1991 was 15.1 ft. The well had been left open until 1991, when LLNL installed a locking cover.	Caldera, 1991; Carter, 1991; video log
CARNRW6	The well CARNRW6 is located in the Carnegie SVRA riding area; however, it has never been used because it collapsed after it was dynamited in a vain attempt to improve water production. The well is now blocked off at a depth of about 8 ft. It was installed in the mid-1960s by lowering about 150 ft of 12-in. corrugated steel pipe into what may be the abandoned (circa 1850s) "People's Mine" shaft.	Caldera, 1991; Carter, 1991
STONEHAM1	The well STONEHAM1 is located west of Site 300 on the Corral Hollow Creek floodplain. The well is used for domestic consumption at the Stoneham residence. Also, the well is sampled annually by LLNL as the background upgradient well for Site 300. It was installed to a depth of 157 ft with a 14-in. steel casing. A 2-hp submersible pump is set at 100 ft. When purged at 10 gpm, the well had 2.3 ft of drawdown after the first 5 min of pumping. The screened interval is not known. The well was probably completed in a fractured interval of the Tesla Formation and possibly in the alluvium. The static depth to water in September 1991 was 15.8 ft.	EMAD files
W-HS1	The well W-HS1 is located on Site 300 next to spring 9 and a ravine with scattered historic structures. The well was probably last used around 1900. Its present depth is 19.6 ft. The 8 in. steel casing is in poor condition. The static depth to water in October 1991 was 15.1 ft. The well may have produced water from the $Tnbs_1$ unit.	No written records
W-MS1, W-MS2, W-MS3, and W-MS4	This series of four wells is located in tall grass near spring 12. The wells are located approximately 250 ft east of an abandoned mine shaft (adit), hence the prefix W-MS. The wells were probably last used around the turn of the century for either dewatering and/or ventilating a mine working. Most likely, each well originally consisted of surface casing with a suspended central pipe that extended upward from the adit to several feet above the ground surface.	No written records

Table 1-19. (Continued)

Well	Well history	Reference
W-MS1	The only visible feature of W-MS1 is a 3.8-in. pipe that extends about 4 ft above the ground surface. The last measured depth to water was 29.7 ft in December 1982; the well is now blocked at about 2 ft.	
W-MS2	The well W-MS2 consists of 11-in. steel-surface casing and a 10-ft length of 3.8-in. pipe that now lies next to the well. The total depth of the well was measured at 29 ft, and the depth to water in February 1992 was 24.5 ft.	
W-MS3	The well W-MS3 consists of 11-in. steel-surface casing and a 3.8-in. pipe that is suspended from the casing. The pipe extends about 2 ft aboveground. The total depth of the well was measured at 31 ft, and the depth to water in February 1992 was 29.2 ft.	
W-MS4	The well W-MS4 consists of 13.5-in. steel-surface casing; the well has collapsed at a depth of 5.4 ft.	

Table 1-20. Summary of source information in the Pit 6 operable unit.

Investigations performed	• Records search and review of engineering drawings, waste material logbook, various memos, and several LLNL ERD reports. • Interviews with former and/or present employees. • Aerial and ground-level photographs. • Building inspections and field observations. • Soil and bedrock analyses of cores collected from boreholes and SVS locations. • AVI SVS. • Ground water analyses for 27 monitor wells and 3 active water-supply wells. • Surface water analyses for an off-site pond and springs 7, 8, and 15. • Soil analyses from two surface locations.
Historical operations summary	Solid waste was buried in the pit 6 landfill during 1964 to 1973. The waste was buried at nine locations and covered with native soil. Approximately 55,281 ft^3 of solid waste still remains buried in pit 6. Trenches 1, 2, and 3 contain approximately 47,571 ft^3 of metal, wood, and plastic debris (Appendix A). Empty drums and tanks were also buried. Animal pits 1–6 contain 7,710 ft^3 of animal carcasses and animal wastes. LLNL uses Buildings 899A and 899B to support firearms training operations. The SFTF consists of three firing ranges and the two buildings. A rifle range is located on the ground surface of pit 6. Gun cleaning solvents are used in Building 899A. No septic system is located at the SFTF; portable latrines are used. A hand washing basin is located outside of Building 899A and probably discharges on the terrace face to the south. The Carnegie SVRA is located south and east of pit 6. Numerous motorcycle trails and hill climbs cross the riding area, which is located south of Corral Hollow Road. Covering approximately 1,500 acres, the Carnegie SVRA is used by recreational off-road motorcyclists (Warr, 1988). The Carnegie SVRA is open to the public 365 days a year and is operated by the State of California Department of Parks and Recreation. Approximately 3 acres of the Carnegie SVRA is located north of the road and about 1,500 ft east of pit 6. This small parcel is known as the Carnegie SVRA residence area and contains four mobile home trailers, two active water-supply wells, and a 0.2-acre residence pond.
Summary of results	A 1989 AVI SVS identified a TCE soil vapor plume of approximately 176,000 ft^2 (4 acres) that extended southeastward from pit 6. Soil vapor samples were collected at 39 locations. Detectable concentrations of VOCs were restricted to depths ranging from 6.0 to 12.5 ft. Soil vapor samples contained a maximum TCE concentration of 160.0 $ppm_{v/v}$. PCE; 1,1,1-TCA; 1,1-DCE; and 1,2-DCA were detected at concentrations of 3.4, 0.61, 8.93, and 38.0 $ppm_{v/v}$, respectively.

Table 1-20. (Continued)

Summary of results (continued)	Soil and rock core samples were collected from 15 boreholes and seven SVS locations. A soil core collected near the eastern end of trench 3 yielded the highest TCE concentration at 0.450 mg/kg (ppm). TCE was not detected at depths greater than 9 ft. Borehole core samples from outside the pit 6 perimeter yielded a maximum TCE concentration of 0.022 mg/kg (ppm); TCE was not detected at depths greater than 16.2 ft. PCBs were not detected in borehole K6-30. Core samples from borehole K6-17 were analyzed for the 17 STLC metals; the core from 30 ft yielded a copper concentration of 47 mg/kg (ppm), which is slightly above the STLC limit of 25 mg/kg (ppm). Surface water samples collected from spring 7 (well BC6-13) contained a maximum TCE concentration of 110.0 µg/L (ppb) in 1988. In November 1991, TCE was detected at 3.4 µg/L (ppb). The one surface water sample collected from spring 15 yielded a TCE concentration of 1.2 µg/L (ppb) in 1991. TCE was not detected in surface water samples collected from spring 8 or the Carnegie SVRA residence pond. A ground water TCE plume extends southeastward from pit 6. Since 1984, ground water samples collected from monitor wells have contained a maximum TCE concentration of 250.0 µg/L (ppb). Other VOCs, including PCE; 1,1,1-TCA; 1,2-DCE; and 1,2-DCA have been detected at lesser concentrations. TCE and other VOCs have not been detected in the two water-supply wells used by the Carnegie SVRA. During the fourth quarter of 1991, six monitor wells had detectable concentrations of TCE; the maximum concentration was 42.0 µg/L (ppb). Ground water with detectable concentrations of TCE (>0.5 µg/L, [ppb]) covers a plume area approximately 48,000 ft^2 (1.1 acres). Ground water containing TCE in excess of the federal MCL for 5.0 µg/L (ppb) covers approximately 31,000 ft^2 (0.7 acres). Ground water in the Pit 6 operable unit does not contain detectable concentrations of HE compounds, PCBs, phenols, or pesticides. Ground water does not appear to be contaminated with uranium isotopes, tritium, metals, or aromatic hydrocarbons such as BTEX. Two surface soil samples (3SS-49-01 and 3SS-49-02) were collected from the Pit 6 operable unit. Location 3SS-49-01 is next to spring 7 and downgradient of pit 6. Location 3SS-49-02 is southwest of pit 6. No BTEX, VOCs, HE, or PCB compounds were detected for either location. Maximum gross alpha and gross beta activities were 7 and 19 pCi/g, respectively. The maximum tritium in soil moisture was 16 pCi/L. The maximum activities for isotopes ^{234}U, ^{235}U, and ^{238}U were 0.8, <0.1, and 0.9 pCi/g, respectively.

Table 1-20. (Continued)

Conclusions	Releases of TCE and other VOCs have been confirmed in the vicinity of pit 6. TCE is the principal released chemical. The source of the TCE and other VOCs is probably the buried debris in trench 3. A plume of TCE in soil vapor extends southeastward from pit 6. A plume of TCE-contaminated ground water also extends southeastward from pit 6 and is confined to Site 300 property and the north side of Corral Hollow Road. The distribution of TCE in ground water is restricted to the uppermost 70 ft section (Qt and $Tnbs_1$) of the Qt-Tmss hydrologic unit. The fate and transport of TCE in ground water has been modeled to the Carnegie SVRA Ranger well (CARNRW2). The Carnegie SVRA uses water from two water-supply wells in their residence area. LLNL does not use ground water in the study area. A Carnegie SVRA motorcycle repair shop and two fuel pumps were once located south of pit 6 and Corral Hollow Road. The initial ground water sample from well W-33C-01 yielded low concentrations of VOCs and BTEX ranging from 1.8 to 8.2 µg/L (ppb). Subsequent samples did not contain any detectable concentrations of these compounds. The spurious detection may reflect a sampling or analytical laboratory error.

Table 1-21. Maximum VOC concentrations ($ppm_{v/v}$) in soil vapor in the Pit 6 operable unit (Vonder Haar et al., 1989; Lamarre et al., 1989; Taffet, 1990).

VOC	No. of locations with VOCs detected	Maximum concentration ($ppm_{v/v}$)
TCE	28	160.0
PCE	16	3.4
1,1,1-TCA	10	0.61
1,1-DCE	4	8.93
1,2-DCA	2	38.0

Table 1-22. Maximum concentrations of aromatic hydrocarbons in soil and bedrock core samples collected in the Pit 6 operable unit.

VOC	No. of boreholes or SVS locations with VOCs detected	Maximum concentration mg/kg (ppm)
Benzene	1	0.0100
Toluene	9	0.0300
Total xylenes	4	0.0057

Table 1-23. Maximum VOC concentrations in µg/L (ppb) in water samples from spring 7 (well BC6-13).

VOC	No. of samples with VOCs detections	Maximum concentration in µg/L (ppb)
TCE	19	110.0
PCE	5	1.4
Cis-1,2 DCE	9	12.0
Trans-1,2 DCE	10	33.0
Total 1,2 DCE	18	45.0
1,2 DCA	2	3.5
Chloroform	1	5.1
Methylene chloride	1	8.9
Toluene	1	0.9
Total xylenes	1	1.6

Table 1-24. Maximum concentrations of VOCs detected in ground water for the Pit 6 Area study area between October 1984 and December 1991.[a]

VOC	Maximum concentration in µg/L (ppb) and corresponding well	Month and year of maximum concentration	Fourth quarter 1991 maximum concentration in µg/L (ppb) and corresponding well
TCE	250.0 (K6-19)	November 1988	42.0 (K6-19)
PCE	2.6 (K6-18)	November 1988	1.1 (K6-19)
1,1,1-TCA	13.0 (K6-18)	May 1990	0.9 (K6-26)
Cis-1,2-DCE	10.0 (BC6-13)	July and October 1990	6.8 (BC6-13)
Trans-1,2-DCE	33.0 (BC6-13)	May 1990 and July 1991	21.0 (BC6-13)
1,2-DCA	3.5 (BC6-13)	November 1987	<0.5 (NA)
Freon 113	4.7 (EP6-07)	May 1987	<0.5 (NA)
Methylene chloride	8.9 (BC6-13)	November 1987	<0.5 (NA)
Chloroform	5.1 (BC6-13)	November 1987	0.6 (K6-19)

[a] Webster-Scholten, 1994.

Table 1-25. Maximum concentrations in µg/L (ppb) of aromatic hydrocarbons in ground water samples collected in the Pit 6 Area study area between October 1984 and December 1991.[a]

Aromatic hydrocarbon	No. of wells with VOCs detected	Maximum concentration in µg/L (ppb)
Benzene	2	0.6
Toluene	17	17.0
Ethylbenzene	6	7.3
Total xylenes	18	15.0
1,3-Dichlorobenzene	2	1.2

[a] Webster-Scholten, 1994.

Table 1-26. Summary of estimated exposure-point concentrations in the Pit 6 operable unit.

Media/process release area(s)	Model and/or method	Potential exposure point(s)	Chemicals of concern	Maximum concentration at release area(s)	95% UCL	Estimated exposure point concentrations
Fugitive (airborne) dust; contaminants bound to resuspended soil particles						
Data evaluated are from surface soil samples collected throughout the study area.	Mass-loading (Anspaugh et al., 1975).	Throughout the study area.	HMX	0.014 mg/kg[a]	0.0074 mg/kg[a]	1.7×10^{-10} mg/m^{3}[b]
			RDX	0.044 mg/kg[a]	0.00224 mg/kg[a]	5.14×10^{-10} mg/m^{3}[b]
			Trichlorofluoromethane	0.009 mg/kg[a]	0.00592 mg/kg[a]	1.36×10^{-10} mg/m^{3}[b]
Direct contact with contaminants in surface soil						
Surface soil.	Measured concentration of contaminants in surface soil.	Throughout study area. (Exposure routes: incidental ingestion and direct dermal contact.)	HMX	0.014 mg/kg[a]	0.0074 mg/kg[a]	7.40×10^{-3} mg/m^{3}[b]
				0.044 mg/kg[a]	0.0224 mg/kg[a]	2.24×10^{-2} mg/m^{3}[b]
				0.009 mg/kg[a]	0.00592 mg/kg[a]	5.92×10^{-3} mg/m^{3}[b]
Volatilization of contaminants from subsurface soil to the atmosphere						
Potential releases in the vicinity of the SFTF rifle range.	Volatilization of contaminants from subsurface soil to the atmosphere (Hwang et al., 1986); air dispersion (Turner, 1982).	In the vicinity of the SFTF rifle range.	1,1,1-TCA	0.0005 mg/kg[c]	0.000171 mg/kg[c]	4.25×10^{-6} mg/m^{3}[b]
			1-2-DCE (total)	0.003 mg/kg[c]	0.000736 mg/kg[c]	7.58×10^{-6} mg/m^{3}[b]
			Chloroform	0.028 mg/kg[c]	0.0111 mg/kg[c]	1.99×10^{-4} mg/m^{3}[b]
			Methylene chloride	0.001 mg/kg[c]	0.001 mg/kg[c]	1.62×10^{-5} mg/m^{3}[b]
			PCE	0.072 mg/kg[c]	0.0533 mg/kg[c]	6.56×10^{-4} mg/m^{3}[b]
			TCE	0.45 mg/kg[c]	0.152 mg/kg[c]	1.96×10^{-3} mg/m^{3}[b]
			Trichorofluoromethane	0.0017 mg/kg[c]	0.000663 mg/kg[c]	5.27×10^{-5} mg/m^{3}[b]
			Trichlorotrifluoroethane	0.0087 mg/kg[c]	0.0031 mg/kg[c]	4.58×10^{-4} mg/m^{3}[b]
Potential releases in the vicinity of spring 7.	Volatilization of contaminants from subsurface soil to the atmosphere (Hwang et al., 1986); air dispersion (Turner, 1982).	In the vicinity of spring 7.	Ethylbenzene	0.0008 mg/kg[c]	0.000687 mg/kg[c]	4.61×10^{-6} mg/m^{3}[b]
			PCE	0.0009 mg/kg[c]	0.000816 mg/kg[c]	1.01×10^{-5} mg/m^{3}[b]
			Toluene	0.007 mg/kg[c]	0.00649 mg/kg[c]	6.19×10^{-5} mg/m^{3}[b]
			TCE	0.019 mg/kg[c]	0.019 mg/kg[c]	2.44×10^{-4} mg/m^{3}[b]
			Xylenes (total isomers)	0.0057 mg/kg[c]	0.00489 mg/kg[c]	3.16×10^{-5} mg/m^{3}[b]
Volatilization of contaminants from surface water to the atmosphere						
Potential releases in the vicinity of spring 7.	Volatilization of contaminants from subsurface soil to the atmosphere (Mackay and Leinonen, 1975; Liss and Slater, 1974); air dispersion (Turner, 1982).	In the vicinity of the surface of spring 7.	1,2-DCA	3.5 µg/L[d]	0.914 µg/L[d]	5.20×10^{-4} mg/m^{3}[b]
			cis-1,2-DCE	12 µg/L[d]	10.5 µg/L[d]	6.76×10^{-3} mg/m^{3}[b]
			trans-1,2-DCE	33 µg/L[d]	31.8 µg/L[d]	2.1×10^{-2} mg/m^{3}[b]
			Chloroform	5.1 µg/L[d]	0.985 µg/L[d]	5.68×10^{-4} mg/m^{3}[b]
			PCE	1.4 µg/L[d]	0.638 µg/L[d]	3.25×10^{-4} mg/m^{3}[b]
			TCE	110 µg/L[d]	74.6 µg/L[d]	4.24×10^{-2} mg/m^{3}[b]
			Xylenes (total isomers)	1.6 µg/L[d]	0.812 µg/L[d]	5.09×10^{-4} mg/m^{3}[b]

Table 1-26. (Continued)

Media/process release area(s)	Model and/or method	Potential exposure point(s)	Chemicals of concern	Maximum concentration at release area(s)	95% UCL	Estimated exposure point concentrations
Potential releases in the vicinity of Carnegie SVRA residence pond.	Mathematical ground water model (Wilson and Miller, 1978); volatilization of contaminants from subsurface water to the atmosphere (Mackay and Leinonen, 1975; Liss and Slater, 1974); and air dispersion (Turner, 1982).	In the vicinity of the surface of the Carnegie SVRA residence pond.	1,2-DCA	1.7 μg/L[e]	0.303 μg/L[e]	8.35×10^{-6} mg/m^3[b]
			Total 1,2-DCE	7.2 μg/L[e]	3.43 μg/L[e]	1.07×10^{-4} mg/m^3[b]
			1,1,1-TCA	13 μg/L[e]	0.689 μg/L[e]	1.89×10^{-5} mg/m^3[b]
			Acetone	11 μg/L[e]	1.91 μg/L[e]	1.36×10^{-5} mg/m^3[b]
			Bis(2-ethylhexyl)phthalate	70 μg/L[e]	18.9 μg/L[e]	2.36×10^{-5} mg/m^3[b]
			Butylbenzylphthalate	78 μg/L[e]	13.1 μg/L[e]	2.24×10^{-5} mg/m^3[b]
			Carbon disulfide	3.0 μg/L[e]	0.229 μg/L[e]	7.48×10^{-6} mg/m^3[b]
			Chloroform	4.7 μg/L[e]	0.235 μg/L[e]	6.61×10^{-6} mg/m^3[b]
			Ethylbenzene	7.3 μg/L[e]	0.165 μg/L[e]	5.02×10^{-6} mg/m^3[b]
			Methylene chloride	5.2 μg/L[e]	0.503 μg/L[e]	1.58×10^{-5} mg/m^3[b]
			Phenolics	0.09 μg/L[e]	0.0216 μg/L[e]	1.71×10^{-6} mg/m^3[b]
			PCE	3.2 μg/L[e]	0.728 μg/L[e]	1.8×10^{-5} mg/m^3[b]
			Toluene	4.8 μg/L[e]	0.792 μg/L[e]	2.58×10^{-5} mg/m^3[b]
			TCE	250 μg/L[e]	70.7 μg/L[e]	1.94×10^{-3} mg/m^3[b]
			Xylenes (total isomers)	2.3 μg/L[e]	0.783 μg/L[e]	2.38×10^{-5} mg/m^3[b]
Soil/rock and ground water						
Pit 6 considered as a single release.	Mathematical ground water model (Wilson and Miller, 1978).	Ground water from the Qt-Tmss hydrologic unit; model is used to simulate the transport of TCE from pit 6 to well CARNRW2.	Primarily TCE[i]	250 μg/L TCE[f]	250 μg/L[g]	1.0 μg/L TCE[h]
Ecological exposure						
Available data throughout the study area considered Chapter 12.	*Chapter 12*	Surface soil, subsurface soil, surface water, ambient outdoor air, and subsurface air throughout the study area.	Primarily TCE[j]	*Chapter 12*	*Chapter 12*	*Chapter 12*

[a] Surface soil.

[b] Air.

[c] Subsurface soil.

[d] Spring 7 surface water.

[e] Residence pond water.

[f] Ground water.

[g] Assumed source term.

[h] Ground water after 60 y at the Ranger well (CARNRW2). Maximum 70-y average TCE concentration estimate is 0.9 μg/L. Concentrations of VOC co-contaminants range from 0.0021 to 0.275 μg/L (ppb).

[i] Co-contaminants detected in ground water samples in the Pit 6 Area study area also considered.

[j] Co-contaminants detected in surface soil, subsurface soil, and surface water in the Pit 6 Area study area also considered.

Table 1-27. Estimated incremental lifetime cancer risk and noncancer hazard index associated with potential adult on-site exposure in the Pit 6 operable unit.

Chemical	Contaminant concentration	Individual lifetime cancer risk		Hazard index (Dose/RfD)
Overall operable unit: inhalation of particulates resuspended from surface soil [$C_{p(ss)}$ (mg/m^3)][a]				
HMX	1.70×10^{-10}	Not carcinogenic		6.67×10^{-10}
RDX	5.14×10^{-10}	Not available[b]		3.36×10^{-8}
Trichlorofluoromethane	1.36×10^{-10}	Not carcinogenic		1.34×10^{-10}
	Σ Risk =	NA[c]	Σ Hazard index =	3.4×10^{-8}
Overall operable unit: ingestion and dermal absorption from surface soil [$C_{s(ss)}$ (mg/kg)][d]				
HMX	7.40×10^{-3}	Not carcinogenic		3.00×10^{-6}
RDX	2.24×10^{-2}	1.78×10^{-8}		1.51×10^{-4}
Trichlorofluoromethane	5.92×10^{-3}	Not carcinogenic		2.14×10^{-8}
	Σ Risk =	2×10^{-8}	Σ Hazard index =	1.5×10^{-4}
Vicinity of Spring 7: inhalation of VOCs that volatilize from subsurface soil to air [$C_{a(sbs)}$ (mg/m^3)][e]				
Ethylbenzene	4.61×10^{-6}	Not carcinogenic		9.04×10^{-6}
Tetrachloroethylene	1.01×10^{-5}	3.58×10^{-8}		1.97×10^{-4}
Toluene	6.19×10^{-5}	Not carcinogenic		6.06×10^{-5}
Trichloroethylene	2.44×10^{-4}	1.71×10^{-7}		6.51×10^{-3}
Xylenes (total isomers)	3.16×10^{-5}	Not carcinogenic		3.10×10^{-6}
	Σ Risk =	2×10^{-7}	Σ Hazard index =	6.8×10^{-3}
Rifle Range: inhalation of VOCs that volatilize from subsurface soil to air [$C_{a(sbs)}$ (mg/m^3)][e]				
1,1,1-Trichloroethane	4.25×10^{-6}	Not carcinogenic		2.78×10^{-6}
1,2-Dichloroethylene	7.58×10^{-6}	Not carcinogenic		1.49×10^{-4}
Chloroform	1.99×10^{-4}	1.13×10^{-6}		3.90×10^{-3}
Methylene chloride	1.62×10^{-5}	3.96×10^{-9}		5.28×10^{-5}
Tetrachloroethylene	6.56×10^{-4}	2.34×10^{-6}		1.29×10^{-2}
Trichloroethylene	1.96×10^{-3}	1.37×10^{-6}		5.23×10^{-2}
Trichlorofluoromethane	5.27×10^{-5}	Not carcinogenic		5.17×10^{-5}
Trichlorotrifluoroethane	4.58×10^{-4}	Not carcinogenic		2.99×10^{-6}
	Σ Risk =	5×10^{-6}	Σ Hazard index =	6.9×10^{-2}

Table 1-27. (Continued)

Chemical	Contaminant concentration	Individual lifetime cancer risk		Hazard index (Dose/RfD)
Spring 7: inhalation of VOCs that volatilize from surface water to air (adult on-site exposure) [Ca(sw)(mg/m³)][f]				
1,2-Dichloroethane	5.20×10^{-4}	3.31×10^{-6}		Not available[g]
cis-1,2-Dichloroethylene	6.76×10^{-3}	Not carcinogenic		1.33×10^{-1}
trans-1,2-Dichloroethylene	2.10×10^{-2}	Not carcinogenic		2.06×10^{-1}
Chloroform	5.68×10^{-4}	3.22×10^{-6}		1.11×10^{-2}
Tetrachlorethylene	3.25×10^{-4}	1.16×10^{-6}		6.37×10^{-3}
Trichloroethylene	4.24×10^{-2}	2.96×10^{-5}		1.13×10^{0}
Xylenes (total isomers)	5.09×10^{-4}	Not carcinogenic		4.99×10^{-5}
	Σ Risk =	4×10^{-5}	Σ Hazard index =	1.5

[a] $C_{p(ss)}$ refers to the concentration (C) of contaminant on resuspended particulates in air (p) (the exposure medium), resulting directly from the presence of contaminant in surface soil (ss).

[b] An inhalation slope factor for RDX is not available.

[c] NA = Not applicable.

[d] $C_{s(ss)}$ refers to the concentration (C) of contaminant in surface soil (s) (the exposure medium), resulting directly from the presence of contaminant in surface soil (ss).

[e] $C_{a(sbs)}$ refers to the concentration (C) of contaminant in air (a) (the exposure medium), resulting directly from the presence of contaminant in subsurface soil (sbs).

[f] $Ca_{(sw)}$ refers to the concentration (C) of contaminant in air (a) (the exposure medium) which results directly from the presence of contaminant in surface water (sw).

[g] A reference dose (RfD) is not available.

Table 1-28. Estimated incremental lifetime cancer risk and noncancer hazard index associated with potential residential exposures to contaminated ground water that originates in the Pit 6 operable unit.

Chemical	Contaminant concentration	Individual lifetime cancer risk	Hazard index (Dose/RfD)
Ranger Well: Residential use of contaminated ground water [$C_{w(gw)}$(mg/L)][a]			
1,1,1-Trichloroethane	8.77×10^{-6}	Not carcinogenic	5.07×10^{-6}
1,2-Dichloroethylene	4.37×10^{-5}	Not carcinogenic	4.54×10^{-4}
1,2-Dichloroethane	3.86×10^{-6}	1.50×10^{-8}	Not available[b]
Acetone	2.43×10^{-5}	Not carcinogenic	1.84×10^{-5}
Bis(2-ethylhexyl)phthalate	2.40×10^{-4}	1.47×10^{-7}	1.29×10^{-3}
Butylbenzyl phthalate	1.67×10^{-4}	Not available[c]	2.95×10^{-5}
Carbon disulfide	2.91×10^{-6}	Not carcinogenic	3.32×10^{-6}
Chloroform	3.00×10^{-6}	8.02×10^{-9}	2.88×10^{-5}
Ethylbenzene	2.10×10^{-6}	Not carcinogenic	2.27×10^{-6}
Methylene chloride	6.40×10^{-6}	1.89 x 10^{-9}	1.15×10^{-5}
Phenolics	2.75×10^{-4}	Not carcinogenic	1.42×10^{-5}
Tetrachloroethylene	9.27×10^{-6}	2.15×10^{-8}	9.74×10^{-5}
Toluene	1.01×10^{-5}	Not carcinogenic	5.10×10^{-6}
Trichloroethylene	9.00×10^{-4}	4.26×10^{-7}	1.14×10^{-2}
Xylenes (total isomers)	9.97×10^{-6}	Not carcinogenic	5.49×10^{-7}
	Σ Risk =	6×10^{-7}	Σ Hazard index = 1.3×10^{-2}
Ranger Well: Recreational use (ingestion) of contaminated ground water [$C_{w(gw)}$(mg/L)][a]			
1,1,1-Trichloroethane	8.77×10^{-6}	Not carcinogenic	1.91×10^{-7}
1,2-Dichloroethane	3.86×10^{-6}	2.95×10^{-10}	Not available[b]
1,2-Dichloroethylene	4.37×10^{-5}	Not carcinogenic	8.56×10^{-6}
Acetone	2.43×10^{-5}	Not carcinogenic	4.77×10^{-7}
Bis(2-ethylhexyl)phthalate	2.40×10^{-4}	2.82×10^{-9}	2.36×10^{-5}
Butylbenzyl phthalate	1.67×10^{-4}	Not available[c]	1.64×10^{-6}
Carbon disulfide	2.91×10^{-6}	Not carcinogenic	5.71×10^{-8}
Chloroform	3.00×10^{-6}	7.80×10^{-11}	5.88×10^{-7}
Ethylbenzene	2.10×10^{-6}	Not carcinogenic	4.12×10^{-8}
Methylene chloride	6.40×10^{-6}	7.52×10^{-11}	2.09×10^{-7}
Phenolics	2.75×10^{-4}	Not carcinogenic	8.99×10^{-7}
Tetrachloroethylene (PCE)	9.27×10^{-6}	4.04×10^{-10}	1.82×10^{-6}
Toluene	1.01×10^{-5}	Not carcinogenic	9.88×10^{-8}

Table 1-28. (Continued)

Chemical	Contaminant concentration	Individual lifetime cancer risk		Hazard index (Dose/RfD)
Trichloroethylene (TCE)	9.00×10^{-4}	1.13×10^{-8}		2.40×10^{-4}
Xylenes (total isomers)	9.97×10^{-6}	Not carcinogenic		9.77×10^{-9}
	Σ Risk =	2×10^{-8}	Σ Hazard index =	2.8×10^{-4}
Residence Pond: inhalation of VOCs that volatilize from surface water to air (residential exposure). [$C_{a(sw)}$ (mg/L)][d]				
1,1,1-Trichloroethane	1.89×10^{-5}	Not carcinogenic		1.73×10^{-5}
1,2-Dichloroethylene	1.07×10^{-4}	Not carcinogenic		2.93×10^{-3}
1,2-Dichloroethane	8.35×10^{-6}	8.89×10^{-8}		Not available[b]
Acetone	1.36×10^{-5}	Not carcinogenic		3.72×10^{-5}
Bis(2-ethylhexyl)phthalate	2.36×10^{-5}	2.32×10^{-8}		3.23×10^{-4}
Butylbenzyl phthalate	2.24×10^{-6}	Not available[c]		3.07×10^{-6}
Carbon disulfide	7.48×10^{-6}	Not carcinogenic		2.05×10^{-5}
Chloroform	6.61×10^{-6}	6.27×10^{-8}		1.81×10^{-4}
Ethylbenzene	5.02×10^{-6}	Not carcinogenic		1.38×10^{-5}
Methylene chloride	1.58×10^{-5}	6.48×10^{-9}		7.23×10^{-5}
Phenolics	1.71×10^{-6}	Not carcinogenic		7.80×10^{-7}
Tetrachloroethylene	1.84×10^{-5}	1.10×10^{-7}		5.05×10^{-4}
Toluene	2.58×10^{-5}	Not carcinogenic		3.53×10^{-5}
Trichloroethylene	1.94×10^{-3}	2.27×10^{-6}		7.24×10^{-2}
Xylenes (total isomers)	2.38×10^{-5}	Not carcinogenic		3.26×10^{-6}
	Risk =	3×10^{-6}	Σ Hazard index =	7.7×10^{-2}

---

[a] $C_{w(gw)}$ refers to the concentration (C) of contaminant in water (w). Water is the exposure medium for ingestion and dermal absorption of contaminants, and also is the transfer medium for exposures that result from ingestion of homegrown beef, milk, and fruits and vegetables that are raised with contaminated groundwater (gw).

[b] A reference dose (RfD) is not available.

[c] A slope factor is not available.

[d] Ca(sw) refers to the concentration (C) of contaminant in air (a) (the exposure medium), which results directly from the presence of contaminant in surface water (sw).

Table 1-29. Summary of hazard indices for deer residing in the Pit 6 operable unit.

				Combined oral and inhalation		
Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	RfD mg/(kg•d)	HI Adult	HI Juvenile
SVRA Residence Pond						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	3.45×10^{-6}	6.24×10^{-6}	7.40×10^{0}	6.05×10^{-6}	6.24×10^{-6}
Bis(2-ethylhexyl)phthalate	1.90×10^{1}	3.80×10^{-6}	6.86×10^{-6}	1.90×10^{1}	5.97×10^{-5}	6.86×10^{-6}
Butylenzyl phthalate	1.59×10^{2}	4.31×10^{-8}	7.79×10^{-8}	1.59×10^{2}	4.67×10^{-6}	7.79×10^{-8}
Phenolics	6.00×10^{1}	8.73×10^{-8}	1.58×10^{-7}	6.00×10^{1}	2.29×10^{-5}	1.58×10^{-7}
total 1,2-Dichloroethene	9.00×10^{0}	3.64×10^{-5}	6.57×10^{-5}	9.00×10^{0}	6.07×10^{-5}	6.57×10^{-5}
Chloroform	6.00×10^{1}	3.36×10^{-7}	6.07×10^{-7}	6.00×10^{1}	5.85×10^{-7}	6.07×10^{-7}
Trichlorofluoromethane	3.49×10^{2}	7.03×10^{-14}	1.27×10^{-13}	3.49×10^{2}	9.11×10^{-9}	4.58×10^{-8}
Ethyl benzene	9.71×10^{1}	1.58×10^{-7}	2.86×10^{-7}	9.71×10^{1}	2.57×10^{-7}	2.86×10^{-7}
Toluene	4.46×10^{2}	1.76×10^{-7}	3.18×10^{-7}	4.46×10^{2}	2.84×10^{-7}	3.18×10^{-7}
Xylene	2.50×10^{2}	2.91×10^{-7}	5.25×10^{-7}	2.50×10^{2}	4.72×10^{-7}	5.25×10^{-7}
Methylene chloride	5.85×10^{0}	8.28×10^{-6}	1.49×10^{-5}	5.85×10^{0}	1.37×10^{-5}	1.49×10^{-5}
Acetone	1.00×10^{2}	4.14×10^{-7}	7.48×10^{-7}	1.00×10^{2}	1.47×10^{-6}	7.48×10^{-7}
Carbon disulfide	1.10×10^{1}	2.08×10^{-6}	3.75×10^{-6}	1.10×10^{1}	3.39×10^{-6}	3.75×10^{-6}
Tetrachloroethene	1.40×10^{1}	4.04×10^{-6}	7.29×10^{-6}	1.40×10^{1}	7.00×10^{-6}	7.29×10^{-6}
Trichloroethene	2.40×10^{1}	2.48×10^{-4}	4.48×10^{-4}	2.40×10^{1}	4.32×10^{-4}	4.48×10^{-4}
1,1,1-Trichloroethane	5.00×10^{2}	1.16×10^{-7}	2.09×10^{-7}	5.00×10^{2}	2.01×10^{-7}	2.09×10^{-7}
VOC total		3.08×10^{-4}	5.56×10^{-4}		6.13×10^{-4}	5.56×10^{-4}
HE						
HMX	5.00×10^{1}	6.12×10^{-13}	1.11×10^{-12}	5.00×10^{1}	7.94×10^{-8}	3.99×10^{-7}
RDX	3.00×10^{-1}	3.08×10^{-10}	5.57×10^{-10}	3.00×10^{-1}	4.00×10^{-5}	2.01×10^{-4}
HE total		3.09×10^{-10}	5.58×10^{-10}		4.01×10^{-5}	2.02×10^{-4}

Table 1-29. (Continued)

Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	Combined oral and inhalation		
				RfD mg/(kg•d)	HI Adult	HI Juvenile
Rifle Range						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	2.15×10^{-4}	3.88×10^{-4}	7.40×10^{0}	2.22×10^{-4}	3.88×10^{-4}
cis-1,2-Dichloroethene	3.20×10^{1}	6.47×10^{-4}	1.17×10^{-3}	3.20×10^{1}	6.66×10^{-4}	1.17×10^{-3}
trans-1,2-Dichloroethene	1.70×10^{1}	3.78×10^{-3}	6.83×10^{-3}	1.70×10^{1}	3.89×10^{-3}	6.83×10^{-3}
total 1,2-Dichloroethene	9.00×10^{0}	2.58×10^{-6}	4.66×10^{-6}	9.00×10^{0}	6.15×10^{-6}	4.66×10^{-6}
Chloroform	6.00×10^{1}	3.92×10^{-5}	7.07×10^{-5}	6.00×10^{1}	4.71×10^{-5}	7.07×10^{-5}
Trichlorofluoromethane	3.49×10^{2}	4.62×10^{-7}	8.34×10^{-7}	3.49×10^{2}	5.05×10^{-7}	8.80×10^{-7}
Trichlorotrifluoroethane	5.70×10^{3}	2.46×10^{-7}	4.44×10^{-7}	5.70×10^{3}	2.50×10^{-7}	4.44×10^{-7}
Toluene	4.46×10^{2}	0.00×10^{0}	0.00×10^{0}	4.46×10^{2}	6.12×10^{-8}	4.23×10^{-12}
Xylene	2.50×10^{2}	6.23×10^{-6}	1.12×10^{-5}	2.50×10^{2}	6.41×10^{-6}	1.12×10^{-5}
Methylene chloride	5.85×10^{0}	8.46×10^{-6}	1.53×10^{-5}	5.85×10^{0}	4.28×10^{-5}	1.53×10^{-5}
Tetrachloroethene	1.40×10^{1}	2.15×10^{-4}	3.88×10^{-4}	1.40×10^{1}	2.39×10^{-4}	3.88×10^{-4}
Trichloroethene	2.40×10^{1}	5.65×10^{-3}	1.02×10^{-2}	2.40×10^{1}	5.96×10^{-3}	1.02×10^{-2}
1,1,1-Trichloroethane	5.00×10^{2}	2.60×10^{-8}	4.70×10^{-8}	5.00×10^{2}	3.25×10^{-8}	4.70×10^{-8}
VOC total		1.06×10^{-2}	1.91×10^{-2}		1.11×10^{-2}	1.91×10^{-2}
HE						
HMX	5.00×10^{1}	6.12×10^{-13}	1.11×10^{-12}	5.00×10^{1}	6.48×10^{-5}	3.99×10^{-7}
RDX	3.00×10^{-1}	3.09×10^{-10}	5.57×10^{-10}	3.00×10^{-1}	1.22×10^{-2}	2.01×10^{-4}
HE total		3.09×10^{-10}	5.58×10^{-10}		1.23×10^{-2}	2.02×10^{-4}

Table 1-29. (Continued)

				Combined oral and inhalation		
Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	RfD mg/(kg•d)	HI Adult	HI Juvenile
Spring 7						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	2.15×10^{-4}	3.88×10^{-4}	7.40×10^{0}	2.22×10^{-4}	3.88×10^{-4}
cis-1,2-Dichloroethene	3.20×10^{1}	6.47×10^{-4}	1.17×10^{-3}	3.20×10^{1}	6.66×10^{-4}	1.17×10^{-3}
trans-1,2-Dichloroethene	1.70×10^{1}	3.78×10^{-3}	6.83×10^{-3}	1.70×10^{1}	3.89×10^{-3}	6.83×10^{-3}
Chloroform	6.00×10^{1}	2.90×10^{-5}	5.23×10^{-5}	6.00×10^{1}	2.99×10^{-5}	5.23×10^{-5}
Trichlorofluoromethane	3.49×10^{2}	7.03×10^{-14}	1.27×10^{-13}	3.49×10^{2}	3.13×10^{-7}	4.58×10^{-8}
Ethyl benzene	9.71×10^{1}	1.45×10^{-7}	2.62×10^{-7}	9.71×10^{1}	2.01×10^{-7}	2.62×10^{-7}
Toluene	4.46×10^{2}	4.24×10^{-7}	7.65×10^{-7}	4.46×10^{2}	6.85×10^{-7}	7.65×10^{-7}
Xylene	2.50×10^{2}	6.61×10^{-6}	1.19×10^{-5}	2.50×10^{2}	6.94×10^{-6}	1.19×10^{-5}
Methylene chloride	5.85×10^{0}	0.00×10^{0}	0.00×10^{0}	5.85×10^{0}	1.76×10^{-5}	4.01×10^{-11}
Tetrachloroethene	1.40×10^{1}	7.32×10^{-5}	1.32×10^{-4}	1.40×10^{1}	7.60×10^{-5}	1.32×10^{-4}
Trichloroethene	2.40×10^{1}	5.43×10^{-3}	9.81×10^{-3}	2.40×10^{1}	5.63×10^{-3}	9.81×10^{-3}
VOC total		1.02×10^{-2}	1.84×10^{-2}		1.05×10^{-2}	1.84×10^{-2}
HE						
HMX	5.00×10^{1}	6.12×10^{-13}	1.11×10^{-12}	5.00×10^{1}	6.48×10^{-5}	3.99×10^{-7}
RDX	3.00×10^{-1}	3.09×10^{-10}	5.57×10^{-10}	3.00×10^{-1}	1.22×10^{-2}	2.01×10^{-4}
HE total		3.09×10^{-10}	5.58×10^{-10}		1.23×10^{-2}	2.02×10^{-4}

Table 1-30. Summary of hazard indices for ground squirrel residing in the Pit 6 operable unit.

				Combined oral and inhalation		
Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	RfD mg/(kg•d)	HI Adult	HI Juvenile
SVRA Residence Pond						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	9.25×10^{-7}	—	7.40×10^{0}	2.82×10^{-6}	2.54×10^{-13}
Bis(2-ethylhexyl)phthalate	1.90×10^{1}	1.02×10^{-6}	—	1.90×10^{1}	2.68×10^{-5}	5.26×10^{-12}
Butylbenzyl phthalate	1.59×10^{2}	1.16×10^{-8}	—	1.59×10^{2}	2.14×10^{-6}	2.26×10^{-13}
Phenolics	6.00×10^{1}	2.34×10^{-8}	—	6.00×10^{1}	1.66×10^{-5}	1.75×10^{-12}
total 1,2-Dichloroethene	9.00×10^{0}	9.75×10^{-6}	—	9.00×10^{0}	2.77×10^{-5}	2.93×10^{-12}
Chloroform	6.00×10^{1}	9.00×10^{-8}	—	6.00×10^{1}	2.73×10^{-7}	1.18×10^{-13}
Trichlorofluoromethane	3.49×10^{2}	1.88×10^{-14}	—	3.49×10^{2}	1.96×10^{-8}	9.69×10^{-15}
Ethyl benzene	9.71×10^{1}	4.24×10^{-8}	—	9.71×10^{1}	9.58×10^{-8}	1.97×10^{-13}
Toluene	4.46×10^{2}	4.72×10^{-8}	—	4.46×10^{2}	1.15×10^{-7}	9.03×10^{-14}
Xylene	2.50×10^{2}	7.79×10^{-8}	—	2.50×10^{2}	1.74×10^{-7}	4.03×10^{-13}
Methylene chloride	5.85×10^{0}	2.22×10^{-6}	—	5.85×10^{0}	6.01×10^{-6}	1.56×10^{-13}
Acetone	1.00×10^{2}	1.11×10^{-7}	—	1.00×10^{2}	5.57×10^{-7}	4.68×10^{-16}
Carbon disulfide	1.10×10^{1}	5.57×10^{-7}	—	1.10×10^{1}	1.49×10^{-6}	3.78×10^{-13}
Tetrachloroethene	1.40×10^{1}	1.08×10^{-6}	—	1.40×10^{1}	2.53×10^{-6}	9.30×10^{-12}
Trichloroethene	2.40×10^{1}	6.65×10^{-5}	—	2.40×10^{1}	1.92×10^{-4}	7.38×10^{-11}
1,1,1-Trichloroethane	5.00×10^{2}	3.11×10^{-8}	—	5.00×10^{2}	8.87×10^{-8}	3.99×10^{-14}
VOC total	—	8.25×10^{-5}	—	—	2.80×10^{-4}	9.49×10^{-11}
HE						
HMX	5.00×10^{1}	1.64×10^{-13}	—	5.00×10^{1}	1.71×10^{-7}	3.36×10^{-16}
RDX	3.00×10^{-1}	8.26×10^{-11}	—	3.00×10^{-1}	8.61×10^{-5}	9.32×10^{-13}
HE total	—	8.28×10^{-11}	—	—	8.63×10^{-5}	9.32×10^{-13}

Table 1-30. (Continued)

Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	Combined oral and inhalation RfD mg/(kg•d)	Combined oral and inhalation HI Adult	Combined oral and inhalation HI Juvenile
Rifle Range						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	5.76×10^{-5}	—	7.40×10^{0}	6.16×10^{-5}	5.54×10^{-12}
cis-1,2-Dichloroethene	3.20×10^{1}	1.73×10^{-4}	—	3.20×10^{1}	1.84×10^{-4}	1.94×10^{-11}
trans-1,2-Dichloroethene	1.70×10^{1}	1.01×10^{-3}	—	1.70×10^{1}	1.07×10^{-3}	1.13×10^{-10}
total 1,2-Dichloroethene	9.00×10^{0}	1.05×10^{-2}	2.56×10^{-2}	9.00×10^{0}	1.05×10^{-2}	2.56×10^{-2}
Chloroform	6.00×10^{1}	3.57×10^{-2}	8.67×10^{-2}	6.00×10^{1}	3.57×10^{-2}	8.67×10^{-2}
Trichlorofluoromethane	3.49×10^{2}	3.16×10^{-3}	7.67×10^{-3}	3.49×10^{2}	3.16×10^{-3}	7.67×10^{-3}
Trichlorotrifluoroethane	5.70×10^{3}	1.75×10^{-3}	4.25×10^{-3}	5.70×10^{3}	1.75×10^{-3}	4.25×10^{-3}
Toluene	4.46×10^{2}	—	—	4.46×10^{2}	3.01×10^{-8}	2.36×10^{-14}
Xylene	2.50×10^{2}	1.67×10^{-6}	—	2.50×10^{2}	1.75×10^{-6}	4.04×10^{-12}
Methylene chloride	5.85×10^{0}	2.49×10^{-2}	6.04×10^{-2}	5.85×10^{0}	2.49×10^{-2}	6.04×10^{-2}
Tetrachloroethene	1.40×10^{1}	4.51×10^{-1}	1.09×10^{0}	1.40×10^{1}	4.51×10^{-1}	1.09×10^{0}
Trichloroethene	2.40×10^{1}	7.49×10^{-1}	1.82×10^{0}	2.40×10^{1}	7.49×10^{-1}	1.82×10^{0}
1,1,1-Trichloroethane	5.00×10^{2}	1.10×10^{-4}	2.68×10^{-4}	5.00×10^{2}	1.10×10^{-4}	2.68×10^{-4}
VOC total	—	1.28×10^{0}	3.10×10^{0}	—	1.28×10^{0}	3.10×10^{0}
HE						
HMX	5.00×10^{1}	1.64×10^{-13}	—	5.00×10^{1}	1.81×10^{-4}	3.56×10^{-13}
RDX	3.00×10^{-1}	8.27×10^{-11}	—	3.00×10^{-1}	3.42×10^{-2}	3.70×10^{-10}
HE total	—	8.28×10^{-11}	—	—	3.44×10^{-2}	3.70×10^{-10}

Table 1-30. (Continued)

Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	Combined oral and inhalation RfD mg/(kg•d)	Combined oral and inhalation HI Adult	Combined oral and inhalation HI Juvenile
Spring 7						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	5.76×10^{-5}	—	7.40×10^{0}	6.16×10^{-5}	5.54×10^{-12}
cis-1,2-Dichloroethene	3.20×10^{1}	1.73×10^{-4}	—	3.20×10^{1}	1.84×10^{-4}	1.94×10^{-11}
trans-1,2-Dichloroethene	1.70×10^{1}	1.01×10^{-3}	—	1.70×10^{1}	1.07×10^{-3}	1.13×10^{-10}
Chloroform	6.00×10^{1}	7.76×10^{-6}	—	6.00×10^{1}	8.29×10^{-6}	3.57×10^{-12}
Trichlorofluoromethane	3.49×10^{2}	1.88×10^{-14}	—	3.49×10^{2}	8.70×10^{-7}	4.30×10^{-13}
Ethyl benzene	9.71×10^{1}	3.20×10^{-4}	7.77×10^{-4}	9.71×10^{1}	3.20×10^{-4}	7.77×10^{-4}
Toluene	4.46×10^{2}	1.08×10^{-3}	2.63×10^{-3}	4.46×10^{2}	1.08×10^{-3}	2.63×10^{-3}
Xylene	2.50×10^{2}	8.97×10^{-4}	2.18×10^{-3}	2.50×10^{2}	8.97×10^{-4}	2.18×10^{-3}
Methylene chloride	5.85×10^{0}	—	—	5.85×10^{0}	9.37×10^{-6}	2.43×10^{-13}
Tetrachloroethene	1.40×10^{1}	6.91×10^{-3}	1.67×10^{-2}	1.40×10^{1}	6.91×10^{-3}	1.67×10^{-2}
Trichloroethene	2.40×10^{1}	9.47×10^{-2}	2.27×10^{-1}	2.40×10^{1}	9.48×10^{-2}	2.27×10^{-1}
VOC total	—	1.05×10^{-1}	2.49×10^{-1}	—	1.05×10^{-1}	2.49×10^{-1}
HE						
HMX	5.00×10^{1}	1.64×10^{-13}	—	5.00×10^{1}	1.81×10^{-4}	3.56×10^{-13}
RDX	3.00×10^{-1}	8.27×10^{-11}	—	3.00×10^{-1}	3.42×10^{-2}	3.70×10^{-10}
HE total	—	8.28×10^{-11}	—	—	3.44×10^{-2}	3.70×10^{-10}

[a] Not relevant for this study area.

Table 1-31. Summary of hazard indices for kit fox residing in the Pit 6 operable unit.

Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	Combined oral and inhalation RfD mg/(kg•d)	Combined oral and inhalation HI Adult	Combined oral and inhalation HI Juvenile
SVRA Residence Pond						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	1.34×10^{-6}	—	7.40×10^{0}	3.85×10^{-6}	2.59×10^{-13}
Bis(2-ethylhexyl)phthalate	1.90×10^{1}	1.47×10^{-6}	—	1.90×10^{1}	6.25×10^{-5}	1.88×10^{-11}
Butylbenzyl phthalate	1.59×10^{2}	1.67×10^{-8}	—	1.59×10^{2}	5.08×10^{-6}	8.18×10^{-13}
Phenolics	6.00×10^{1}	3.38×10^{-8}	—	6.00×10^{1}	2.21×10^{-5}	3.57×10^{-12}
total 1,2-Dichloroethene	9.00×10^{0}	1.41×10^{-5}	—	9.00×10^{0}	3.75×10^{-5}	6.05×10^{-12}
Chloroform	1.29×10^{1}	6.06×10^{-7}	—	1.29×10^{1}	1.72×10^{-6}	3.58×10^{-13}
Trichlorofluoromethane	3.49×10^{2}	2.72×10^{-14}	—	3.49×10^{2}	7.74×10^{-9}	5.83×10^{-15}
Ethyl benzene	9.71×10^{1}	6.13×10^{-8}	—	9.71×10^{1}	1.66×10^{-7}	5.20×10^{-13}
Toluene	4.46×10^{2}	6.84×10^{-8}	—	4.46×10^{2}	1.77×10^{-7}	2.12×10^{-13}
Xylene	2.50×10^{2}	1.13×10^{-7}	—	2.50×10^{2}	3.05×10^{-7}	1.08×10^{-12}
Methylene chloride	5.85×10^{0}	3.21×10^{-6}	—	5.85×10^{0}	8.49×10^{-6}	3.35×10^{-13}
Acetone	1.00×10^{2}	1.60×10^{-7}	—	1.00×10^{2}	1.33×10^{-6}	1.71×10^{-15}
Carbon disulfide	1.10×10^{1}	8.05×10^{-7}	—	1.10×10^{1}	2.08×10^{-6}	8.06×10^{-13}
Tetrachloroethene	1.40×10^{1}	1.56×10^{-6}	—	1.40×10^{1}	4.76×10^{-6}	2.67×10^{-11}
Trichloroethene	2.40×10^{1}	9.62×10^{-5}	—	2.40×10^{1}	2.77×10^{-4}	1.62×10^{-10}
1,1,1-Trichloroethane	5.00×10^{2}	4.49×10^{-8}	—	5.00×10^{2}	1.30×10^{-7}	7.59×10^{-14}
VOC total	—	1.20×10^{-4}	—	—	4.27×10^{-4}	2.22×10^{-10}
HE						
HMX	5.00×10^{1}	2.37×10^{-13}	—	5.00×10^{1}	6.74×10^{-8}	2.02×10^{-16}
RDX	3.00×10^{-1}	1.20×10^{-10}	—	3.00×10^{-1}	3.40×10^{-5}	5.61×10^{-13}
HE total	—	1.20×10^{-10}	—	—	3.40×10^{-5}	5.61×10^{-13}

Table 1-31. (Continued)

Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	Combined oral and inhalation RfD mg/(kg•d)	Combined oral and inhalation HI Adult	Combined oral and inhalation HI Juvenile
Rifle Range						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	8.33×10^{-5}	—	7.40×10^{0}	9.09×10^{-5}	6.12×10^{-12}
cis-1,2-Dichloroethene	3.20×10^{1}	2.51×10^{-4}	—	3.20×10^{1}	2.71×10^{-4}	4.37×10^{-11}
trans-1,2-Dichloroethene	1.70×10^{1}	1.47×10^{-3}	2.76×10^{-2}	1.70×10^{1}	1.58×10^{-3}	2.55×10^{-10}
total 1,2-Dichloroethene	9.00×10^{0}	1.52×10^{-2}	4.36×10^{-1}	9.00×10^{0}	1.52×10^{-2}	2.76×10^{-2}
Chloroform	1.29×10^{1}	2.40×10^{-1}	8.28×10^{-3}	1.29×10^{1}	2.40×10^{-1}	4.36×10^{-1}
Trichlorofluoromethane	3.49×10^{2}	4.57×10^{-3}	4.59×10^{-3}	3.49×10^{2}	4.57×10^{-3}	8.28×10^{-3}
Trichlorotrifluoroethane	5.70×10^{3}	2.53×10^{-3}	—	5.70×10^{3}	2.53×10^{-3}	4.59×10^{-3}
Toluene	4.46×10^{2}	—	—	4.46×10^{2}	6.59×10^{-8}	7.89×10^{-14}
Xylene	2.50×10^{2}	2.41×10^{-6}	6.53×10^{-2}	2.50×10^{2}	2.61×10^{-6}	9.23×10^{-12}
Methylene chloride	5.85×10^{0}	3.60×10^{-2}	1.18×10^{0}	5.85×10^{0}	3.60×10^{-2}	6.53×10^{-2}
Tetrachloroethene	1.40×10^{1}	6.52×10^{-1}	1.96×10^{0}	1.40×10^{1}	6.52×10^{-1}	1.18×10^{0}
Trichloroethene	2.40×10^{1}	1.08×10^{0}	2.90×10^{-4}	2.40×10^{1}	1.08×10^{0}	1.96×10^{0}
1,1,1-Trichloroethane	5.00×10^{2}	1.60×10^{-4}	3.69×10^{0}	5.00×10^{2}	1.60×10^{-4}	2.90×10^{-4}
VOC total	—	2.04×10^{0}	—	—	2.04×10^{0}	3.69×10^{0}
HE						
HMX	5.00×10^{1}	2.37×10^{-13}	—	5.00×10^{1}	6.74×10^{-8}	2.02×10^{-16}
RDX	3.00×10^{-1}	1.20×10^{-10}	—	3.00×10^{-1}	3.40×10^{-5}	5.61×10^{-13}
HE total	—	1.20×10^{-10}	—	—	3.40×10^{-5}	5.61×10^{-13}

Table 1-31. (Continued)

				Combined oral and inhalation		
Analyte	Inhalation RfD mg/(kg•d)	HI Adult	HI Juvenile	RfD mg/(kg•d)	HI Adult	HI Juvenile
Spring 7						
VOCs						
1,2-Dichloroethane	7.40×10^{0}	8.33×10^{-5}	—	7.40×10^{0}	9.09×10^{-5}	6.12×10^{-12}
cis-1,2-Dichloroethene	3.20×10^{1}	2.51×10^{-4}	—	3.20×10^{1}	2.71×10^{-4}	4.37×10^{-11}
trans-1,2-Dichloroethene	1.70×10^{1}	1.47×10^{-3}	—	1.70×10^{1}	1.58×10^{-3}	2.55×10^{-10}
Chloroform	1.29×10^{1}	5.22×10^{-5}	—	1.29×10^{1}	5.69×10^{-5}	1.18×10^{-11}
Trichlorofluoromethane	3.49×10^{2}	2.72×10^{-14}	—	3.49×10^{2}	7.74×10^{-9}	5.83×10^{-15}
Ethyl benzene	9.71×10^{1}	4.63×10^{-4}	8.40×10^{-4}	9.71×10^{1}	4.63×10^{-4}	8.40×10^{-4}
VOC total	—	1.52×10^{-1}	2.69×10^{-1}	—	1.53×10^{-1}	2.69×10^{-1}
HE						
HMX	5.00×10^{1}	2.37×10^{-13}	—	5.00×10^{1}	6.74×10^{-8}	2.02×10^{-16}
RDX	3.00×10^{-1}	1.20×10^{-10}	—	3.00×10^{-1}	3.40×10^{-5}	5.61×10^{-13}
HE total	—	1.20×10^{-10}	—	—	3.40×10^{-5}	5.61×10^{-13}

[a] Not relevant for this study area.

Table 2-1. Potential federal, state, and local ARARs for the Pit 6 operable unit.

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
Federal chemical-specific requirements			
Safe Drinking Water Act [42 USCA 300 and 40 CFR 141.11–141.16, 141.50–141.51]	This law establishes chemical-specific standards for public drinking water systems by setting Maximum Contaminant Levels (MCLs) and nonzero Maximum Contaminant Level Goals. MCLs are potentially applicable for off-site water supply.	1–4	A
Clean Air Act [42 USCA 7401–7642, 40 CFR 50–69]	National primary and secondary ambient air quality standards (NAAQS) are defined under Section 109 of the Clean Air Act and are listed in 40 CFR 50. Treatment Alternatives 1–4 may include equipment operation and aeration of drilling and/or excavation wastes.	1–4	A
Federal action-specific requirements			
<u>Action: Closure</u>			
Hazardous Waste Control Act Closure Requirements, Health and Safety Code Sections 25150–25245 [22 CCR 66264.111–120]	Requires that hazardous waste management facilities be closed in a manner that minimizes the need for further maintenance and is protective of human health and the environment.	1–4	A
Health and Safety Code Section 25159 [22 CCR 66264.178]	Requires removal of all hazardous waste and waste residues from containment systems at closure. There are no containment systems at the Pit 6 operable unit. Since treatment facilities used in Alternatives 3 and 4 may use containment systems, this closure requirement will be considered RAR.	3, 4	RAR
<u>Action: Pump and treat</u>			
Health and Safety Code Sections 25150–59 [22 CCR 66264.190–192]	Design and operating standards for tank systems. Tank systems may be used for Alternatives 3 and 4.	3, 4	A

Table 2-1. (Continued)

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
<u>Action: Discharge of treatment system effluent</u>			
Clean Water Act [33 USCA 1251–1376] NPDES [40 CFR 122–125]	Both on- and off-site discharges from CERCLA sites to surface waters are required to meet the substantive Clean Water Act limitations, monitoring requirements [40 CFR 122.41(i); 40 CFR 136.1; 40 CFR 136.4], and best management practices [40 CFR 125.100]. WDR and NPDES permits are required to discharge treated water to the ground surface.	3, 4	A
General action-specific ARARs			
DOE Order 5400.4	Prescribes conduct of operations on DOE facilities for compliance with CERCLA, and provides for the integration of NEPA and CERCLA documentation for DOE. This is an unpromulgated order.	1–4	TBC
Noise Control Act of 1972, as amended by the Quiet Communities Act of 1978 [40 CFR 204, 205, 211]	Construction and transportation equipment noise levels (e.g., portable air compressors, and medium and heavy trucks), process equipment noise levels, and noise levels at the property boundaries of the project are regulated under this Act. State or local agencies typically enforce these levels.	1–4	A
Federal location-specific requirements			
Clean Water Act Section 404 [33 USC 1344]	Establishes a national program to control the discharge of dredged or fill materials into "waters of the United States." "Waters of the US" include all tributaries to navigable waters and nearly all wetlands. No "404 Permit" would be required for actions affecting a wetland, but substantive provisions of Section 404, including agency coordination prior to construction, state water quality certification, and possibly even mitigation for loss apply.		
Executive Order 11988 (floodplain management) and 11990 (protection of wetlands) [40 CFR 6, 44 Federal Register 12594]	Requires actions to avoid adverse effects, minimize potential harm, restore and preserve natural and beneficial values. Any DOE action in a floodplain and new construction not located in a floodplain would receive careful evaluation of potential effects. 44 Federal Register 12594 states that DOE can meet requirements of these Executive Orders through applicable DOE and NEPA procedures.	2–4	TBC

Table 2-1. (Continued)

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
Endangered Species Act of 1973 [16 USC Section 1531 et seq., 50 CFR Part 200, 50 CFR Part 402, 40 CFR 257.3-2]	Facilities or practices shall not cause or contribute to the taking of any endangered or threatened species of plants, fish, or wildlife. Even though no federal endangered species have been found within the Pit 6 operable unit, the habitat for the San Joaquin kit fox does exist. Specific mitigation measures for this species will be met prior to any construction. All of these requirements will be additionally met through NEPA and DOE implementing requirements.	1–4	A
National Historic Preservation Act of 1966 (16 USC 470 et seq.), Public Law 89-665 and amendments of 1980, Public Law 96-515	Requires federal agencies to take into account the effects of their projects on historic properties listed, or eligible for listing, on the National Register of Historic Properties and to afford the Advisory Council a reasonable opportunity to comment on them. Several historic sites are located within the Pit 6 operable unit.	1–4	A
Archaeological Resource Protection Act of 1979 [16 USC 470], Public Law 96-96	Requires federal land managers to provide protection for archaeological resources located on public lands and Indian lands. Construction personnel will be advised of the laws and penalties for disturbing or collecting cultural resources located on Site 300 property.	1–4	A
American Indian Religious Freedom Act (1978) [42 USC 1996], Public Law 95-341	Requires federal land managers to consult directly with local Native American groups, including religious and political leaders, to ensure Native American access to religious sites and to protect and preserve these cultural rights and practices. On June 10, 1993, we requested the California Native American Heritage Council to assist in locating Native American groups or individuals to provide input into cultural resource planning. We followed this telephone request with a written request on June 21, 1993, in accordance with Council requirements.	1–4	A

Table 2-1. (Continued)

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
Native American Graves Protection and Repatriation Act of 1990 [25 USC 3001], Public Law 101-601	Requires federal agencies to provide for the protection of Native American graves and associated cultural objects and to repatriate sacred objects, burials, and associated objects to Native American groups. In the event that interested local Native Americans are identified and burial sites or artifacts are discovered, identified local Native Americans will be contacted. Project construction personnel will be advised of the possibility of buried cultural deposits and be alerted to likely indicators. If a human burial is discovered during project construction, all work will be halted in the vicinity of the discovery and the archaeologist and the County Coroner will be called immediately.	1–4	A
California Environmental Quality Act (CEQA) Appendix K 1983	Provides standards to guide agencies in deciding what kinds of archaeological resources need to be analyzed under CEQA and procedures for the analysis.	1–4	A
State and local chemical-specific requirements			
Hazardous Waste Control Act [Health and Safety Code, Sections 25100–25395], CCR, Title 22, ch. 30: Minimum Standards for Management of Hazardous and Extremely Hazardous Wastes	Controls hazardous wastes from their point of generation through accumulation, transportation, treatment, storage, and ultimate disposal. All potentially hazardous materials are handled in accordance with standard chain-of-custody procedures. These requirements are, therefore, applicable to all treatment alternatives.	1–4	A
Criteria for Identifying Hazardous Wastes [CCR, Title 22, 66261. 21–33]	Tests for identifying hazardous characteristics are set forth in these regulations. If a chemical is either listed or tested and found hazardous, then remedial actions must comply with CCR, Title 22 requirements. All treatment alternatives use these criteria.	2–4	A

Table 2-1. (Continued)

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
Persistent and Bioaccumulative Toxic Substances [CCR, Title 22, 66261.113]	Total Threshold Limit Concentrations and Soluble Threshold Limit Concentrations have been established for selected toxics to be used in establishing whether waste is hazardous. If a chemical is either listed or tested and found hazardous, then remedial actions must comply with the hazardous waste requirements under CCR, Title 22. All treatment alternatives use these criteria.	2–4	A
Porter-Cologne Water Quality Control Act [13000 et seq.], as administered by the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCB) under CCR Title 23, subch. 15, 2510–2559, 2580–2601	Establishes authority for state and regional water boards to determine site-specific waste discharge requirements and to regulate disposal of waste to land. Contains corrective action requirements stating that a constituent of concern shall have a concentration limit not to exceed background unless it can be shown that it is technologically and economically infeasible to achieve a background value and that the constituent will not pose a substantial present or potential hazard to human health or the environment.	1–4	A
Water Quality Control Plan (Basin Plan) for the Central Valley Regional Water Quality Control Board	Describes water basins in the Central Valley Region, establishes beneficial uses of ground and surface waters, establishes water quality objectives, establishes implementation plans to meet water quality objectives and protect beneficial uses, and incorporates statewide water quality control plans and policies.	1–4	A
State Water Resources Control Board Resolution 68-16	The state board's policy for discharged water to maintain the high quality of California's waters implies that ground water cleanup should continue to achieve background conditions if it can be shown that doing so is technically feasible, cost effective, and more protective of human health and the environment. The resolution also allows alternative discharge levels if Site 300 can demonstrate that nondegradation cannot be practically achieved and that the alternative is protective of human health and the environment.	1–4	RAR
State Water Resources Control Board Resolution 92–49	The state board's policies and procedures for the oversight of investigations and cleanup and abatement activities resulting from discharges of waste that affect or threaten water quality.	1–4	A

Table 2-1. (Continued)

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
California Safe Drinking Water Act, Health and Safety Code, Section 2549.5	Regulations and standards for public water systems (CA MCLs), which are enforceable in California. Should any chemicals be detected in the ground water at off-site wells in the future, these standards will apply.	1–4	RAR
State and local action-specific requirements			
<u>Action: General treatment of hazardous waste</u>			
Hazardous Waste Control Act, Health and Safety Code, Sections 25100–25395 [22 CCR 66264.1–77]	Requirements for general operations of interim status and permitted facilities, including preparedness and prevention [66264.30–37], contingency plans and emergency procedures [66264.50–55], and manifesting and monitoring requirements [66264.70–77].	1–4	A
Hazardous Waste Control Act Land Disposal Restrictions [22 CCR 66268.1–124]	This law requires that certain hazardous wastes meet minimum treatment standards prior to disposal at a landfill. Generated waste for Alternatives 3 and 4 includes regeneration of granular activated carbon.	1–4	A
Hazardous Materials Release Response Plans and Inventory (Health and Safety Code, Div. 20, ch. 6.95) [19 CCR, ch. 3, subch. 3]	This law requires businesses handling hazardous materials to plan for emergency response actions.	1–4	A
<u>Action: Transportation</u>			
Hazardous Waste Control Act Hauler Registration Requirements and Requirements for Transporters of Hazardous Waste [22 CCR 66263.10–31]	Standards applicable to transporters of hazardous waste. Establishes transporter operating standards (66263.23) registration requirements (66263.11-12), record keeping procedures (66263.15), and immediate action and discharge cleanup requirements for an accidental discharge of hazardous waste (66263.30–31). Generated waste being transported to an off-site disposal facility would be subject to these requirements. Generated waste for Alternatives 2, 3, and 4 includes regeneration of granular activated carbon.	2–4	A

Table 2-1. (Continued)

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
Requirements for Generators of Hazardous Waste [Title 22 66262.10]	Owners or operators who ship hazardous waste from a TSD facility shall comply with the generator standards in these regulations. These standards include keeping of manifests [66261.21], submission of manifest to the Department of Toxic Substances Control within 30 days of shipment [66262.23], preparation of a biennial report [66262.41], and a maximum 90-day accumulation time [66262.34]. These regulations are applicable to transportation and off-site disposal of hazardous waste. Generated waste for Alternatives 2, 3, and 4 includes regeneration of granular activated carbon.	2–4	A
Action: Discharge of treatment system effluent			
California Fish and Game Regulations on Pollution	Prohibits water pollution with any substance or material deleterious to fish, plant, or bird life.	3, 4	A
Porter-Cologne Water Quality Control Act [13000 et seq.], as administered by the SWRCB and the nine RWQCBs under CCR Title 23, subch. 15, 2510–2559, 2580–2601	Establishes authority for State and Regional Water Boards to determine site-specific discharge requirements and to regulate disposal of waste to land.	3, 4	A
Water Quality Control Plan (Basin Plan) for the Central Valley Regional Water Quality Control Board	Describes water basins in the Central Valley Region, establishes beneficial uses of ground and surface waters, establishes water quality objectives, establishes implementation plans to meet water quality objectives and protect beneficial uses, and incorporates statewide water quality control plans and policies.	3, 4	A
State Water Resources Control Board Resolution 68-16	The state board's policy for discharged water to maintain the high quality of California's waters implies that ground water cleanup should continue to achieve background conditions if it can be shown that doing so is technically feasible, cost effective, and more protective of human health and the environment. The resolution also allows alternative discharge levels if Site 300 can demonstrate that nondegradation cannot be practically achieved and that the alternative is protective of human health and the environment.	3, 4	RAR

Table 2-1. (Continued)

Regulation	Comments	Alternative No.[a]	ARAR Category[b]
State location-specific requirements			
California Fish and Game Code Section 1601	Requires a government agency project that will alter the natural flow, bed, or channel of a body of water in which there are fish or wildlife to submit their plans to the Department of Fish and Game. If the fish or wildlife resource may be substantially adversely affected by the project, the Department will have the opportunity to propose modifications to mitigate damage to the fish or wildlife resources.	3, 4	A
Alquist-Priolo Special Studies Zone Act of 1972 [California Public Resource Code, Section 2621, et. seq.]	Specifies criteria to determine an active fault for the purposes of enforcement.	1–4	RAR
California regulation for faults [22 CCR 66264.18]	Requires that new treatment, storage and disposal facilities be located at least 200 ft from an active fault.	3, 4	A
California Endangered Species Act California Fish and Game Code Sections 2050–2068	Requires action to preserve endangered species or threatened species. Even though no endangered species have been found within pit 6, there is potential habitat for the San Joaquin kit fox. Prior to conducting any ground-disturbing activities, surveys will be conducted for the San Joaquin kit fox as well as other species of concern.	1–4	A

[a] 1—Monitoring/no remedial action.

2—Long-term monitoring, covering of pit 6, and contingency point-of-use treatment.

3—All of Alternative 2 plus ground water extraction and treatment.

4—All of Alternative 3 plus subsurface permeability reduction barriers beneath pit 6.

[b] A = Applicable.

RAR = Relevant and appropriate.

TBC = To be considered.

Table 2-2. Summary comparison of corresponding ARARs and factors to be considered for the Pit 6 operable unit.

	Alternative[a]			
ARAR/TBC	1	2	3	4
Federal chemical-specific requirements				
Safe Drinking Water Act [42 USCA 300, 40 CFR 141.11–141.16; 141.50–141.51]	A	A	A	A
Clean Air Act [42 USCA 7401–7642, 40 CFR 50–69]	A	A	A	A
Federal action-specific requirements				
<u>Action: Closure</u>				
Hazardous Waste Control Act Closure Requirements, Health and Safety Code, Sections 25150–25245 [22 CCR 66264.111–120]	A	A	A	A
Health and Safety Code, Section 25159 [22 CCR 66264.178]	—	—	RAR	RAR
<u>Action: Pump and treat</u>				
Health and Safety Code, Sections 25150–59 [22 CCR 66264.190–92]	—	—	A	A
<u>Action: Discharge of treatment system effluent</u>				
Clean Water Act [33 USCA 1251–1376] NPDES [40 CFR 122–125]	—	—	A	A
General action-specific ARARs				
DOE Order 5400.4	TBC	TBC	TBC	TBC
29 CFR 1910 et seq. Noise Control Act of 1972, as amended by the Quiet Communities Act of 1978 [40 CFR 204, 205, 211]	A	A	A	A
Federal location-specific requirements				
Clean Water Act Section 404 [33 USC 1344]	—	A	A	A
Executive Order 11988 (floodplain management) and 11990 (protection of wetlands) [40 CFR 6, FR 12594]	—	TBC	TBC	TBC
Endangered Species Act of 1973 [16 USC Section 1531 et seq., 50 CFR Part 200, 50 CFR Part 402, 40 CFR 257.3–2]	A	A	A	A
National Historic Preservation Act of 1966 (16 USC 470 et seq.), Public Law 89-665 and amendments of 1980, Public Law 96-515	A	A	A	A
Archaeological Resource Protection Act of 1979 [16 USC 470], Public Law 96-96	A	A	A	A
American Indian Religious Freedom Act (1978), Public Law 95-341.	A	A	A	A

Table 2-2. (Continued)

ARAR/TBC	Alternative[a]			
	1	2	3	4
Native American Graves Protection and Repatriation Act of 1990 [25 USC 3001], Public Law 101-601	A	A	A	A
California Environmental Quality Act (CEQA) Appendix K, 1983	A	A	A	A
State and local chemical-specific requirements				
Hazardous Waste Control Act [Health and Safety Code, Sections 25100–25395], CCR, Title 22, ch. 30: Minimum Standards for Management of Hazardous and Extremely Hazardous Wastes	A	A	A	A
Criteria for Identifying Hazardous Wastes [CCR, Title 22, 66261.21–33]	—	A	A	A
Persistent and Bioaccumulative Toxic Substances [CCR, Title 22, 66261.113]	—	A	A	A
Porter-Cologne Water Quality Control Act [13000 et seq.], as administered by the State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCB) under CCR Title 23, subch. 15, 2510–2559, 2580–2601	A	A	A	A
Water Quality Control Plan (Basin Plan) for the Central Valley Region Water Quality Control Board	A	A	A	A
State Water Resources Control Board Resolution 68-16	RAR	RAR	RAR	RAR
State Water Resources Control Board Resolution 92-49	A	A	A	A
California Safe Drinking Water Act, Health and Safety Code, Section 2549.5	RAR	RAR	RAR	RAR
State and local action-specific requirements				
Action: General treatment of hazardous waste				
Hazardous Waste Control Act, Health and Safety Code, Sections 25100–25395 [22 CCR 66264.1–77]	A	A	A	A
Hazardous Waste Control Act Land Disposal Restrictions [22 CCR 66268.1–124]	A	A	A	A
Hazardous Materials Release Response Plans and Inventory (Health and Safety Code, Div. 20, ch. 6.95) [19 CCR, ch. 3, subch. 3]	A	A	A	A
Action: Transportation				
Hazardous Waste Control Act Hauler Registration Requirements and Requirements for Transporters of Hazardous Waste [22 CCR 66263.10–31]	—	A	A	A
Requirements for Generators of Hazardous Waste [Title 22 66262.10]	—	A	A	A

Table 2-2. (Continued)

	Alternative[a]			
ARAR/TBC	1	2	3	4
Action: Discharge of treatment system effluent				
California Fish and Game Regulations on Pollution	—	—	A	A
Porter-Cologne Water Quality Control Act [13000 et seq.], as administered by the SWRCB and the nine RWQCBs under CCR Title 23, subch. 15, 2510–2559, 2580–2601	—	—	A	A
Water Quality Control Plan (Basin Plan) for the Central Valley Regional Water Quality Control Board	—	—	A	A
State Water Resources Control Board Resolution 68-16	—	—	RAR	RAR
State location-specific requirements				
California Fish and Game Code Section 1601	—	—	A	A
Alquist-Priolo Special Studies Zone Act of 1972 [California Public Resource Code, Section 2621, et. seq.]	RAR	RAR	RAR	RAR
California regulation for faults [22 CCR 66264.18]	—	—	A	A
California Endangered Species Act California Fish and Game Code Sections 2050–2068	A	A	A	A

[a] 1—Monitoring/no remedial action.

2—Long-term monitoring, covering of pit 6, and contingency point-of-use treatment.

3—All of Alternative 2 plus ground water extraction and treatment.

4—All of Alternative 3 plus subsurface permeability reduction barriers beneath pit 6.

A = Applicable.

RAR = Relevant and appropriate.

TBC = To be considered.

— = Not ARAR or TBC.

Table 2-3. Chemical specific ARARs for chemicals of concern at the Pit 6 operable unit.

Chemical of concern	Media of concern[a]	Cancer group[b]	Federal MCL (µg/L)	State MCL (µg/L)	Level of detection (µg/L)[c]
1,1,1-Trichloroethane	GW	D	200	200	0.5
1,2-Dichloroethane	GW/SW	B2	5	0.5	0.5
cis-1,2-Dichloroethylene	GW/SW	D	70	6	0.5
trans-1,2-Dichloroethylene	GW/SW	D	100	10	0.5
Acetone	GW	NA	NA	NA	10
bis(2-ethylhexyl)phthalate	GW	B2	6[d]	4	4[e]
Butylbenzyl phthalate	GW	C	100[f]	NA	10
Carbon disulfide	GW	NA	NA	NA	0.5
Chloroform	GW/SW	B2	100[g]	100[g]	0.5
Ethylbenzene	GW	D	700	680	0.5
Methylene chloride	GW	B2	5	NA	0.5
Phenolics (phenol)	GW	D	NA	NA	10
Tetrachloroethylene	GW/SW	B2-C	5	5	0.5
Toluene	GW	D	1,000	NA	0.5
Trichloroethylene	GW/SW	B2-C	5	5	0.5
Xylenes (total isomers)	GW/SW	D	10,000	1,750	0.5

[a] GW = Ground water from the Carnegie SVRA Ranger well.

SW = Surface water from spring 7.

[b] Integrated Risk Information System (IRIS) database maintained by the U.S. EPA.

U.S. EPA cancer group:

A = Known carcinogen

B2 = Probable carcinogen.

C = Possible carcinogen.

D = Noncarcinogen.

[c] Limit of detection typically reported by analytical laboratories. The limit of detection is instrument- and batch-specific and shall be determined in accordance with U.S. EPA (1986) SW-846.

[d] Effective January 17, 1994.

[e] Estimated.

[f] Proposed.

[g] Total trihalomethanes.

NA = Not available.

Table 2-4. Quantitative remedial action objectives by media.

Media/exposure point	Chemicals of concern	Remedial action objectives
Ground water		
Ranger well	VOCs, primarily TCE	Prevent ingestion of water having chemical concentrations in excess of the MCLs Prevent ingestion of water having chemical (noncarcinogenic) concentrations in excess of MCLs
Surface water		
Carnegie SVRA residence pond	VOCs	Prevent inhalation of VOCs that volatilize from surface water when contaminant concentrations in air are associated with a total excess cancer risk greater than 10^{-4} to 10^{-6} or a hazard index >1.0
Spring 7	VOCs	Prevent inhalation of VOCs that volatilize from surface water when contaminant concentrations in air are associated with a total excess cancer risk greater than 10^{-4} to 10^{-6} or a hazard index >1.0
Subsurface soil (0.5 to 12 ft below ground surface)		
Vicinity of spring 7	VOCs	None required[a,b]
Vicinity of SFTF rifle range	VOCs	Prevent inhalation of VOCs that volatilize from soil when VOC concentrations are associated with a total excess cancer risk greater than 10^{-4} to 10^{-6} or a hazard index >1.0
Surface soil (<0.5 ft below ground surface)		
Throughout study area	HE compounds VOCs	None required[a,b]
Air		
Vicinity of Carnegie SVRA residence pond	VOCs	None required[a,b]
Vicinity of spring 7	VOCs	None required[a,b]

Table 2-4. (Continued)

Media/exposure point	Chemicals of concern	Remedial action objectives
Vicinity of SFTF rifle range	VOCs	None required[a,b]
Throughout the study area	HE compounds VOCs	None required[a,b]
Pit 6 debris	Metals[c] Radiologic substances[c] PCBs[c] VOCs[c]	Prevent inhalation of contaminants that volatilize from soil and prevent ingestion/direct contact with soil/debris when contaminant concentrations are associated with a total excess cancer risk greater than 10^{-4} to 10^{-6} or a hazard index >1.0[d]

[a] In accordance with 40 CFR Section 300.430(e)(i)(A)(2), the baseline cancer risk falls within acceptable exposure levels, which are associated with an excess individual lifetime cancer risk of less than 10^{-6}.

[b] The baseline hazard index (HI) does not exceed 1.0. When the HI exceeds 1.0, it is indicative of the potential for adverse noncarcinogenic health effects to occur (U.S. EPA, 1989).

[c] Identified by historical document review. Post-burial characterization data are not available.

[d] A baseline risk assessment could not be conducted at the pit 6 burial trenches because quantitative analytic data were not available.

Table 3-1. Description of General Response Actions.

General Response Action	Description
No action	No attempt to remove or alter existing contaminants of concern. Requires continued monitoring to ensure institutional and public safety. Natural degradation, dispersion, and adsorption may reduce VOC concentration in ground water.
Containment	Restriction of contaminant movement by physical or chemical barriers.
Extraction	Removal of contaminants from an affected media.
Source removal	Removal of contaminant and affected media. This includes contaminated soil/rock and buried debris.
Treatment	Degradation, detoxification, destruction, or removal of contaminants present in extracted vapor, excavated soil/rock, buried debris, and/or extracted ground water on site or at an off-site permitted facility.
Disposal	Disposal of treated or untreated air emissions, ground water, buried debris or contaminants on or off site.
Administrative controls	Limiting or restricting access to and use of areas or media with elevated risk/hazard.

Table 3-2. Response action screening and evaluation.

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
No action	None	Natural degradation, dilution, adsorption, and evapotranspiration	Applicable	Unknown. VOCs show decreasing concentration trends over last several years.	Implementable	No additional costs above continued monitoring	Yes
Containment	Infiltration/ drainage controls	Landfill cover	Applicable	Retards leaching from soil and reduces VOC flux to atmosphere. Mitigates animal burrowing.	Implementable. Requires leachate monitoring system.	Medium	Yes
		Lined ditches	Applicable	Effective when combined with other technologies	Implementable	Low	Yes
	Vertical barrier	Emplacement of barrier fluids or solids adjacent to the source	Applicable	Effective when combined with other technologies	Implementable	Medium–high	Yes
	Horizontal barrier	Emplacement of barrier fluids or solids below the source	Innovative application of proven technology	Effective when combined with monitoring program	Unknown	High	Yes
	Intersecting inclined barrier	Emplacement of barrier fluids or solids adjacent to and below the source	Innovative application of proven technology	Effective when combined with monitoring program	Unknown	High	Yes

Table 3-2. (Continued)

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Stabilization	Solidification by mixing of grout and/or polymers with source materials	Innovative technology. Applicable.	Effectiveness unknown due to lack of characterization of buried debris	May cause additional releases or mixing of incompatible materials	NCF	No
		In situ vitrification by electric process heating	Innovative technology. Application to landfills is uncertain.	Effectiveness uncertain. Possible migration of contaminants such as mercury and arsenic.	Not implementable due to high void space in buried debris	NCF	No
Extraction	Ground water removal from wells	Ground water pumping	Applicable	Effective	Implementable	Medium	Yes
	Venting	Induced soil vapor extraction	Applicable when combined with other technologies	Effective for mass removal	Implementable	Medium	No
		Passive soil vapor extraction	Innovative technology. Applicable. Emissions need to be permitted or routed to a treatment facility	Uncertain	Implementable	NCF	No
	Gravity drainage	French drains	Applicable. Limited to shallow depth.	Effective	Not implementable. Depth of plume and geologic conditions exceed limits of conventional excavation.	Medium–high	No

Table 3-2. (Continued)

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Thermal enhancement	Steam flooding	Innovative technology for source removal of volatile compounds	Uncertain	Not implementable. No upper confining horizon to contain steam. May cause release of hazardous material to atmosphere.	High	No
		Joule heating	Innovative technology	Effectiveness considered to be extremely localized	Not implementable. May cause release of hazardous material to atmosphere.	Medium–high	No
Source removal	Excavation	Soil and landfill debris removal	Applicable CERCLA removal action needs to be combined with other technologies.	Removes source materials, but not a permanent solution. Materials would be land disposed elsewhere.	Need to protect excavation workers from increased risk to exposure. Need to locate disposal facility to accept waste.	Very high	No
Treatment	Fixation	Chemical treatment of source materials	Innovative technology. Applicable.	Effectiveness unknown due to lack of characterization of buried debris	May cause additional releases or mixing of incompatible materials	NCF	No
	In situ ground water treatment	Air sparging	Innovative technology. Applicable.	Effective	May require horizontal wells	NC	Yes (RITD)
		Surfactant flushing	Innovative technology. Applicable only to NAPL removal.	Can increase mobility of NAPLs	No NAPL present at site	NCF	No

Table 3-2. (Continued)

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Ex situ ground water treatment	Biologically enhanced degradation	Innovative technology	Compound-specific. Not proven effective.	Compound-specific	NCF	No
		GAC sorption	Applicable	Effective for most VOCs	Implementable. Spent carbon requires disposal/regeneration off site.	Low–medium	Yes
		Air stripping	Applicable. Air permit required.	Effective. Possible reduced efficiency due to carbonate precipitation. Requires GAC for air effluent.	Implementable. Potentially high O&M due to carbonate precipitation and reduced efficiency. Design to prevent scaling.	Medium	Yes
		Air sparging	Applicable. Air permit required.	Effective. Possible reduced efficiency due to carbonate precipitation. Requires GAC for air effluent.	Implementable. Potentially high O&M due to carbonate precipitation and reduced efficiency. Design to prevent scaling.	Medium	Yes

Table 3-2. (Continued)

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
		UV/oxidation	Applicable	Effective, destroys most VOCs and FHCs. Reduced efficiency due to carbonate precipitation, turbidity.	Implementable. High energy consumption. May require polishing unit to achieve discharge requirement. High O&M costs.	High	Yes
		Biological treatment	Technology not proven	Not proven effective for VOCs	VOC concentrations may make technology difficult to implement.	High	No
		Electron accelerator	Innovative technology	Effective	Potentially implementable. Possible high energy consumption.	High	Yes (RITD)
	Vapor treatment/air emissions control						
		GAC sorption	Applicable	Effective	Implementable. Spent carbon requires off-site regeneration or disposal.	Low–medium	Yes

Table 3-2. (Continued)

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
		Thermal oxidation	Applicable	Effectively destroys VOCs. However, produces HCl, which must be handled and disposed of.	NCF	NCF	No
		Catalytic oxidation	Not applicable	Not effective for chlorinated VOCs due to production of potentially toxic by-products.	NCF	NCF	No
		Electron accelerator	Innovative technology. Applicable.	Effective	Potentially implementable. Possible high energy consumption.	High	Yes (RITD)
		Resin^a sorption	Innovative technology	Effective	Potentially implementable	NC	Yes (RITD)
		UV/oxidation	Innovative technology. Applicable.	Effective at destroying TCE. Produces off-gas products.	Potentially implementable	High	Yes (RITD)
Disposal	Treated ground water disposal	Permitted discharge to sanitary sewer or storm drain	Not applicable. There is no sanitary sewer or storm drains in the vicinity of the Pit 6 operable unit.	NCF	NCF	NCF	No

Table 3-2. (Continued)

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
		On-site surface discharge	Applicable. Infiltration basin or irrigation.	Effectiveness is a function of flow rates and infiltration rates. May interfere with dewatering.	Implementable. Discharge water must meet regulatory standards. Must ensure that recharge does not adversely affect subsurface (e.g., migration of VOCs).	Low	Yes
		Air misting	Applicable	Effective for low flow rates	Implementable	Low	Yes
		Reinjection	Applicable	Effective. May be used to flush contaminants toward extraction wells/trenches.	Must ensure that recharge does not adversely affect subsurface (e.g., migration of VOCs). Discharge water must meet regulatory standards. Low permeability subsurface may make this difficult to implement.	Low–medium	Yes
		On-site recycling/reuse	Not applicable	Effective	Difficult. Need to replumb facilities. Limited demand for water.	NCF	No

Table 3-2. (Continued)

General Response Action	Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
Administrative controls	Restrict access and use	Fencing and signs	Applicable for long-term exposure concerns	Effective	Readily implementable	Low	Yes
		Security guards/patrols	Applicable	Effective	Implementable	High	Yes
		Perpetual deed restrictions	Applicable	Effective	Implementable	Low	Yes
	Point-of-use	GAC treatment	Applicable	Effective	Implementable	Low	Yes

[a] PADRE™ units.

NC = Not considered.

NCF = Not considered further.

RITD = Retained for innovative technology development.

Table 3-3. Retained remedial technologies and process options.

Technology (process options)	Effectiveness	Cost
Natural degradation, dilution, adsorption, and evapotranspiration	Unknown. VOCs show decreasing concentration trends over last several years.	No additional costs above continued monitoring
Landfill cover	Retards leaching from soil and reduces VOC flux to atmosphere. Mitigates animal burrowing.	Medium
Lined ditches	Effective when combined with other technologies	Low
Emplacement of barrier fluids or solids adjacent to the source.	Effective when combined with other technologies	Medium–high
Emplacement of barrier fluids or solids below the source.	Effective when combined with monitoring program	High
Emplacement of barrier fluids or solids adjacent to and below the source.	Effective when combined with monitoring program	High
Ground water pumping	Effective	Medium
GAC sorption (ground water)	Effective for most VOCs	Low–Medium
Air stripping	Effective. Possible reduced efficiency due to carbonate precipitation. Requires GAC for air effluent.	Medium
Air sparging	Effective. Possible reduced efficiency due to carbonate precipitation. Requires GAC for air effluent.	Medium
UV/oxidation (ground water)	Effective, destroys most VOCs and FHCs. Reduced efficiency due to carbonate precipitation, turbidity.	High
GAC sorption (vapor)	Effective	Low–medium
On-site surface discharge	Effectiveness is a function of flow rates and infiltration rates. May interfere with dewatering.	Low
Air misting	Effective for low flow rates	Low
Reinjection	Effective. May be used to flush contaminants toward extraction wells/trenches.	Low–medium
Fencing and signs	Effective	Low
Security guards/patrols	Effective	High
Perpetual deed restrictions	Effective	Low
POU GAC treatment	Effective	Low

Table 4-1. Summary of Pit 6 operable unit remedial alternatives.

Alternative 1—No action	Ground water sampling/water level measurement
	Quarterly water level measurements of 27 monitor wells for 30 years, as follows.
	First 5 years:
	Quarterly sampling of 8 wells and 1 spring, semiannual sampling of 12 wells, annual sampling of 7 wells.
	Following 25 years:
	Annual sampling of 27 wells and 1 spring.
	10% QA/QC samples.
	Other
	Well and pump maintenance. Reporting. Project management. Database management. QA/QC.
	Project life: 30 years of ground water monitoring.
Alternative 2—Risk mitigation and natural attenuation	All components of Alternative 1 plus:
	Construction of an impermeable landfill cover and associated drainage control.
	Installation of 8 monitor wells.
	Contingency POU treatment.
	Installation of fencing and signs around spring 7, and continued property stewardship.
	Ground water sampling/water level measurement
	Quarterly water level measurements of 35 monitor wells for 30 years.
	First 5 years:
	Quarterly sampling of 16 wells and 1 spring, semiannual sampling of 12 wells, annual sampling of 7 wells.
	Following 25 years:
	Annual sampling of 35 wells and 1 spring.
	10% QA/QC samples.
	Project life: 30 years of ground water monitoring.

Table 4-1. (Continued)

Alternative 3—Risk mitigation with enhanced mass removal	All components of Alternative 2 plus: Installation of 5 ground water extraction wells and 10 additional monitor wells. Plume containment and enhanced mass removal by ground water extraction and treatment, if necessary. Operation and maintenance for 25 years. Ground water sampling/water level measurement Quarterly water level measurements of 35 monitor wells for first 5 years then 50 wells for next 25 years. First 5 years (prior to starting ground water extraction) Quarterly sampling of 16 wells and 1 spring, semiannual sampling of 12 wells, annual sampling of 7 wells. First 5 years of ground water extraction: Quarterly sampling of 37 wells and 1 spring, semiannual sampling of 8 wells, annual sampling of 5 wells. Following 20 years: Annual sampling of 50 wells and 1 spring. 10% QA/QC samples. Project life: 5 years of pre-extraction monitoring followed by 25 years of ground water extraction if necessary. Ground water monitoring would be conducted for a total of 30 years whether or not ground water extraction was implemented.
Alternative 4—Release mitigation with enhanced mass removal	All components of Alternative 3 plus: Installation of subsurface permeability reduction barriers. Project life: 5 years of pre-extraction monitoring followed by 25 years of ground water extraction if necessary. Ground water monitoring would be conducted for a total of 30 years whether or not ground water extraction was implemented.

Table 4-2. Estimated average TCE concentration in extracted ground water.

Proposed well (nearby well)[a]	Average 1993 TCE concentration in ground water (µg/L)	Estimated flow rate (gpm)	Flow weighted average TCE concentration in ground water (µg/L)
K6-34 (EP6-09)	16	10	
K6-35 (K6-01S)	2.1	0.5	
K6-36 (K6-18)	9.2	0.1	
K6-37 (K6-16)	4.4	0.1	
K6-48 (K6-17)	1.3	0.1	
Totals:		10.8	15.0

[a] Because extraction wells are not yet installed, we used the concentration and well yield data from the nearest, comparably screened monitor well.

Table 5-1. Detailed evaluation of remedial alternatives for the Pit 6 operable unit.

	Evaluation criteria					
Remedial alternative	Overall protection of human health and the environment[a]	Compliance with ARARs	Long-term effectiveness and permanence	Reduction in toxicity, mobility, and volume (TMV)	Short-term effectiveness	Implementability
Alternative 1 No action	May not be protective of human health and the environment.[a] Does not address safety hazards related to current pit cover.	May not meet all requirements of State Resolutions 68-16 and 92-49.	May not result in timely reduction of VOCs in ground water. However, declining concentration trends suggest that natural attenuation/degradation to less than MCLs will occur within a few years. May not preserve all beneficial uses of ground water. Does not address potential risks to human health and environment from waste in trenches.	TMV of waste in trenches/pits not reduced. TMV of VOCs in ground water not actively reduced. VOC mass removal by natural degradation and evapotranspiration continues.	No impact to general public. Possible exposure of workers during ground water sampling. Use of protective procedures, clothing, and equipment mitigate risk.	Technically and administratively implementable.
Alternative 2 Risk mitigation and natural attenuation	Human health risks reduced to EPA-accepted levels. Reduces exposure potential for sensitive ground-dwelling species. Eliminates potential human health risk associated with VOCs reaching downgradient supply wells, CARNRW1 and CARNRW2, and the SVRA residence pond through POU treatment and subsequent permanent remedies. Pit cover eliminates potential inhalation risk from VOCs in subsurface soils. Pit cover reduces but does not eliminate potential risks from future releases from the trenches pits. Eliminates potential direct exposure to the waste and any contaminated surface soils. Pit cover removes potential safety hazards associated with current condition of pit cover layer.	May not meet all requirements of State Resolutions 68-16 and 92-49. Pit cover construction meets all ARARs. GAC disposal (if necessary) from POU is in accordance with ARARs.	Fence and signs, and site access restrictions control inhalation health risks at spring 7.[a] May not preserve all beneficial uses of ground water. However, declining concentration trends suggest that natural attenuation/degradation to less than MCLs will occur within a few years. If POU treatment is necessary, permanent remedies will be determined at that time. Pit cover and drainage control mitigate future releases and migration of VOCs from source areas by eliminating infiltration. Pit cover prevents direct exposure to waste in trenches and eliminates potential inhalation exposure to VOCs in subsurface soils. Pit cover requires inspection and maintenance to ensure integrity and is subject to degradation by rain, erosion, settlement, and seismic activity.	Pit cover reduces mobility of waste in trenches caused by infiltration. There is no reduction in the potential mobility of waste in the trenches/pits from liquid releases or a rising water table. Toxicity and volume of waste in trenches/pits are not reduced. TMV of VOCs in ground water not actively reduced. VOC mass removal by natural degradation and evapotranspiration continues.	Possible environmental and worker risk of exposure during monitoring, pit cover construction, and installation of monitor wells. Exposures and releases could occur from cave-ins, rupture of waste containers, and dust generated while grading and compacting or during monitor well construction. Safety precautions, including planning, screening, monitoring, and personal protective equipment (PPE) mitigate risk. Construction activities necessitate an interruption in use of rifle range. Requires temporary relocation of rifle range activities.	Technically and administratively implementable. Equipment and materials for cover and monitor wells are readily available. Pit cover grading and compacting activities could cause additional releases by disturbing buried containers. Liquid-phase GAC is BAT for removing VOCs from ground water at POU. Services and materials for POU treatment system construction, operation, and maintenance, and off-site regeneration of GAC are available if necessary. Drilling activities would produce about 20 yd^3 of soil cuttings that might require treatment and/or off-site disposal.

Table 5-1. (Continued)

	Evaluation criteria					
Remedial alternative	Overall protection of human health and the environment[a]	Compliance with ARARs	Long-term effectiveness and permanence	Reduction in toxicity, mobility, and volume	Short-term effectiveness	Implementability
Alternative 3 Risk mitigation with enhanced mass removal	Human health risks reduced to EPA-accepted levels. Reduces exposure potential for sensitive ground-dwelling species. Eliminates potential human health risk associated with VOCs reaching downgradient supply wells, CARNRW1 and CARNRW2, and the SVRA residence pond through POU treatment and subsequent permanent remedies. Pit cover reduces but does not eliminate potential risks from future releases from the trenches. Eliminates potential direct exposure to the waste and any contaminated surface soils. Pit cover eliminates potential inhalation risk from VOCs in subsurface soils. Pit cover removes potential safety hazards associated with current condition of pit cover layer. If necessary, ground water extraction and treatment is protective of environment.	Pit cover construction meets all ARARs. Ground water remediation meets all existing ARARs. GAC disposal (if necessary) from POU and ground water treatment system is in accordance with ARARs. Treated ground water discharge meets ARARs. Achievable cleanup levels may not meet State Resolutions 68-16 and 92-49 requirement of restoration to background concentrations.	Fence and signs control inhalation health risks at spring 7[a] and will not be necessary after VOCs are remediated. Site access continues to be restricted. If POU treatment is necessary, permanent remedies will be determined at that time. Pit cover and drainage control mitigate future releases and migration of VOCs from source areas as a result of infiltration, but do not reduce potential unquantified risks of waste in the trenches/pits. Pit cover mitigates direct exposure to waste in trenches and eliminates potential inhalation exposure to VOCs in subsurface soils. Pit cover requires maintenance to ensure integrity and is subject to degradation by rain, erosion, settlement, and seismic activity. If implementation is necessary, ground water extraction reduces VOC mass and prevents off-site migration. Declining concentration trends suggest that natural attenuation/degradation to less than MCLs will occur within a few years.	Pit cover reduces mobility of waste in trenches/pits caused by infiltration. There is no reduction in the potential mobility of waste in the trenches/pits from liquid releases or a rising water table. Toxicity and volume of waste in trenches/pits are not reduced. If implementation is necessary, ground water extraction reduces mobility and volume of VOCs. Off-site thermal regeneration of GAC (from either POU or extracted ground water treatment) destroys recovered VOCs. VOC mass removal by natural degradation and evapotranspiration continues.	Possible environmental and worker risk of exposure during monitoring, pit cover construction, and installation of monitor wells. Exposures and releases could occur from cave-ins, rupture of waste containers, and dust generated while grading, compacting, or drilling. Safety precautions including planning, screening, monitoring, and PPE mitigate risk. Construction activities necessitate an interruption in use of rifle range. Requires temporary relocation of rifle range activities. Ground water extraction and treatment system operation have no impact on general public. Plume control (if necessary) prevents off-site migration of VOCs. Provides capability to implement and conduct pilot tests on promising innovative ground water treatment technologies. BAT used in conjunction with innovative technology ensures no releases occur.	Technically and administratively implementable. Equipment and materials for cover and monitor/extraction wells are readily available. Pit cover grading and compacting activities could cause additional releases by disturbing buried containers. Liquid-phase GAC is BAT for removing VOCs from ground water. Services, materials, and permits for ground water extraction and treatment; POU treatment system construction, operation, and maintenance; and off-site regeneration of GAC are available if necessary. Drilling activities would produce about 600 yd^3 of cuttings that might require treatment and/or off-site disposal.

Table 5-1. (Continued)

	Evaluation criteria					
Remedial alternative	Overall protection of human health and the environment[a]	Compliance with ARARs	Long-term effectiveness and permanence	Reduction in toxicity, mobility, and volume	Short-term effectiveness	Implementability
Alternative 4 Release mitigation with enhanced mass removal	Human health risks reduced to EPA-accepted levels. Reduces exposure potential for sensitive ground-dwelling species. Eliminates potential human health risk associated with VOCs reaching downgradient supply wells, CARNRW1 and CARNRW2, and the SVRA residence pond through POU treatment and subsequent permanent remedies. Pit cover and permeability reduction barriers reduce but do not eliminate potential risks from future releases from the trenches. Eliminates potential direct exposure to the waste and any contaminated surface soils. Pit cover eliminates potential inhalation risk from VOCs in subsurface soils. Pit cover removes potential safety hazards associated with current condition of pit cover layer. If necessary, ground water extraction and treatment is protective of environment.	Pit cover and permeability reduction barrier construction meet all ARARs. Ground water remediation meets all existing ARARs. GAC disposal (if necessary) from POU and ground water treatment system is in accordance with ARARs. Treated ground water discharge meets ARARs. Achievable cleanup levels may not meet State Resolutions 68-16 and 92-49 requirement of restoration to background concentrations.	Fence and signs control inhalation health risks at spring 7[a] and will not be necessary after VOCs are remediated. Site access continues to be restricted. If POU treatment is necessary, permanent remedies will be determined at that time. Pit cover and drainage control mitigate future releases and migration of VOCs from source areas as a result of infiltration, but do not reduce potential unquantified risks of waste in the trenches/pits. Pit cover mitigates direct exposure to waste in the trenches and eliminates potential inhalation exposure to VOCs in subsurface soils. Pit cover requires maintenance to ensure integrity and is subject to degradation by rain, erosion, settlement, and seismic activity. If implementation is necessary, ground water extraction reduces VOC mass and prevents off-site migration. Declining concentration trends suggest that natural attenuation/degredation to less than MCLs will occur within a few years. Permeability reduction barriers provide added long-term protection to the environment by mitigating the potential for releases from the buried waste or leaching caused by a water table rise. Integrity of permeability reduction barriers could be affected by potential seismic activity.	Pit cover reduces mobility of waste in trenches/pits caused by infiltration. Permeability reduction barriers reduce potential mobility of waste in trenches by liquid releases or by leaching resulting from rising water table. Toxicity and volume of waste in trenches are not reduced. If implementation is necessary, ground water extraction reduces mobility and volume of VOCs. Off-site thermal regeneration of GAC (from either POU or extracted ground water treatment) destroys recovered VOCs. VOC mass removal by natural degradation and evapotranspiration continues.	Possible environmental and worker risk of exposure during monitoring, pit cover construction, installation of monitor wells, and installation of permeability reduction cells. Exposures could occur from cave-ins, rupture of waste containers, and dust generated while grading, compacting, drilling, or trenching. Safety precautions, including planning, screening, monitoring, and PPE mitigate risk. Construction activities necessitate an interruption in use of rifle range. Requires temporary relocation of rifle range activities. Ground water extraction and treatment system operation have no impact on general public. Plume control (if necessary) prevents off-site migration of VOCs. Provides capability to implement and conduct pilot tests on promising innovative ground water treatment technologies. BAT used in conjunction with innovative technology ensures no releases occur.	Technically and administratively implementable; however, integrity of permeability reduction barriers cannot be verified, only monitored. Equipment and materials for cover and monitor/extraction wells are readily available. Pit cover grading and compacting activities could damage containers and cause a release from the pit contents. Liquid-phase GAC is BAT for removing VOCs from ground water. Services, materials, and permits for ground water extraction and treatment; POU treatment system construction, operation, and maintenance; and off-site regeneration of GAC are available if necessary. Drilling and barrier installation would produce more than 3,000 yd^3 of cuttings that might require treatment and/or off-site disposal.

---

[a] Because spring 7 has been dry since the summer of 1992, there is no current elevated risk to human health or the environment.

Table 5-2. Summary of present-worth costs for the Pit 6 operable unit remedial alternatives (in millions of 1994 dollars).

Remedial alternative	Capital costs[a]	Operation and maintenance costs	Monitoring costs[b]	Overhead[c]	Subtotal[d]	Contingency (20%)	Total present worth[d]
Alternative 1 No action	0	0	1.44	0.20	1.64	0.33	1.97
Alternative 2 Risk mitigation and natural attenuation	2.08	0.12	1.49	0.52	4.21	0.84	5.05
Alternative 3 Risk mitigation with enhanced mass removal	4.02	2.15	2.06	1.15	9.38	1.88	11.25
Alternative 4 Release mitigation with enhanced mass removal	9.60	2.15	2.06	1.93	15.74	3.15	18.89

[a] Capital costs include engineering design, construction, and management of remediation systems.

[b] Monitoring costs include ground water and treatment system monitoring.

[c] Overhead includes LLNL General & Administrative tax at 7.5% and Lab-Directed Research & Development tax at 6.0%.

[d] Rounding may cause subtotal or total to appear incorrect by ±0.01 million dollars. Subtotals and totals are taken directly from Tables G1–G4.

Table 5-3. Comparative evaluation of remedial alternatives for the Pit 6 operable unit.

Alternative	Overall protection of:		Compliance with ARARs[a]	Long-term effectiveness and permanance		Reduction in toxicity, mobility, and volume (TMV)						Short-term effectiveness	Implement-ability	Cost[d]	State acceptance	Community acceptance
	Human health	Environ-ment		Ground water[b]	Trenches	Ground water[b]			Trenches							
						T	M	V	T	M[c]	V					
Alternative 1	◐	◐	●	◐	○	◐	◐	◐	○	○	○	Not applicable	●	1.97M	TBD	TBD
Alternative 2	●	◐	●	◐	●	◐	◐	◐	○	●	○	●	●	5.05M	TBD	TBD
Alternative 3	●	●	●	●	●	●	●	●	○	●	○	●	●	11.25M	TBD	TBD
Alternative 4	●	●	●	●	●	●	●	●	○	●	○	●	●	18.89M	TBD	TBD

○ = Does not meet criteria

◐ = May meet criteria

● = Meets criteria

TBD = To be determined

a = Alternatives may not meet all requirements of SWRCB Resolutions 68-16 and 92-49.

b = VOCs in ground water are naturally attenuating, thus TMV may also be reduced by Alternatives 1 and 2.

c = In Alternatives 2, 3, and 4, mobility is reduced by the installation of a pit cover. In Alternative 4, mobility is further reduced by installing subsurface permeability reduction barriers.

d = Total present worth.

Table 6-1. Comparison of concentrations of airborne contaminants with ACGIH TLV-STELs during a potential accident scenario.

Chemical	Concentration in exposed drill cuttings (g/kg)	Concentration in air near the borehole (mg/m³)	Concentration in air at the nearest site boundary (mg/m³)	TLV/TWA (mg/m³)	CAPCOA reference exposure levels (acute)
TCE	50	78	1.4	269	N/A
PCB	48	1.8×10^{-3}	3.3×10^{-5}	5×10^{-1}	N/A
Mercury	7.8	7.5×10^{-3}	1.3×10^{-4}	5×10^{-2}	3×10^{-3}

Table 6-2. Incremental cancer risk and noncancer HI associated with adult off-site exposures to contaminants in soils exposed to air during a potential accident scenario.

Receptor	Incremental cancer risk	Noncancer HI
Maximum exposed off-site individual	4.0×10^{-7}	5.1×10^{-1}

Table 6-3. Concentrations of contaminants in soils as a result of air-fall deposition at selected exposure points during a potential accident scenario.

Contaminant	Concentration of contaminants in soils at spring 7 (mg/kg)	Concentration of contaminants in soils at spring 15 (mg/kg)	Concentration in soils considered protective of species (mg/kg)
TCE	1.1×10^{-3}	9.0×10^{-5}	3.9
PCB	1.0×10^{-3}	9.0×10^{-5}	1.0×10^{-1}
Mercury	2.0×10^{-4}	1.0×10^{-5}	1.3×10^{-1}

Appendix A

Estimates of Area, Volume, and Mass, and Calculation Sensitivities

Appendix A

Estimates of Area, Volume, and Mass, and Calculation Sensitivities

A-1. Estimates of Area, Volume, and Mass

This appendix presents estimates of the volume and mass of TCE in ground water at the Pit 6 operable unit and shows how these estimates are derived. Table A-1 summarizes the estimated volume of waste contained in pit 6 (Webster-Scholten, 1994). Table A-3 presents the estimated area, volume, and mass of TCE in the saturated zone in the Pit 6 operable unit.

TCE has the highest mass contribution of all VOCs detected in ground water at the Pit 6 operable unit. Other detected chemicals of concern are present at lower concentrations and frequencies of detection relative to TCE (SWRI report Chapters 4 and 12, and Appendix P). Therefore, we used TCE as the primary indicator chemical to delineate areas and volumes of releases at the Pit 6 operable unit. Although we do not address other chemicals of potential concern in this appendix, we considered them in the design of alternatives discussed in Chapter 4. Figure A-1 shows the distribution of TCE in ground water as defined by the isoconcentration contours.

In our calculations, we assumed a porosity of 25% (SWRI Chapter 12), and a TCE density of 1.46 (g/cc) (Windholz, 1983). The TCE concentrations used in these estimates were derived from our most recent complete sampling data (second and third quarter 1993). Isoconcentration contours were used to define the areas affected (Fig. A-1). We assume complete vertical mixing of contaminants in ground water. A representative saturated thickness was obtained from well EP6-09, the only well that penetrates the bottom of the aquifer, using second quarter 1993 water level data. To calculate the total volume of TCE in ground water, we used the geometric mean TCE concentration to represent the bulk concentration of the contaminated volume between adjacent contours. For example, the volume between 0.5 μg/L (ppb) and 5 μg/L (ppb) TCE isoconcentration contours was assigned a concentration value of 1.58 μg/L (ppb). We calculated the volume of contaminated ground water, the mass of TCE, and the liquid equivalent of TCE corresponding to this mass for each of the two contour intervals shown in Figure A-1 (i.e., 0.5 to 5 μg/L [ppb] and > 5 μg/L). The corresponding masses/volumes calculated for each of the two contour intervals were summed to estimate the total quantity of contaminated ground water and the corresponding volume/mass of TCE contained within the plume (Table A-3).

We used the following equation to calculate the total volume (in gallons) of ground water contaminated with TCE ($V_{c\text{-}gw}$):

$$V_{c\text{-}gw} = A \times b \times n \times 7.48 \qquad \text{(A-1)}$$

where,

A = area between TCE contour intervals (ft^2),

b = saturated thickness (ft),

n = porosity (dimensionless),

7.48 = conversion factor (gal/ft^3).

We used the following equation to calculate mass of TCE (M_{tce}) dissolved in ground water:

$$M_{tce} = A \times b \times n \times (C_{tce}/10^6) \times 28.32 \qquad \text{(A-2)}$$

where,

A = area between contour intervals (ft^2),

b = saturated thickness (ft),

n = porosity (dimensionless),

C_{tce} = geometric-mean TCE ground water concentrations (µg/L),

10^6 and 28.32 = conversion factors (µg/g and L/ft^3, respectively).

We used the following equations to convert the mass of TCE into an equivalent liquid volume of TCE (V_{TCE}):

$$V_{TCE} = M_{TCE} / (1.46 \times 1000 \times 3.785) \qquad \text{(A-3)}$$

where,

M_{TCE} = mass of TCE (g) from equation A-2

$(1.46 \times 1000 \times 3.785)$ = conversion factor for the density of TCE (ml/L and L/gal, respectively).

Table A-2 summarizes the input values used in the above equations. Table A-3 presents the results for the corresponding calculations.

A-2. Sensitivity Analysis for TCE Mass Estimates

As shown in Equation A-2, three variables need to be considered when estimating the mass of TCE in ground water: area, saturated thickness, and porosity. The sensitivity analyses were performed by changing one variable while holding all other variables constant. The sensitivities of these three variables are discussed below.

A-2.1. Area

Figure A-2 shows the linear relationship between the area affected and the mass of TCE in ground water. As displayed in the figure, a decrease in the area that is affected results in a linear decrease in TCE mass in ground water.

A-2.2. Saturated Thickness

Figure A-3 shows the linear relationships between saturated thickness and TCE mass. As expected, an increase in saturated thickness results in a linear increase in TCE mass in ground water.

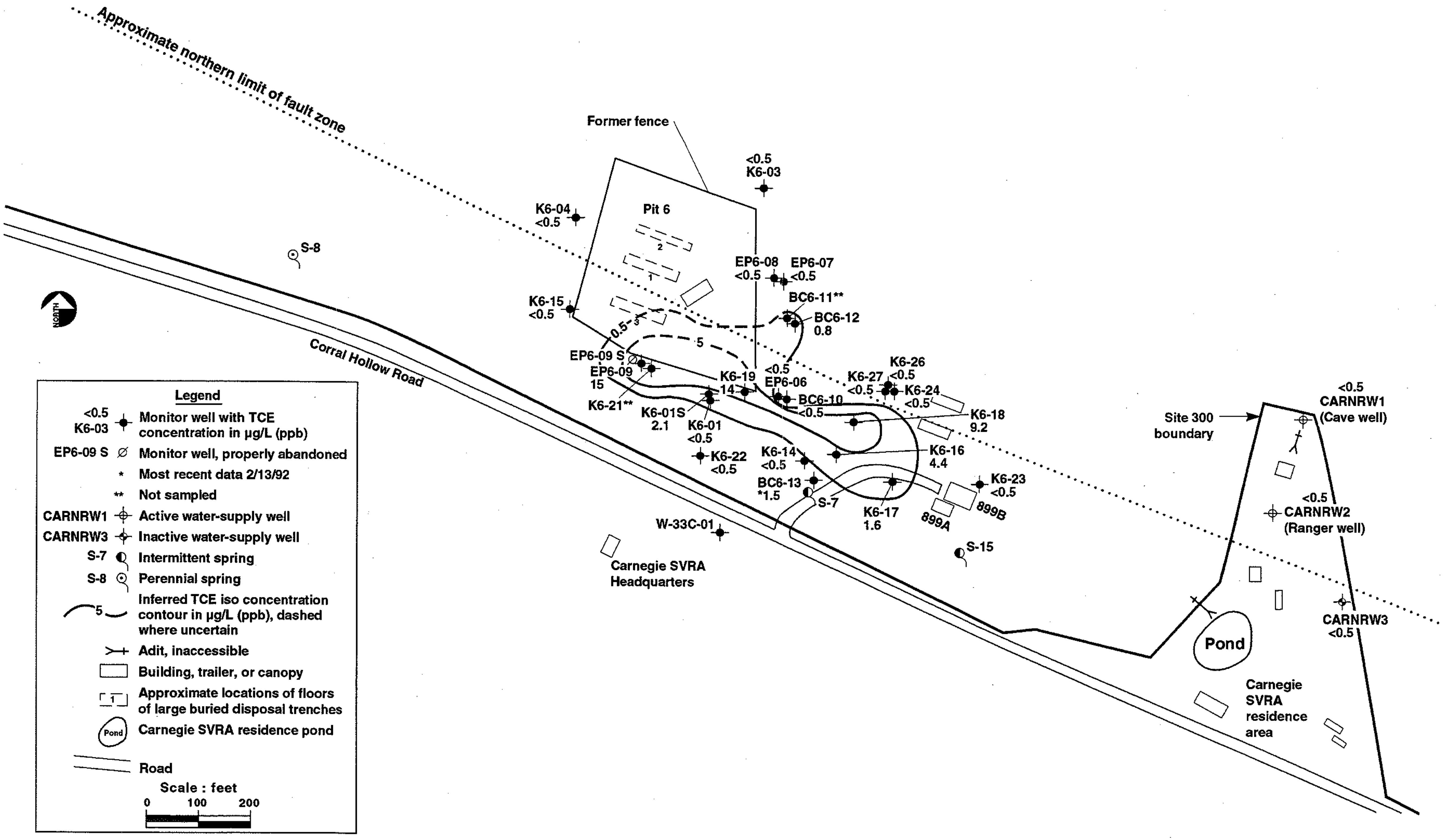
A-2.3. Porosity

Figure A-4 shows the linear relationship between porosity and TCE mass. These data indicate that an increase in porosity results in a linear increase in TCE mass in ground water.

A-3. References

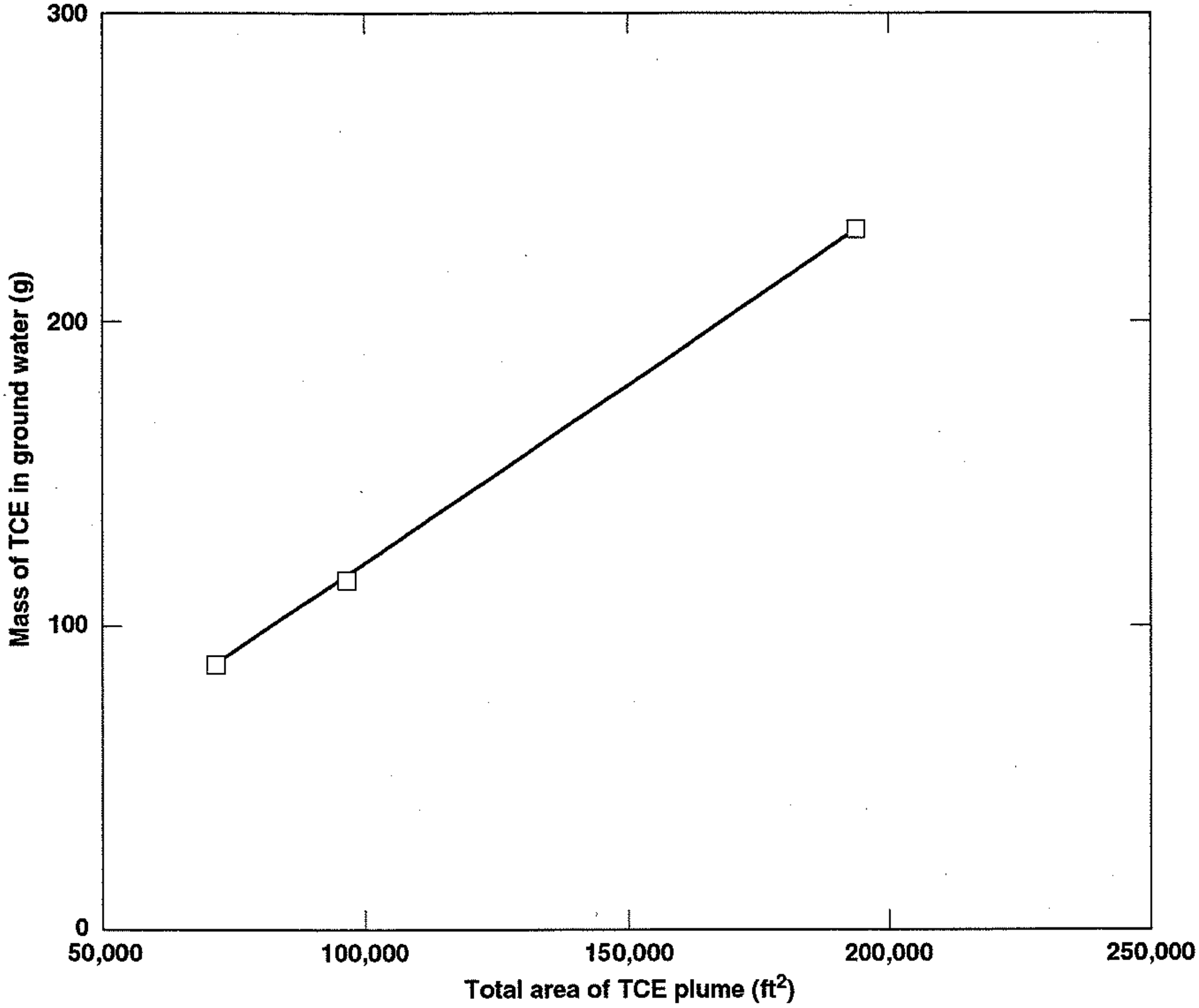
Windholz, M., Ed. (1983), *The Merck Index, 10th Edition* (Merck & Co., Rahway, N.J.).

Webster-Scholten, C. P., Ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-108131).



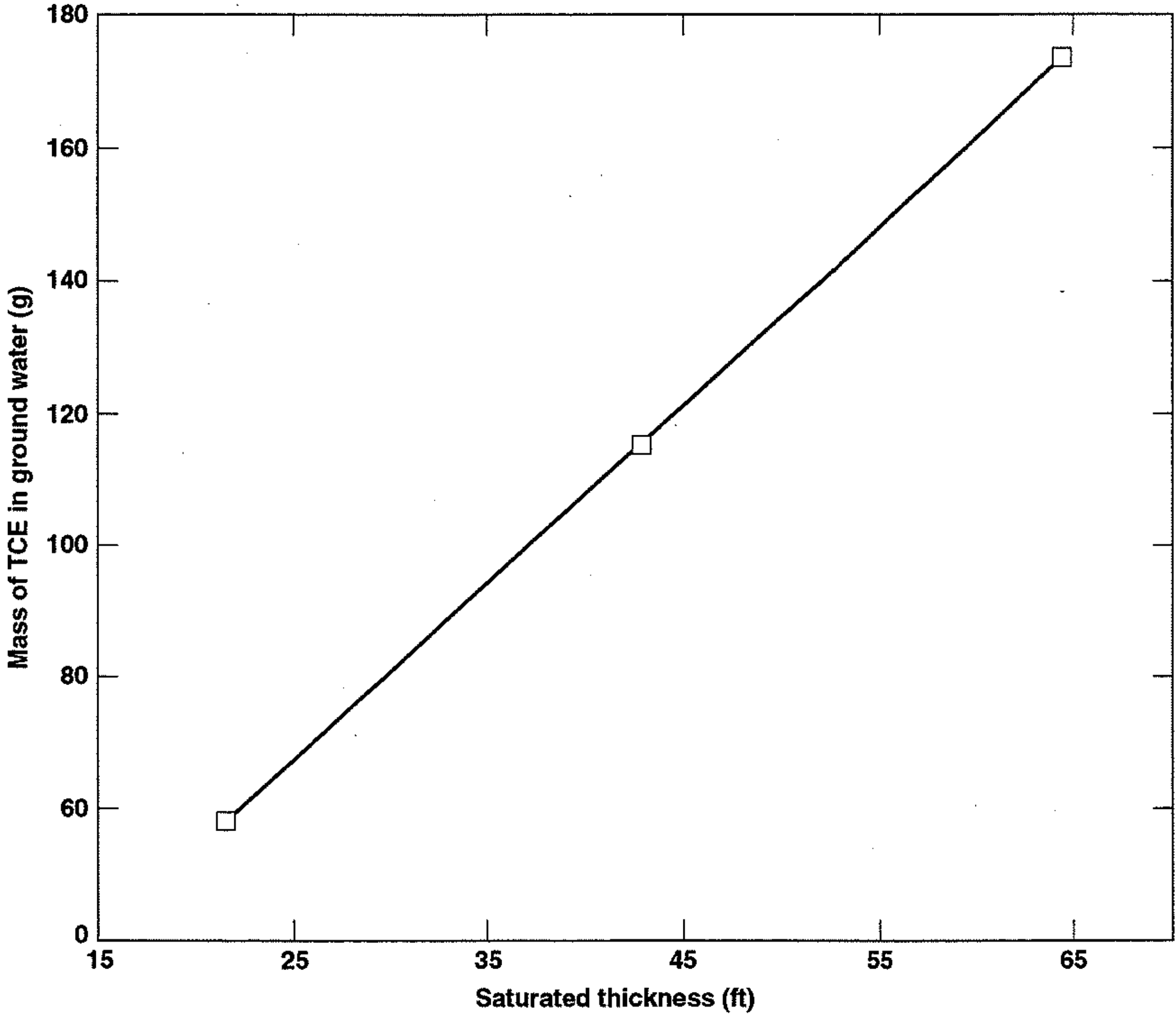
ERD-FS-PT6-3199

Figure A-1. Distribution of TCE in ground water, Pit 6 operable unit, May–July 1993.



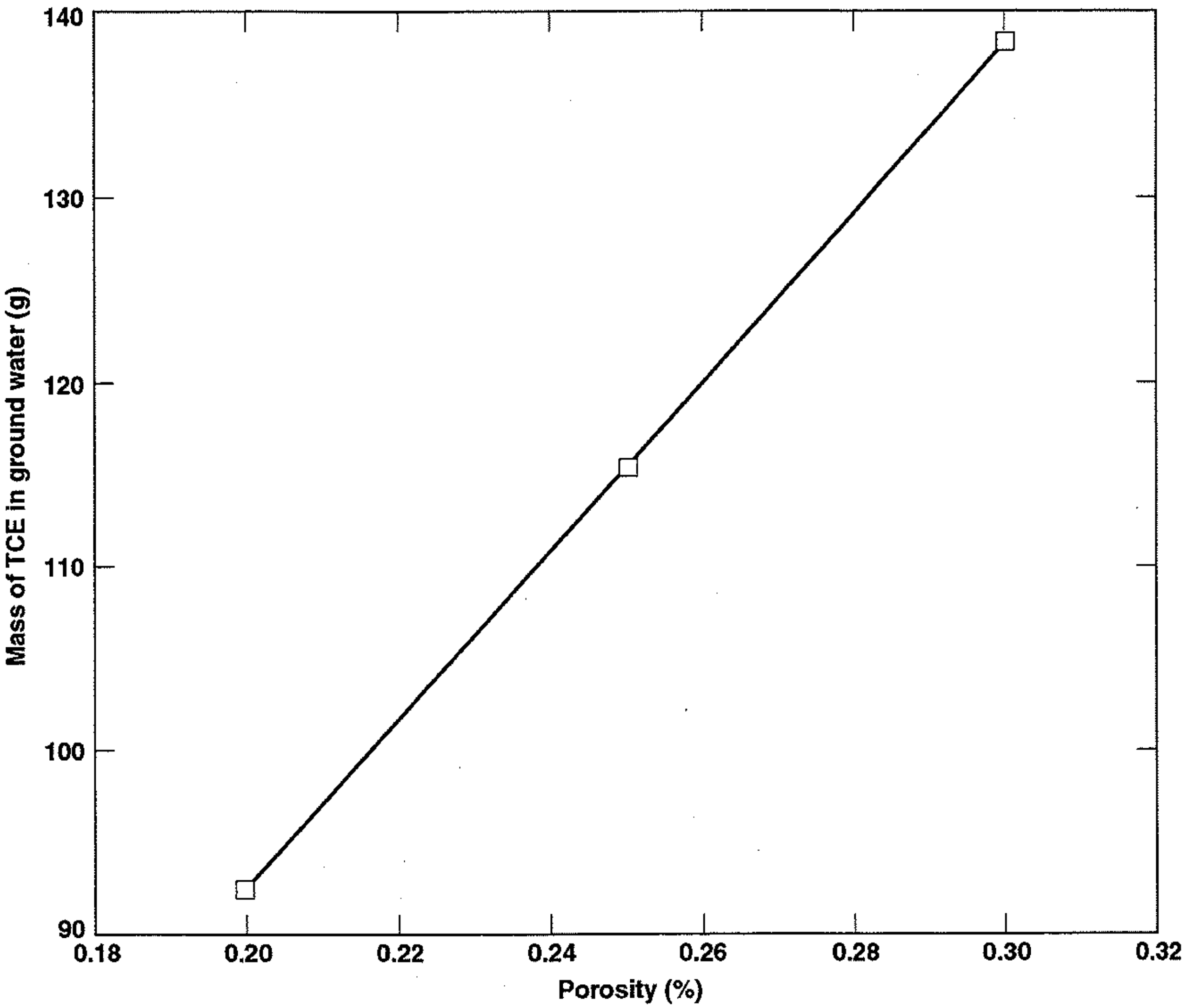
ERD-FS-PT6-3196

Figure A-2. Estimated mass of TCE in ground water vs plume area.



ERD-FS-PT6-3197

Figure A-3. Estimated mass of TCE in ground water vs saturated thickness.



ERD-FS-PT6-3198

Figure A-4. Estimated mass of TCE in ground water vs porosity.

Table A-1. Waste volume estimates for pit 6.[a]

Trench or animal pit	Estimated volume (yd^3)	Estimated volume (% of total)
Trenches 1, 2, and 3	1,760	86
Animal pits 1 and 6	287	14
Total	2,047	100

[a] Estimates obtained from SWRI Chapter 12 (Webster-Scholten, 1994).

Table A-2. Input parameters and values used in saturated zone contaminant mass and volume estimates for the Pit 6 operable unit.

Input Parameter	Values	
Contour range [1]	0.5–5 µg/L	> 5 µg/L
Area between concentration contours (A)	64,640 ft^2	32,000 ft^2
Saturated thickness (b)	43 ft	43 ft
Porosity (n)	0.25	0.25
Geometric mean concentration (C_{tce})	1.58 µg/L	8.66 µg/L

[1] From Figure A-1.

Table A-3. Estimated area, volume, and mass of TCE in the saturated zone in the Pit 6 operable unit.

Representative saturated thickness (ft)	Approximate area affected (ft^2)[a]	Estimated volume of contaminated ground water (gal.)[b]	Estimated volume of dissolved TCE (gal.)[c]	Estimated mass of dissolved TCE (g)[d]	Estimated total mass of TCE (g)[e]
43	97,000	7,800,000	0.021	115	207

[a] Area containing TCE concentrations above 0.5 µg/L (ppb). Estimated by planimeter (see Fig. A-1).

[b] The product of the affected area, representative saturated thickness, and an assumed porosity of 0.25.

[c] Product of the pore volume and the geometric mean of the concentration divided by a TCE density of 1.46 g/cc.

[d] Product of the pore volume and geometric mean of TCE concentration.

[e] Equal to mass in ground water plus mass sorbed, assuming a retardation factor of 1.8 (Webster-Scholten, 1994).

Appendix B

Evaluation of Baseline, Post-SWRI, and Cumulative Data on Environmental Contamination

Appendix B

Evaluation of Baseline, Post-SWRI, and Cumulative Data on Environmental Contamination

This appendix presents a comparative statistical analysis of the baseline data presented in the SWRI report (Webster-Scholten, 1994) and cumulative data obtained through June 1993. Also included is a description of post-SWRI data collected between the SWRI data cutoff date of December 31, 1991 and June 1993. The primary purpose of these comparisons is to determine, to the extent possible, whether environmental contamination in this area differs substantially from contamination at the time the SWRI was prepared. This comparison of baseline and cumulative data is limited to ground water and surface water (at spring 7) because no samples of surface soil (< 0.5 ft) or subsurface soil have been collected since the SWRI data cutoff date.

B-1. Post-SWRI Data on Substances Detected in Ground Water and Surface Water

We examined ground water data obtained between January 1, 1992 and June 23, 1993 to determine if any substances have been detected other than those identified as contaminants of potential concern in the SWRI report. This examination included all monitoring wells within the operable unit and was not restricted to those wells in the principal region of ground water contamination (EP6-09, K6-01, -16, -18, and -19). Of particular interest was whether there have been any detections of polychlorinated biphenyls (PCBs) in ground water, as historical records indicate that PCB-containing capacitors may have been disposed of in the pit (Webster-Scholten, 1994). Through the last quarter of 1991, we routinely sampled for these compounds at the Pit 6 operable unit wells; none had been detected by the SWRI data cutoff date. Since the first quarter of 1992, sampling for PCBs has been limited to two wells, EP6-06 and K6-19, that are downgradient of pit 6. Analyses of the PCB isomers PCB 1016, 1221, 1232, 1242, 1248, 1254, and 1260, as well as total PCBs, in water from these wells have been performed on a quarterly basis. The analytical limit-of-detection has ranged from 0.3 to 3.0 µg/L. There have been no detections of PCBs in ground water.

Our examination of post-SWRI data indicated that there have been sporadic, low-level (<1.0 µg/L) detections of 1,1,1-trichloroethane and 1,1-dichloroethane, and a single detection of tetrahydrofuran in well W-34-01, located in the Paper Canyon region of the Pit 6 Area study area, but outside of the Pit 6 operable unit. Monitoring of ground water in this area will continue.

There have also been one or more detections of 1,2-dichloroethane, 1,2-dichloropropane, 1,3-dichlorobenzene, 1,2-dichlorobenzene, bromodichloromethane, bromoform, chloroform, dibromochloromethane, m- and p-xylenes, and ethylbenzene in well CARNRW2. This is a public water-supply well, and provides water to staff of the Carnegie State Vehicle Recreational

Area (SVRA) and their families, as well as to recreational users of that area. The detection of trihalomethanes (e.g., bromoform and chloroform) is thought to be attributable to collection of samples after well water had flowed through the chlorination unit on well CARNRW2. Detection of the substituted benzenes and miscellaneous VOCs may be indicative of sample and/or analytical laboratory contamination; in general there have not been multiple detections of these substances, and most detections were from samples collected on a single date (August 18, 1992).

Samples from well CARNRW3 have yielded single detections of 1,1,1-trichloroethane, toluene, and carbon disulfide (0.5 to 1.2 µg/L). These detections were all from a sample taken on March 10, 1992; sample and/or analytical laboratory contamination is again believed to be the causative factor.

Spring 7 has been sampled once since the SWRI data cutoff date. No new surface water contaminants were identified from that sample.

B-2. Comparison of Baseline and Cumulative Data on Contaminants of Potential Concern in Ground Water

For the SWRI report, we calculated the 95% upper confidence limit (UCL) of the mean concentration of ground water contaminants in the Pit 6 Area study area. Table B-1 presents summary baseline statistics for these contaminants; these data were originally presented in Chapters 4 and 12 of the SWRI report.

To determine whether the mean concentration of VOCs has changed over time, we recalculated the 95% UCLs using data collected through June 1993. Table B-2 presents the summary statistics that resulted from those calculations. A comparison of values between Tables B-1 and B-2 indicates that for almost all compounds the maximum measured concentration remains unchanged, and the 95% UCL has decreased relative to the values originally presented in the SWRI. The exceptions to this are 1,2-dichloroethane (1,2-DCA), 1,2-dichloroethylene (total) (1,2-DCE), and chloroform.

The maximum measured concentration for 1,2-DCA reported in the SWRI (1.7 µg/L) remains unchanged. However, the 95% UCL has increased slightly from 3.03×10^{-1} µg/L to 3.16×10^{-1} µg/L, an increase of approximately 4%. The increase in the 95% UCL appears to be the result of three relatively recent detections of 1,2-DCA in well EP6-09 (concentration range 0.6 to 1.0 µg/L).

For 1,2-DCE, the maximum measured concentration has increased from 7.2 to 11 µg/L. Both of these concentrations were measured in well K6-01S. That well has yielded evidence of 1,2-DCE in each sample since ground water analysis was initiated in December 1987. For that well, analyses of specific isomers of 1,2-DCE began in January 1990; the results indicated that the contaminant was cis-1,2-dichloroethylene. In the last three reported analyses, however, there have also been detections of the trans-isomer. Although our data indicate that the concentration of 1,2-DCE is increasing slightly in well K6-01S, for the operable unit as a whole the concentration has decreased approximately 89% since data were collected for the SWRI, resulting in a 95% UCL of 3.82×10^{-1} µg/L.

The maximum concentration of chloroform measured in ground water in the Pit 6 Area study area, 4.7 µg/L, has not changed. However, the 95% UCL has increased by approximately 23%, from 2.35×10^{-1} to 2.91×10^{-1} µg/L. This increase is apparently attributable to one additional detection of chloroform (2 µg/L in well K6-16).

There have been no analyses of ground water for bis(2-ethylhexyl)phthalate, butylbenzyl phthalate, or phenolics since December 31, 1991.

B-3. Comparison of Baseline and Cumulative Data on Contaminants of Potential Concern in Surface Water

As described previously with respect to ground water, the SWRI report contained 95% UCLs for contaminants of concern in spring 7. Table B-3 lists summary baseline statistics for surface water contaminants in this operable unit (originally presented in Chapters 4 and 12 of the SWRI report). Table B-4 presents 95% UCLs for these same substances based on cumulative data collected through June 1993.

We had limited additional data available to us to calculate the values given in Table B-4. Spring 7, monitored by well BC6-13, has been sampled only once since the SWRI data cutoff. Nonetheless, a comparison of values between Tables B-3 and B-4 indicates that no new maxima have been recorded, and the 95% UCLs have either remained the same or have decreased for all contaminants. The magnitude of the decrease ranges from 3 to 17%.

B-4. Cancer Risk and Noncancer Hazard Associated With Contaminated Ground Water and Surface Water

In the SWRI, we presented a series of risk and hazard calculations for potential exposures associated with ground water and surface water contamination in the vicinity of pit 6. For ground water-based exposures, we used the methodology presented in section 12-5 of the SWRI to estimate concentrations of VOCs expected to reach the off-site water-supply well CARNRW2. Those concentrations were used to calculate the potential risk and hazard associated with (1) residential use of water from well CARNRW2; (2) inhalation exposure of residents to VOCs that volatilize from the surface of the SVRA residence pond and migrate to the nearby houses; and (3) ingestion of water from well CARNRW2 by recreational users of the SVRA. As described in the SWRI, calculations of potential inhalation exposure to VOCs from the residence pond were based on the assumption that contaminated water from well CARNRW2 would be used to fill this man-made pond. For surface water, we examined the inhalation exposure of adults on site to contaminants that may volatilize from the surface of spring 7. The methodologies used to estimate contaminant concentrations in the spring and the volatilization flux rate were presented in Chapter 12 of the SWRI.

We used the data, methodology, pathway exposure factors, and toxicity values presented in Chapter 6 and Appendix P of the SWRI in conjunction with newly estimated contaminant concentrations in ground water and surface water to calculate the incremental excess cancer risk and the noncancer hazard index (HI) for each of the exposure scenarios noted above. These calculations yielded estimates of excess cancer risk and HI of 7×10^{-7} and 1.4×10^{-2}, respectively, for residential use of ground water; 3×10^{-6} and 7.4×10^{-2}, respectively, for inhalation of VOCs from the surface of the residence pond; 2×10^{-8} and 2.8×10^{-4}, respectively, for recreational use of water from well CARNRW2; and 3×10^{-5} and 1.4, respectively, for adult on-site exposures to VOCs that volatilize from the surface of spring 7.

For all exposure scenarios except residential use of ground water, the estimates of risk and hazard are less than or equal to those presented in the SWRI. With respect to residential use of ground water, the current estimates of risk and hazard are marginally greater than those calculated for the SWRI (6×10^{-7} and 1.3×10^{-2}, respectively), yet still within acceptable risk parameters. These increases are due to the slight increase in the 95% UCL for 1,2-DCA and chloroform.

B-5. Reference

Webster-Scholten, C. P., Ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-108131).

Table B-1. Summary statistics for contaminants of potential concern in ground water in the vicinity of pit 6, baseline data set.[a]

Contaminant	Frequency of detection (%)	No. detections/no. samples	Maximum concentration (µg/L)	Mean concentration (µg/L)[b]	95% UCL (µg/L)
1,1,1-Trichloroethane	4.9	4/81	1.3×10^{1}	2.30×10^{-1}	6.89×10^{-1}
1,2-Dichloroethane	7.4	6/81	1.7×10^{0}	2.08×10^{-1}	3.03×10^{-1}
1,2-Dichloroethylene[c]	5.4	16/295	7.2×10^{0}	9.79×10^{-1}	3.43×10^{0}
Acetone	3.2	4/124	1.1×10^{1}	1.11×10^{0}	1.91×10^{0}
Bis(2-ethylhexyl)phthalate	3.7	2/54	7.0×10^{1}	9.87×10^{0}	1.89×10^{1}
Butylbenzyl phthalate	9.1	2/22	7.8×10^{1}	5.82×10^{0}	1.31×10^{1}
Carbon disulfide	6.5	8/124	3.0×10^{0}	1.62×10^{-1}	2.29×10^{-1}
Chloroform[d]	3.7	3/81	4.7×10^{0}	1.17×10^{-1}	2.35×10^{-1}
Ethylbenzene	3.4	6/177	7.3×10^{0}	1.06×10^{-1}	1.65×10^{-1}
Phenolics[e]	12.2	5/41	9.0×10^{1}	1.16×10^{1}	2.16×10^{1}
Methylene chloride	3.3	10/306	1.6×10^{2}	4.15×10^{-1}	1.33×10^{0}
Tetrachloroethylene	37.0	30/81	3.2×10^{0}	6.12×10^{-1}	7.28×10^{-1}
Toluene	13.9	5/36	4.8×10^{0}	4.10×10^{-1}	7.92×10^{-1}
Trichloroethylene	79.0	64/81	2.5×10^{2}	5.15×10^{1}	7.07×10^{1}
Xylenes (total isomers)	13.3	4/30	1.5×10^{1}	5.65×10^{-1}	1.01×10^{0}

[a] Values include data collected through the SWRI cutoff date, December 31, 1991.

[b] Estimate of the arithmetic mean of the log-normal distribution.

[c] The chemical 1,2-Dichloroethylene (1,2-DCE) exists as two isomers, cis-1,2-DCE and trans-1,2-DCE. At various times throughout the nine years of ground water analysis at Site 300, this chemical has been analyzed as 1,2-DCE (total), as one or both of the specific isomers, or as all three. When concentration data were available for one or both isomers, we used those values and omitted the less specific analysis for 1,2-DCE (total) from further consideration. The exceptions to this were in cases where the concentration reported for 1,2-DCE (total) was greater than that reported for one or both isomers.

[d] The maximum measured concentration of chloroform is 4.9×10^{0} µg/L. That concentration was measured in a well that was not included in the subset of wells that delineate the principal region of ground water contamination in the operable unit. As a consequence, that value was not used to calculate the mean or the 95% UCL.

[e] The Site 300 monitoring database contains entries for phenol and the related analyses "phenolics" and "low-level phenolics." When data for an operable unit contained results from more than one of these analyses, we selected the single type of analysis, e.g., "phenolics," that yielded the highest 95% UCL.

Table B-2. Summary statistics for contaminants of potential concern in ground water in the vicinity of pit 6, cumulative data set.[a]

Contaminant	Frequency of detection (%)	No. detections/no. samples	Maximum concentration (µg/L)	Mean concentration (µg/L)[b]	95% UCL (µg/L)
1,1,1-Trichloroethane	4.9	5/102	1.3×10^1	1.7×10^{-1}	3.72×10^{-1}
1,2-Dichloroethane	8.8	9/102	1.7×10^0	2.34×10^{-1}	3.16×10^{-1}
1,2-Dichloroethylene[c]	5.5	21/381	1.1×10^1	2.55×10^{-1}	3.82×10^{-1}
Acetone	2.3	4/174	1.1×10^1	9.36×10^{-1}	1.71×10^0
Bis(2-ethylhexyl)phthalate	3.7	2/54	7.0×10^1	9.87×10^0	1.89×10^1
Butylbenzyl phthalate	9.1	2/22	7.8×10^1	5.82×10^0	1.31×10^1
Carbon disulfide	4.6	8/174	3.0×10^0	1.30×10^{-1}	1.89×10^{-1}
Chloroform	3.9	4/102	4.7×10^0	1.34×10^{-1}	2.91×10^{-1}
Ethylbenzene	3.0	7/235	7.3×10^0	8.84×10^{-2}	1.33×10^{-1}
Phenolics[d]	12.2	5/41	9.0×10^1	1.16×10^1	2.16×10^1
Methylene chloride	2.5	10/398	1.6×10^2	3.66×10^{-1}	1.28×10^0
Tetrachloroethylene	30.4	31/102	3.2×10^0	5.27×10^{-1}	6.29×10^{-1}
Toluene	8.1	6/45	4.8×10^0	3.48×10^{-1}	5.95×10^{-1}
Trichloroethylene	77.4	79/102	2.5×10^2	4.02×10^1	5.29×10^1
Xylenes (total isomers)	10.8	20/186	1.5×10^1	4.27×10^{-1}	7.83×10^{-1}

[a] Values include data collected through June 23, 1993.

[b] Estimate of the arithmetic mean of the log-normal distribution.

[c] The chemical 1,2-Dichloroethylene (1,2-DCE) exists as two isomers, cis-1,2-DCE and trans-1,2-DCE. At various times throughout the nine years of ground water analysis at Site 300, this chemical has been analyzed as 1,2-DCE (total), as one or both of the specific isomers, or as all three. When concentration data were available for one or both isomers, we used those values and omitted the less specific analysis for 1,2-DCE (total) from further consideration. The exceptions to this were in cases where the concentration reported for 1,2-DCE (total) was greater than that reported for one or both isomers.

[d] The Site 300 monitoring database contains entries for phenol and the related analyses "phenolics" and "low-level phenolics." When data for an operable unit contained results from more than one of these analyses, we selected the single type of analysis, e.g., "phenolics," that yielded the highest 95% UCL.

Table B-3. Summary statistics for contaminants of potential concern in surface water (spring 7) in the vicinity of pit 6, baseline data set.[a]

Contaminant	Frequency of detection (%)	No. detections/no. samples	Maximum concentration (µg/L)	Mean concentration (µg/L)[b]	95% UCL (µg/L)
1,2-Dichloroethane	10.5	2/19	3.5×10^0	3.14×10^{-1}	9.14×10^{-1}
cis-1,2-Dichloroethylene[c]	100.0	9/9	1.2×10^1	9.47×10^0	1.05×10^1
trans-1,2-Dichloroethylene[c]	100.0	10/10	3.3×10^1	2.64×10^1	3.18×10^1
Chloroform	5.3	1/19	5.1×10^0	5.45×10^{-1}	9.85×10^{-1}
Methylene chloride	5.3	1/19	8.9×10^0	9.95×10^{-1}	1.77×10^0
Tetrachloroethylene	26.3	5/19	1.4×10^0	4.59×10^{-1}	6.38×10^{-1}
Toluene	9.1	1/11	9.0×10^{-1}	2.33×10^{-1}	4.79×10^{-1}
Trichloroethylene	95.0	19/20	1.1×10^2	5.22×10^1	7.46×10^1
Xylenes (total isomers)	9.1	1/11	1.6×10^0	2.46×10^{-1}	8.12×10^{-1}

[a] Values include data collected through the SWRI cutoff date, December 31, 1991.

[b] Estimate of the arithmetic mean of the log-normal distribution.

[c] The chemical 1,2-dichloroethylene (1,2-DCE) exists as two isomers, cis-1,2-DCE and trans-1,2-DCE. At various times throughout the nine years of ground water analysis at Site 300, this chemical has been analyzed as 1,2-DCE (total), as one or both of the specific isomers, or as all three. When concentration data were available for one or both isomers, we used those values and omitted the less specific analysis for 1,2-DCE (total) from further consideration. The exceptions to this were in cases where the concentration reported for 1,2-DCE (total) was greater than that reported for one or both isomers.

Table B-4. Summary statistics for contaminants of potential concern in surface water (spring 7) in the vicinity of pit 6, cumulative data set.[a]

Contaminant	Frequency of detection[b] (%)	No. detections/no. samples	Maximum concentration (μg/L)	Mean concentration (μg/L)[c]	95% UCL (μg/L)
1,2-Dichloroethane	10.5	2/19	3.5×10^{0}	3.14×10^{-1}	9.14×10^{-1}
cis-1,2-Dichloroethylene[d]	100.0	9/9	1.2×10^{1}	9.47×10^{0}	1.05×10^{1}
trans-1,2-Dichloroethylene[d]	100.0	10/10	3.3×10^{1}	2.44×10^{1}	2.90×10^{1}
Chloroform	5.3	1/19	5.1×10^{0}	5.45×10^{-1}	9.85×10^{-1}
Methylene chloride	5.3	1/19	8.9×10^{0}	9.95×10^{-1}	1.77×10^{0}
Tetrachloroethylene	26.3	5/19	1.4×10^{0}	4.59×10^{-1}	6.38×10^{-1}
Toluene	9.1	1/11	9.0×10^{-1}	2.33×10^{-1}	4.78×10^{-1}
Trichloroethylene	95.0	19/20	1.1×10^{2}	5.42×10^{1}	6.83×10^{1}
Xylenes (total isomers)	9.1	1/11	1.6×10^{0}	2.46×10^{-1}	8.12×10^{-1}

[a] Values include data collected through June 23, 1993.

[b] During our re-calculations of the 95% UCLs for spring 7, we found that data from duplicate samples had erroneously been included in the values presented in the SWRI report (Webster-Scholten, 1994). The results from these duplicate samples were removed from our database for the calculations presented here.

[c] Estimate of the arithmetic mean of the log-normal distribution.

[d] The chemical 1,2-dichloroethylene (1,2-DCE) exists as two isomers, cis-1,2-DCE and trans-1,2-DCE. At various times throughout the nine years of ground water analysis at Site 300, this chemical has been analyzed as 1,2-DCE (total), as one or both of the specific isomers, or as all three. When concentration data were available for one or both isomers, we used those values and omitted the less specific analysis for 1,2-DCE (total) from further consideration. The exceptions to this were in cases where the concentration reported for 1,2-DCE (total) was greater than that reported for either isomer.

Appendix C

Assessment of Incremental Cancer Risk and Noncancer Hazard Indices Associated with Potential Remediation of Ground Water and Surface Water

Appendix C

Assessment of Incremental Cancer Risk and Noncancer Hazard Indices Associated with Potential Remediation of Ground Water and Surface Water

In this appendix, we present an evaluation of the incremental cancer risk and noncancer hazard indices (HIs) associated with various potential remediation goals for contaminants in ground water and surface water in the Pit 6 operable unit. Identification and selection of specific remedial action objectives are presented in Chapter 2. To develop these potential remedial action objectives, we calculated the incremental cancer risk and noncancer HIs associated with:

- Contaminants in ground water at the Carnegie SVRA Ranger well (CARNRW2) if they are present at concentrations equal to either federal or state maximum contaminant levels (MCLs).
- Contaminants in surface water at the SVRA residence pond and spring 7 if they are present at concentrations equal to either federal or state MCLs.
- Contaminants in ground water if they are present at concentrations equal to the limit of detection (LOD).
- Contaminants in surface water if they are present at concentrations equal to the LOD.

We also calculated concentrations of contaminants in surface water at spring 7 that are associated with a specific target level of risk and/or HI. These levels were selected based on the range of acceptable risk or the maximum acceptable HI presented in the National Contingency Plan (NCP) (40 CFR 300) and U.S. EPA (1989), respectively.

C-1. Evaluation of Maximum Contaminant Levels as Potential Remediation Goals

Maximum contaminant levels (MCLs) are concentration standards that represent the maximum permissible level of contaminants in public drinking water systems. MCLs have been selected by regulatory agencies as remediation goals for contaminants in ground water at CERCLA sites where ground water is, or has the potential to become, a drinking water source.

To provide perspective, we used state and/or federal MCLs as exposure-point concentrations at SVRA Ranger well CARNRW2 to calculate risk and noncancer hazard associated with residential and recreational use. The results of these calculations are presented in Tables C-1 and C-2.

For well CARNRW2, MCLs are greater than the 95% upper confidence limit (UCL) of the mean concentration of contaminants used to estimate baseline risk and noncancer hazard.

Consequently, for potential residential exposure associated with well CARNRW2, ground water contaminant concentrations that are equal to the state or federal MCL for each contaminant results in an increase in total risk (R_T) and hazard (HI) relative to the values calculated in the baseline risk assessment (Webster-Scholten, 1994). MCLs as exposure-point concentrations would increase the total cancer risk for this exposure location (R_T) to ~3×10^{-4} and the corresponding HI to 2.6. Tables C-3 and C-4 present a comparison of the baseline risk and HIs associated with potential residential use of ground water at well CARNRW2 and the cancer risk and noncancer hazard associated with use of this water if contaminant concentrations were equal to MCLs. Tables C-5 and C-6 present a comparison of the baseline risk and HIs calculated for potential recreational use of ground water at well CARNRW2, and estimates of cancer risk and noncancer hazard where the exposure-point concentrations are assumed to be equal to MCLs. MCLs as exposure-point concentrations increase the total cancer risk (R_T) for recreational use to 3×10^{-6} and the HI to 5.4×10^{-2}.

In addition, we evaluated the risk and hazard associated with VOCs that volatilize from surface water to air if contaminant concentrations in surface water are equal to the MCLs. The MCLs were used in our model to estimate exposure-point concentrations of VOCs in air (Ca_{sw}) in the vicinities of the SVRA residence pond and spring 7. Ca_{sw} refers to the concentration (c) of contaminant in air (a), which results directly from the presence of the contaminant in surface water (sw). For example, the MCL for TCE (5.0 µg/L) was used to solve for Nw (the volatilization flux rate of a VOC from surface waters; Equation 12-6 in the SWRI report). Nw, applied in SWRI Equation 12-8, yields the value Qw (emission rate of contaminant from water), which is the last variable needed to solve for Ca_{sw}, the exposure-point concentration of TCE in air. The parameters used to calculate the exposure-point concentrations, when the concentrations in surface water at spring 7 and the SVRA residence pond are equal to the MCLs, are given in Tables C-7 and C-8, respectively. The MCLs and the associated cancer risk and noncancer hazard are presented in Tables C-9 and C-10.

The exposure-point concentrations (Ca_{sw}) derived from the MCLs and the associated risk and hazard in the vicinities of the SVRA residence pond and spring 7 are compared to the baseline case in Tables C-11 through C-14. For potential residential (inhalation) exposure associated with surface water at the residence pond, contaminants that are present at concentrations equal to the MCL would result in an increased total cancer risk and hazard index. Exposure-point concentrations derived from the MCLs are greater than the baseline exposure-point concentrations; therefore, they increase the total cancer risk to 2×10^{-3} and the corresponding hazard index to 16. For potential exposure associated with spring 7, contaminants in surface water that are present at concentrations equal to the MCLs result in an increased risk and no change in the hazard index. Exposure-point concentrations derived from the MCLs increase the total cancer risk to 3×10^{-4} and the hazard index remains at 1.5.

C-2. Evaluation of the LOD Concentrations as Potential Remedial Goals

To evaluate the potential human health effects associated with residential and recreational use of ground water if LOD concentrations were selected as remediation goals for SVRA Ranger well CARNRW2, we calculated incremental cancer risk and noncancer hazard under the assumption that exposure-point concentrations of contaminants are equal to the LOD. The results of these calculations are presented in Tables C-15 and C-16. For potential exposure at the SVRA Ranger well CARNRW2, the exposure-point concentrations used to estimate the baseline risk and hazard are less than the LOD for each contaminant. Consequently, contaminant concentrations equal to the LOD for each contaminant results in an increased cancer risk (R_T) and noncancer hazard index (HI) relative to the values calculated in the baseline risk assessment. When we used exposure-point concentrations of contaminants that were equal to the LOD, the result was an estimated total risk, (R_T) of 2×10^{-5}, and an HI of 1.4×10^{-1} for potential residential exposure. This compares to values of R_T and HI calculated for the baseline case, which were 6×10^{-7} and 1.3×10^{-2}, respectively (Webster-Scholten, 1994). For potential recreational exposure, exposure-point concentrations that are equal to the LOD are associated with an R_T of 3×10^{-7} and an HI of 2.8×10^{-3}. The baseline values of risk and hazard are 2×10^{-8} and 2.8×10^{-4}, respectively (Webster-Scholten, 1994). Tables C-17 through C-20 present a comparison of the baseline cancer risks and HIs with those calculated using the LODs as exposure-point concentrations.

In addition, we evaluated the risk and hazard associated with VOCs that volatilize from surface water to air when contaminant concentrations in surface water are equal to the LOD. The LOD concentrations were used in the model described above to estimate exposure-point concentrations of VOCs in air (Ca_{sw}) in the vicinities of the SVRA residence pond and spring 7. The parameters used to calculate the exposure-point concentrations, when the concentrations in surface water are equal to the LOD, are given in Tables C-21 and C-22. The LOD concentrations and the associated cancer risk and noncancer hazard at spring 7 and the residence pond are presented in Tables C-23 and C-24, respectively.

The exposure-point concentrations derived from the LOD and associated risk and hazard for the SVRA residence pond and spring 7 are compared to the baseline case in Tables C-25 through C-28. For potential residential (inhalation) exposure associated with surface water at the SVRA residence pond, contaminant concentrations that are equal to the LOD are greater than baseline exposure-point concentrations and would therefore result in an increased total cancer risk and hazard index. Exposure-point concentrations derived from the LOD increase the total cancer risk to 3×10^{-5} and the corresponding hazard index to 1.9×10^{-1}. For potential adult on-site (inhalation) exposure associated with spring 7, remediation of contaminants so that they are equal to the LOD results in a reduction of risk and hazard. Exposure-point concentrations derived from the LOD decrease the total cancer risk to 5×10^{-6} and the hazard index to 2.8×10^{-2}. This compares to baseline values of 4×10^{-5} and 1.5 for R_T and HI, respectively.

C-3. Derivation of Risk- and Hazard-Based Concentrations of Contaminants as Potential Remediation Goals

The NCP established a range of 1×10^{-4} to 1×10^{-6} as the acceptable risk for CERCLA sites. Separately, the U.S. EPA (1989) identified a maximum acceptable HI of 1.0 associated with noncancer effects of contaminants. Selection of chemical-specific MCLs as remediation goals does not necessarily yield estimates of risk or hazard that fall within the range of acceptable levels delineated by the U.S. EPA (1989; 1990), especially when exposure from multiple pathways is considered. There is additional disparity between the health-based goals of the U.S. EPA (40 CFR 300, and U.S. EPA, 1989) and MCL-related risks and hazards when multiple contaminants are present at an exposure location and additivity of health effects is assumed.

This section describes the methodology we used to calculate potential remediation levels (RLs) for contaminants in surface water at spring 7. This method is applied to the adult on-site exposure scenario associated with an unacceptable level of hazard, and yields a range of potential RLs for each contaminant.

We began by identifying two target risk levels, 1.0×10^{-4} and 1.0×10^{-6}, based on the range of acceptable risk (40 CFR Part 300). For each carcinogen present in surface water at spring 7, the fractional contribution to total risk for the baseline case was calculated as

$$R_{T(F)} = \frac{R_t}{R_T} \tag{C-1}$$

where

R_t = chemical-specific risk for a particular exposure location and exposure scenario (e.g., adult on-site exposure in the vicinity of spring 7),

R_T = total risk attributable to all chemicals present at that exposure location, and

$R_{T(F)}$ = fractional contribution to total risk for a specific chemical for the baseline case.

We multiplied the values of $R_{T(F)}$ by each of the target risk levels (e.g., 1.0×10^{-4} and 1.0×10^{-6}), in turn, to obtain the estimated allowable chemical-specific contribution to risk for remediated surface water, $R_{t(RL)}$.

We also identified a target HI of 1.0 based on U.S. EPA (1989). For each substance with noncarcinogenic effects, the fractional contribution to the HI for the baseline case was calculated as

$$HI_{(F)} = \frac{HQ}{HI} \tag{C-2}$$

where

HQ = chemical-specific hazard quotient for a particular exposure location and exposure scenario (e.g., adult on-site exposure in the vicinity of spring 7),

HI = hazard index, the sum of the hazard quotients attributable to all chemicals present at that exposure location, and

$HI_{(F)}$ = fractional contribution to the hazard index for a specific chemical for the baseline case.

We multiplied the values of $HI_{(F)}$ by the target HI of 1.0 to obtain the estimated allowable chemical-specific contribution to hazard for remediated surface water, $HQ_{(RL)}$. Table C-29 lists the chemical-specific values of risk and hazard for potential exposure in the vicinity of spring 7 (baseline case), as well as the values of $R_{T(F)}$ and $HI_{(F)}$. Table C-30 gives the estimated allowable chemical-specific values of risk and hazard associated with potential RLs of contaminants in surface water based on exposure in the vicinity of spring 7.

For each value of $R_{t(RL)}$ and $HQ_{(RL)}$, we then completed a series of calculations, working backwards through the set of models that were used to calculate the baseline estimates of risk and hazard, to obtain concentrations of contaminants in surface water that represent potential RLs. For example, to calculate a potential RL for TCE in surface water (based on exposure in the vicinity of spring 7), we began with the estimated allowable chemical-specific value of risk $R_{t(RL)}$ for one of the two target risk levels (1.0×10^{-4} or 1.0×10^{-6}). We rearranged, and then solved, SWRI Equation 6-5 (Webster-Scholten, 1994) to obtain Ca_{sw}. The value Ca_{sw} was used to solve for Q_w after rearranging SWRI Equation 12-9. Similarly, Q_w, applied to SWRI Equation 12-8 gave the value Nw, which is the last variable needed to solve for C_l (g/cm^3) (liquid phase VOC concentration; SWRI Equation 12-6), which is then converted to Cw (µg/L) (estimated concentration of the VOC in water), the potential RL. A similar set of calculations was completed for all chemicals, for each of the target risk levels, as well as for the target HI of 1.0. The parameters we calculated for each target level of risk and/or hazard, including values of C_w (the potential RLs), are presented in Tables C-31 through C-33.

C-4. Comparison of Risk- and Hazard-Based Concentrations of Contaminants with Baseline Concentrations Presented in the SWRI Report

As noted in the preceding discussion, the contaminant concentrations presented in Tables C-31 through C-33 were calculated to correspond to a total risk (R_T) of 1×10^{-4} or 1×10^{-6} and target HI of 1.0.

For spring 7, where the baseline estimate of R_T is 4×10^{-5}, only contaminant concentrations associated with an R_T of 1×10^{-6} would result in a decrease in R_T relative to the baseline values.

Selection of the contaminant concentrations associated with an HI of 1.0 as remediation goals would result in a decrease from the baseline HI of 1.5 (Webster-Scholten, 1994). The concentrations of VOCs in surface water associated with a target HI of 1.0 and potential exposure in the vicinity of spring 7, presented in Table C-33, represent estimates of remediation levels. However, as indicated in Chapter 2, Table 2-4, quantitative remediation goals are based on a target risk of 1×10^{-4} to 1×10^{-6} and a target hazard index of 1.0, and, as such, would depend on the actual measured suite and concentrations of contaminants present.

C-5. References

U.S. EPA (1986), *Quality Criteria for Water*, Office of Water Regulations and Standards, Criteria and Standard Division, Washington, D.C. (EPA 44015-86-001).

U.S. EPA (1989), *Risk Assessment Guidance for Superfund, Human Health Evaluation Manual (Part A) Interim Final*, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. (EPA/540/1-89/002).

U.S. EPA (1990), *Exposure Factors Handbook,* Office of Health and Environmental Assessment, U.S. Environmental Protection Agency, Washington, D.C. (EPA 600-8-89-043).

Webster-Scholten, C. P., Ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-108131).

Table C-1. Predicted incremental lifetime cancer risk and HI attributable to residential use of contaminated ground water from well CARNRW2. Exposure-point concentrations of contaminants are equal to MCLs.

Chemical	MCL concentration (µg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1}[a]	1.94×10^{-6}	Not available[b]
1,1,1-Trichloroethane	2.00×10^{2}[c]	Not carcinogenic	1.16×10^{-1}
1,2-Dichloroethylene	6.00×10^{0}[a]	Not carcinogenic	6.24×10^{-2}
Acetone	Not available[d]	Not carcinogenic	Not available[d]
Bis(2-ethylhexyl)phthalate	4.00×10^{0}[a]	2.45×10^{-6}	2.15×10^{-2}
Butylbenzyl phthalate	1.00×10^{2}[e]	Not available[f]	1.77×10^{-2}
Carbon disulfide	Not abailable[d]	Not carcinogenic	Not available[d]
Chloroform	1.00×10^{2}[c]	2.68×10^{-4}	9.62×10^{-1}
Ethylbenzene	6.80×10^{2}[a]	Not carcinogenic	7.34×10^{-1}
Methylene chloride	5.00×10^{0}[c]	1.47×10^{-6}	8.97×10^{-3}
Phenolics	Not available[d]	Not carcinogenic	Not available[d]
Tetrachloroethylene (PCE)	5.00×10^{0}[c]	1.16×10^{-5}	5.26×10^{-2}
Toluene	1.00×10^{3}[c]	Not carcinogenic	5.06×10^{-1}
Trichloroethylene (TCE)	5.00×10^{0}[c]	2.36×10^{-6}	6.36×10^{-2}
Xylenes (total isomers)	1.75×10^{3}[a]	Not carcinogenic	9.64×10^{-2}
		$\sum$ Risk = 3×10^{-4}	HI = 2.6×10^{0}

[a] State of California MCL.

[b] Reference dose (RfD) is not available.

[c] Federal MCL.

[d] MCL is not available.

[e] Proposed federal MCL.

[f] Slope factor is not available.

Table C-2. Predicted incremental lifetime cancer risk and HI attributable to recreational use of contaminated ground water from well CARNRW2. Exposure-point concentrations of contaminants are equal to MCLs.

Chemical	MCL concentration (µg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1a}	3.82×10^{-8}	Not available[b]
1,1,1-Trichloroethane	2.00×10^{2c}	Not carcinogenic	4.36×10^{-3}
1,2-Dichloroethylene	6.00×10^{0a}	Not carcinogenic	1.18×10^{-3}
Acetone	Not available[d]	Not carcinogenic	Not available[d]
Bis(2-ethylhexyl)phthalate	4.00×10^{0a}	4.70×10^{-8}	3.92×10^{-4}
Butylbenzyl phthalate	1.00×10^{2e}	Not available[f]	9.80×10^{-4}
Carbon disulfide	Not available[d]	Not carcinogenic	Not available[d]
Chloroform	1.00×10^{2c}	$2..60 \times 10^{-6}$	1.96×10^{-2}
Ethylbenzene	6.80×10^{2a}	Not carcinogenic	1.33×10^{-2}
Methylene chloride	5.00×10^{0c}	5.87×10^{-8}	1.63×10^{-4}
Phenolics	Not available[d]	Not carcinogenic	Not available[d]
Tetrachloroethylene (PCE)	5.00×10^{0c}	2.18×10^{-7}	9.80×10^{-4}
Toluene	1.00×10^{3c}	Not carcinogenic	9.80×10^{-3}
Trichloroethylene (TCE)	5.00×10^{0c}	6.29×10^{-8}	1.33×10^{-3}
Xylenes (total isomers)	1.75×10^{3a}	Not carcinogenic	1.72×10^{-3}
		Σ Risk = 3×10^{-6}	HI = 5.4×10^{-2}

[a] State of California MCL.

[b] Reference dose (RfD) is not available.

[c] Federal MCL.

[d] MCL is not available.

[e] Proposed federal MCL.

[f] Slope factor is not available.

Table C-3. Comparison of cancer risk estimates for the baseline case (residential use) to cancer risk associated with MCLs, well CARNRW2.

	Baseline risk		Cancer risk associated with the federal or state MCL	
Chemical	**Concentration (μg/L)**	**Cancer risk**	**MCL concentration (μg/L)**	**Cancer risk**
1,2-Dichloroethane	3.86×10^{-3}	1.50×10^{-8}	5.00×10^{-1}[a]	1.94×10^{-6}
1,1,1-Trichloroethane	8.77×10^{-3}	Not carcinogenic	2.00×10^{2}[b]	Not carcinogenic
1,2-Dichloroethylene	4.37×10^{-2}	Not carcinogenic	6.00×10^{0}[a]	Not carcinogenic
Acetone	2.43×10^{-2}	Not carcinogenic	NA	Not carcinogenic
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	1.47×10^{-7}	4.00×10^{0}[a]	2.45×10^{-6}
Butylbenzyl phthalate	1.67×10^{-1}	Not available[c]	1.00×10^{2}[d]	Not available[c]
Carbon disulfide	2.91×10^{-3}	Not carcinogenic	NA	Not carcinogenic
Chloroform	3.00×10^{-3}	8.02×10^{-9}	1.00×10^{2}[b]	$2..68 \times 10^{-4}$
Ethylbenzene	2.10×10^{-3}	Not carcinogenic	6.80×10^{2}[a]	Not carcinogenic
Methylene chloride	6.40×10^{-3}	1.89×10^{-9}	5.00×10^{0}[b]	1.47×10^{-6}
Phenolics	2.75×10^{-1}	Not carcinogenic	NA	Not carcinogenic
Tetrachloroethylene (PCE)	9.27×10^{-3}	2.15×10^{-8}	5.00×10^{0}[b]	1.16×10^{-5}
Toluene	1.01×10^{-2}	Not carcinogenic	1.00×10^{3}[b]	Not carcinogenic
Trichloroethylene (TCE)	9.00×10^{-1}	4.26×10^{-7}	5.00×10^{0}[b]	2.36×10^{-6}
Xylenes (total isomers)	9.97×10^{-3}	Not carcinogenic	1.75×10^{3}[a]	Not carcinogenic
		$\sum$ Risk = 6×10^{-7}		$\sum$ Risk = 3×10^{-4}

[a] State of California MCL.

[b] Federal MCL.

[c] Slope factor is not available.

[d] Proposed federal MCL.

Table C-4. Comparison of HI estimates for the baseline case (residential use) to HIs associated with MCLs, well CARNRW2.

	Baseline hazard index		Hazard index associated with the federal or state MCL	
Chemical	Concentration (μg/L)	Hazard quotient	MCL concentration (μg/L)	Hazard quotient
1,2-Dichloroethane	3.86×10^{-3}	Not available[a]	5.00×10^{-1}[b]	Not available[a]
1,1,1-Trichloroethane	8.77×10^{-3}	5.07×10^{-6}	2.00×10^{2}[c]	1.16×10^{-1}
1,2-Dichloroethylene	4.37×10^{-2}	4.54×10^{-4}	6.00×10^{0}[b]	6.24×10^{-2}
Acetone	2.43×10^{-2}	1.84×10^{-5}	Not available[d]	Not available[d]
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	1.29×10^{-3}	4.00×10^{0}[b]	2.15×10^{-2}
Butylbenzyl phthalate	1.67×10^{-1}	2.95×10^{-5}	1.00×10^{2}[e]	1.77×10^{-2}
Carbon disulfide	2.91×10^{-3}	3.32×10^{-6}	Not available[d]	Not available[d]
Chloroform	3.00×10^{-3}	2.88×10^{-5}	1.00×10^{2}[c]	9.62×10^{-1}
Ethylbenzene	2.10×10^{-3}	2.27×10^{-6}	6.80×10^{2}[b]	7.34×10^{-1}
Methylene chloride	6.40×10^{-3}	1.15×10^{-5}	5.00×10^{0}[c]	8.97×10^{-3}
Phenolics	2.75×10^{-1}	1.42×10^{-5}	Not available[d]	Not available[d]
Tetrachloroethylene (PCE)	9.27×10^{-3}	9.74×10^{-5}	5.00×10^{0}[c]	5.26×10^{-2}
Toluene	1.01×10^{-2}	5.10×10^{-6}	1.00×10^{3}[c]	5.06×10^{-1}
Trichloroethylene (TCE)	9.00×10^{-1}	1.14×10^{-2}	5.00×10^{0}[c]	6.36×10^{-2}
Xylenes (total isomers)	9.97×10^{-3}	5.49×10^{-7}	1.75×10^{3}[b]	9.64×10^{-2}
		HI = 1.3×10^{-2}		HI = 2.6×10^{0}

[a] Reference dose (RfD) is not available.

[b] State of California MCL.

[c] Federal MCL.

[d] MCL is not available.

[e] Proposed federal MCL.

Table C-5. Comparison of cancer risk estimates for the baseline case (recreational use) to cancer risks associated with MCLs, well CARNRW2.

	Baseline risk		Cancer risk associated with the federal or state MCL	
Chemical	**Concentration (µg/L)**	**Cancer risk**	**MCL concentration (µg/L)**	**Cancer risk**
1,2-Dichloroethane	3.86×10^{-3}	2.95×10^{-10}	5.00×10^{-1}[a]	3.82×10^{-8}
1,1,1-Trichloroethane	8.77×10^{-3}	Not carcinogenic	2.00×10^{2}[b]	Not carcinogenic
1,2-Dichloroethylene	4.37×10^{-2}	Not carcinogenic	6.00×10^{0}[a]	Not carcinogenic
Acetone	2.43×10^{-2}	Not carcinogenic	Not available[c]	Not carcinogenic
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	2.82×10^{-9}	4.00×10^{0}[a]	4.70×10^{-8}
Butylbenzyl phthalate	1.67×10^{-1}	Not available[d]	1.00×10^{2}[d]	Not available[e]
Carbon disulfide	2.91×10^{-3}	Not carcinogenic	Not available[c]	Not carcinogenic
Chloroform	3.00×10^{-3}	7.80×10^{-11}	1.00×10^{2}[b]	2.60×10^{-6}
Ethylbenzene	2.10×10^{-3}	Not carcinogenic	6.80×10^{2}[a]	Not carcinogenic
Methylene chloride	6.40×10^{-3}	7.52×10^{-11}	4.00×10^{0}[b]	5.87×10^{-8}
Phenolics	2.75×10^{-1}	Not carcinogenic	Not available[c]	Not carcinogenic
Tetrachloroethylene (PCE)	9.27×10^{-3}	4.04×10^{-10}	5.00×10^{0}[b]	2.18×10^{-7}
Toluene	1.01×10^{-2}	Not carcinogenic	1.00×10^{3}[b]	Not carcinogenic
Trichloroethylene (TCE)	9.00×10^{-1}	1.13×10^{-8}	5.00×10^{0}[b]	6.29×10^{-8}
Xylenes (total isomers)	9.97×10^{-3}	Not carcinogenic	1.75×10^{3}[a]	Not carcinogenic
		Σ Risk = 2×10^{-8}		Σ Risk = 3×10^{-6}

[a] State of California MCL.

[b] Federal MCL.

[c] A MCL is not available.

[d] Proposed federal MCL.

[e] Slope factor is not available.

Table C-6. Comparison of HI estimates for the baseline case (recreational use) to HIs associated with MCLs, well CARNRW2.

	Baseline hazard index		Hazard index associated with the federal or state MCL	
Chemical	Concentration (µg/L)	Hazard quotient	MCL concentration (µg/L)	Hazard quotient
1,2-Dichloroethane	3.86×10^{-3}	Not available[a]	5.00×10^{-1}[b]	Not available[a]
1,1,1-Trichloroethane	8.77×10^{-3}	1.91×10^{-7}	2.00×10^{2}[c]	4.36×10^{-3}
1,2-Dichloroethylene	4.37×10^{-2}	8.56×10^{-6}	6.00×10^{0}[b]	1.18×10^{-3}
Acetone	2.43×10^{-2}	4.77×10^{-7}	Not available[d]	Not available[d]
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	2.36×10^{-5}	4.00×10^{0}[b]	3.92×10^{-4}
Butylbenzyl phthalate	1.67×10^{-1}	1.64×10^{-6}	1.00×10^{2}[e]	9.80×10^{-4}
Carbon disulfide	2.91×10^{-3}	5.71×10^{-8}	Not available[d]	Not available[d]
Chloroform	3.00×10^{-3}	5.88×10^{-7}	1.00×10^{2}[c]	1.96×10^{-2}
Ethylbenzene	2.10×10^{-3}	4.12×10^{-8}	6.80×10^{2}[b]	1.33×10^{-2}
Methylene chloride	6.40×10^{-3}	2.09×10^{-7}	5.00×10^{0}[c]	1.63×10^{-4}
Phenolics	2.75×10^{-1}	8.99×10^{-7}	Not available[d]	Not available[d]
Tetrachloroethylene (PCE)	9.27×10^{-3}	1.82×10^{-6}	5.00×10^{0}[c]	9.80×10^{-4}
Toluene	1.01×10^{-2}	9.88×10^{-8}	1.00×10^{3}[c]	9.80×10^{-3}
Trichloroethylene (TCE)	9.00×10^{-1}	2.40×10^{-4}	5.00×10^{0}[c]	1.33×10^{-3}
Xylenes (total isomers)	9.97×10^{-3}	9.77×10^{-9}	1.75×10^{3}[b]	1.72×10^{-3}
		HI = 2.8×10^{-4}		HI = 5.4×10^{-2}

[a] Federal MCL.

[b] State of California MCL.

[c] Proposed federal MCL.

[d] Reference dose (RfD) is not available.

[e] MCL is not available.

Table C-7. Parameters used to calculate the exposure point concentrations, Ca_{sw}, when the VOC concentrations in surface water at spring 7 are equal to the MCLs.

Chemical	Cw (µg/L)[a]	Nw ($g/cm^2 \bullet s$)[b]	Qw (g/s)[c]	Ca_{sw} (mg/m^3)[d]
1,2-Dichloroethane	5.00×10^{-1}	1.36×10^{-12}	1.90×10^{-7}	2.85×10^{-4}
cis-1,2-Dichloroethylene	6.00×10^{0}	1.86×10^{-11}	2.59×10^{-6}	3.88×10^{-3}
trans-1,2-Dichloroethylene	1.00×10^{1}	3.16×10^{-11}	4.41×10^{-6}	6.61×10^{-3}
Chloroform	1.00×10^{2}	2.78×10^{-10}	3.87×10^{-5}	5.80×10^{-2}
Tetrachloroethylene (PCE)	5.00×10^{0}	1.22×10^{-11}	1.70×10^{-6}	2.55×10^{-3}
Trichloroethylene (TCE)	5.00×10^{0}	1.36×10^{-11}	1.90×10^{-6}	2.85×10^{-3}
Xylenes (total isomers)	1.75×10^{3}	5.26×10^{-9}	7.33×10^{-4}	1.10×10^{0}

[a] Ca_{sw} (mg/m^3) is the calculated concentration of VOC in air in the vicinity of spring 7.

[b] Qw (g/s) is the calculated emission rate of VOC from surface water.

[c] Nw ($g/cm^2 \bullet s$) is the calculated volatilization flux rate of VOC from surface water.

[d] Cw (µg/L) is the concentration of VOC in spring 7 surface water, and represents a potential remediation level.

Table C-8. Parameters used to calculate the exposure point concentrations, Ca_{sw}, when the VOC concentrations in surface water at the SVRA residence pond are equal to the MCLs.

Chemical	Cw (µg/L)[a]	Nw (g/cm^2•s)[b]	Qw (g/s)[c]	Ca_{sw} (mg/m^3)[d]
1,2-Dichloroethane	5.00×10^{-1}	1.36×10^{-12}	1.10×10^{-5}	1.08×10^{-3}
1, 1,1-Trichloroethane	2.00×10^{2}	5.44×10^{-10}	4.40×10^{-3}	4.32×10^{-1}
1,2-Dichloroethylene	6.00×10^{0}	1.86×10^{-11}	1.50×10^{-4}	1.47×10^{-2}
Acetone	Not available[e]	Not available[e]	Not available[e]	Not available[e]
Bis(2-ethylhexyl)phthalate	4.00×10^{0}	4.94×10^{-13}	3.99×10^{-6}	3.92×10^{-4}
Butylbenzyl phthalate	1.00×10^{2}	1.69×10^{-12}	1.36×10^{-5}	1.34×10^{-3}
Carbon disulfide	Not available[e]	Not available[e]	Not available[e]	Not available[e]
Chloroform	1.00×10^{2}	2.78×10^{-10}	2.25×10^{-3}	2.21×10^{-1}
Ethylbenzene	6.80×10^{2}	2.05×10^{-9}	1.66×10^{-2}	1.63×10^{0}
Methylene chloride	5.00×10^{0}	1.56×10^{-11}	1.26×10^{-4}	1.24×10^{-2}
Phenolics	Not available[e]	Not available[e]	Not available[e]	Not available[e]
Tetrachloroethylene (PCE)	5.00×10^{0}	1.22×10^{-11}	9.86×10^{-5}	9.72×10^{-3}
Toluene	1.00×10^{3}	3.22×10^{-9}	2.60×10^{-2}	2.55×10^{0}
Trichloroethylene (TCE)	5.00×10^{0}	1.36×10^{-11}	1.10×10^{-4}	1.07×10^{-2}
Xylenes (total isomers)	1.75×10^{3}	5.26×10^{-9}	4.25×10^{-2}	4.17×10^{0}

[a] Cw (µg/L) is the concentration of VOC in the surface water at the SVRA residence pond, and represents a potential remediation level.

[b] Nw (g/cm^2•s) is the calculated volatilization flux rate of VOC from surface water.

[c] Qw (g/s) is the calculated emission rate of VOC from surface water.

[d] Ca_{sw} (mg/m^3) is the calculated concentration of VOC in air in the vicinity of the SVRA residence pond.

[e] MCL is not available.

Table C-9. Predicted incremental lifetime cancer risk and HI attributable to inhalation of VOCs that volatilize from the surface of spring 7. Exposure-point concentrations of contaminants are derived from MCLs.

Chemical	MCL concentration (μg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1a}	1.81×10^{-6}	Not available[b]
cis-1,2-Dichloroethylene	6.00×10^{0a}	Not carcinogenic	7.60×10^{-2}
trans-1,2-Dichloroethylene	1.00×10^{1a}	Not carcinogenic	6.48×10^{-2}
Chloroform	1.00×10^{2c}	3.28×10^{-4}	1.14×10^{0}
Tetrachloroethylene (PCE)	5.00×10^{0c}	9.09×10^{-6}	5.00×10^{-2}
Trichloroethylene (TCE)	5.00×10^{0c}	1.99×10^{-6}	7.60×10^{-2}
Xylenes (total isomers)	1.75×10^{3a}	Not carcinogenic	1.08×10^{-1}
		$\sum$ Risk = 3×10^{-4}	HI = 1.5×10^{0}

[a] State of California MCL.

[b] Reference dose (RfD) is not available.

[c] Federal MCL.

Table C-10. Predicted incremental lifetime cancer risk and HI attributable to inhalation of VOCs that volatilize from the surface of the residence pond (residential exposure). Exposure-point concentrations of contaminants are derived from MCLs.

Chemical	MCL concentration (μg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1}[d]	1.15×10^{-5}	Not available[b]
1,1,1-Trichloroethane	2.00×10^{2}[c]	Not carcinogenic	3.95×10^{-1}
1,2-Dichloroethylene	6.00×10^{0}[a]	Not carcinogenic	4.03×10^{-1}
Acetone	Not available[d]	Not carcinogenic	Not available[d]
Bis(2-ethylhexyl)phthalate	4.00×10^{0}[a]	3.85×10^{-7}	5.37×10^{-3}
Butylbenzyl phthalate	1.00×10^{2}[e]	Not available[f]	1.83×10^{-3}
Carbon disulfide	Not available[d]	Not carcinogenic	Not available[d]
Chloroform	1.00×10^{2}[c]	2.09×10^{-3}	6.06×10^{0}
Ethylbenzene	6.80×10^{2}[a]	Not carcinogenic	4.47×10^{0}
Methylene chloride	5.00×10^{0}[c]	5.08×10^{-6}	5.66×10^{-2}
Phenolics	Not available[d]	Not carcinogenic	Not available[d]
Tetrachloroethylene (PCE)	5.00×10^{0}[c]	5.80×10^{-5}	2.66×10^{-1}
Toluene	1.00×10^{3}[c]	Not carcinogenic	3.49×10^{0}
Trichloroethylene (TCE)	5.00×10^{0}[c]	1.25×10^{-5}	3.99×10^{-1}
Xylenes (total isomers)	1.75×10^{3}[a]	Not carcinogenic	5.71×10^{-1}
		$\sum$ Risk = 2×10^{-3}	HI = 1.6×10^{1}

[a] State of California MCL.

[b] Reference dose (RfD) is not available.

[c] Federal MCL.

[d] MCL is not available.

[e] Proposed federal MCL.

[f] Slope factor is not available.

Table C-11. Comparison of cancer risk estimates for the baseline case (residential use) to cancer risks associated with MCLs, SVRA residence pond.

	Baseline risk		Cancer risk associated with the federal or state MCL	
Chemical	Ca_{sw} Concentration[a] (mg/m^3)	Cancer risk	Derived from MCL Ca_{sw} concentration[b] (mg/m^3)	Cancer risk
1,2-Dichloroethane	8.35×10^{-6}	8.89×10^{-8}	1.08×10^{-3}	1.15×10^{-5}
1,1,1-Trichloroethane	1.89×10^{-5}	Not carcinogenic	4.32×10^{-1}	Not carcinogenic
1,2-Dichloroethylene	1.07×10^{-4}	Not carcinogenic	1.47×10^{-2}	Not carcinogenic
Acetone	1.36×10^{-5}	Not carcinogenic	Not available[c]	Not carcinogenic
Bis(2-ethylhexyl)phthalate	2.36×10^{-5}	2.32×10^{-8}	3.92×10^{-4}	3.85×10^{-7}
Butylbenzyl phthalate	2.24×10^{-6}	Not available[d]	1.34×10^{-3}	Not available[d]
Carbon disulfide	7.48×10^{-6}	Not carcinogenic	Not available[c]	Not carcinogenic
Chloroform	6.61×10^{-6}	6.27×10^{-8}	2.21×10^{-1}	2.09×10^{-3}
Ethylbenzene	5.02×10^{-6}	Not carcinogenic	1.63×10^{0}	Not carcinogenic
Methylene chloride	1.58×10^{-5}	6.48×10^{-9}	1.24×10^{-2}	5.08×10^{-6}
Phenolics	1.71×10^{-6}	Not carcinogenic	Not available[c]	Not carcinogenic
Tetrachloroethylene (PCE)	1.84×10^{-5}	1.10×10^{-7}	9.72×10^{-3}	5.80×10^{-5}
Toluene	2.58×10^{-5}	Not carcinogenic	2.55×10^{0}	Not carcinogenic
Trichloroethylene (TCE)	1.94×10^{-3}	2.27×10^{-6}	1.07×10^{-2}	1.25×10^{-5}
Xylenes (total isomers)	2.38×10^{-5}	Not carcinogenic	4.17×10^{0}	Not carcinogenic
		Σ Risk = 3×10^{-6}		Σ Risk = 2×10^{-3}

[a] Method used to derive baseline exposure-point concentrations, Ca_{sw}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in Appendix C to this Feasibility Study.

[c] MCL is not available.

[d] Slope factor is not available.

Table C-12. Comparison of HI estimates for the baseline case (residential use) to HIs associated with MCLs, SVRA residence pond.

	Baseline hazard index		Hazard index associated with the federal or state MCL	
Chemical	Ca_{sw} concentration[a] (mg/m^3)	Hazard quotient	Derived from MCL Ca_{sw} concentration[b] (mg/m^3)	Hazard quotient
1,2-Dichloroethane	8.35×10^{-6}	Not available[c]	1.08×10^{-3}	Not available[c]
1,1,1-Trichloroethane	1.89×10^{-5}	1.73×10^{-5}	4.32×10^{-1}	3.95×10^{-1}
1,2-Dichloroethylene	1.07×10^{-4}	2.93×10^{-3}	1.47×10^{-2}	4.03×10^{-1}
Acetone	1.36×10^{-5}	3.72×10^{-5}	Not available[d]	Not available[d]
Bis(2-ethylhexyl)phthalate	2.36×10^{-5}	3.23×10^{-4}	3.92×10^{-4}	5.37×10^{-3}
Butylbenzyl phthalate	2.24×10^{-6}	3.07×10^{-6}	1.34×10^{-3}	1.83×10^{-3}
Carbon disulfide	7.48×10^{-6}	2.05×10^{-5}	Not available[d]	Not available[d]
Chloroform	6.61×10^{-6}	1.81×10^{-4}	2.21×10^{-1}	6.06×10^{0}
Ethylbenzene	5.02×10^{-6}	1.38×10^{-5}	1.63×10^{0}	4.47×10^{-0}
Methylene chloride	1.58×10^{-5}	7.23×10^{-5}	1.24×10^{-2}	5.66×10^{-2}
Phenolics	1.71×10^{-6}	7.80×10^{-7}	Not available[d]	Not available[d]
Tetrachloroethylene (PCE)	1.84×10^{-5}	5.05×10^{-4}	9.72×10^{-3}	2.66×10^{-1}
Toluene	2.58×10^{-5}	3.53×10^{-5}	2.55×10^{0}	3.49×10^{-0}
Trichloroethylene (TCE)	1.94×10^{-3}	7.24×10^{-2}	1.07×10^{-2}	3.99×10^{-1}
Xylenes (total isomers)	2.38×10^{-5}	3.26×10^{-6}	4.17×10^{0}	5.71×10^{-1}
		HI = 7.7×10^{-2}		HI = 1.6×10^{1}

[a] Method used to derive baseline exposure-point concentrations, Ca_{sw}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in Appendix C to this Feasibility Study.

[c] Reference dose (RfD) is not available.

[d] MCL is not available.

Table C-13. Comparison of cancer risk estimates for the baseline case to cancer risk associated with MCLs, spring 7.

	Baseline risk		Cancer risk associated with the federal or state MCL	
Chemical	Ca_{SW} concentration[a] (mg/m^3)	Cancer risk	Derived from MCL Ca_{SW} concentration[b] (mg/m^3)	Cancer risk
1,2-Dichloroethane	5.20×10^{-4}	3.31×10^{-6}	2.85×10^{-4}	1.81×10^{-6}
cis-1,2-Dichloroethylene	6.76×10^{-3}	Not carcinogenic	3.88×10^{-3}	Not carcinogenic
trans-1,2-Dichloroethylene	2.10×10^{-2}	Not carcinogenic	6.61×10^{-3}	Not carcinogenic
Chloroform	5.68×10^{-4}	3.22×10^{-6}	5.80×10^{-2}	3.28×10^{-4}
Tetrachloroethylene (PCE)	3.25×10^{-4}	1.16×10^{-6}	2.55×10^{-3}	9.09×10^{-6}
Trichloroethylene (TCE)	4.24×10^{-2}	2.96×10^{-5}	2.85×10^{-3}	1.99×10^{-6}
Xylenes (total isomers)	5.09×10^{-4}	Not carcinogenic	1.10×10^{0}	Not carcinogenic
		Σ Risk = 4×10^{-5}		Σ Risk = 3×10^{-4}

[a] Method used to derive baseline exposure-point concentrations, Ca_{SW}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in Appendix C to this Feasibility Study.

Table C-14. Comparison of HI estimates for the baseline case to HIs associated with MCLs, spring 7.

	Baseline hazard index		Hazard index associated with the federal or state MCL	
Chemical	Ca_{SW} Concentration[a] (mg/m^3)	Hazard quotient	Derived from MCL Ca_{SW} concentration[b] (mg/m^3)	Hazard quotient
1,2-Dichloroethane	5.20×10^{-4}	Not available[c]	2.85×10^{-4}	Not available[c]
cis-1,2-Dichloroethylene	6.76×10^{-3}	1.33×10^{-1}	3.88×10^{-3}	7.60×10^{-2}
trans-1,2-Dichloroethylene	2.10×10^{-2}	2.06×10^{-1}	6.61×10^{-3}	6.48×10^{-2}
Chloroform	5.68×10^{-4}	1.11×10^{-2}	5.80×10^{-2}	1.14×10^{0}
Tetrachloroethylene (PCE)	3.25×10^{-4}	6.37×10^{-3}	2.55×10^{-3}	5.00×10^{-2}
Trichloroethylene (TCE)	4.24×10^{-2}	1.13×10^{0}	2.85×10^{-3}	7.60×10^{-2}
Xylenes (total isomers)	5.09×10^{-4}	4.99×10^{-5}	1.10×10^{0}	1.08×10^{-1}
		HI = 1.5		HI = 1.5

[a] Method used to derive baseline exposure-point concentrations, Ca_{SW}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in Appendix C to this Feasibility Study.

[c] Reference dose (RfD) is not available.

Table C-15. Predicted incremental lifetime cancer risk and HI attributable to residential use of contaminated ground water from well CARNRW2. Exposure-point concentrations of contaminants are equal to the LOD.

Chemical	LOD concentration[a] (µg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1}	1.94×10^{-6}	Not available[b]
1,1,1-Trichloroethane	5.00×10^{-1}	Not carcinogenic	2.89×10^{-4}
1,2-Dichloroethylene	5.00×10^{-1}	Not carcinogenic	5.20×10^{-3}
Acetone	1.00×10^{1}	Not carcinogenic	7.57×10^{-3}
Bis(2-ethylhexyl)phthalate	2.00×10^{1}	1.22×10^{-5}	1.08×10^{-1}
Butylbenzyl phthalate	1.00×10^{1}	Not available[c]	1.77×10^{-3}
Carbon disulfide	5.00×10^{-1}	Not carcinogenic	5.71×10^{-4}
Chloroform	5.00×10^{-1}	1.34×10^{-6}	4.81×10^{-3}
Ethylbenzene	5.00×10^{-1}	Not carcinogenic	5.40×10^{-4}
Methylene chloride	5.00×10^{-1}	1.47×10^{-7}	8.97×10^{-4}
Phenolics	1.00×10^{1}	Not carcinogenic	5.14×10^{-4}
Tetrachloroethylene (PCE)	5.00×10^{-1}	1.16×10^{-6}	5.26×10^{-3}
Toluene	5.00×10^{-1}	Not carcinogenic	2.53×10^{-4}
Trichloroethylene (TCE)	5.00×10^{-1}	2.36×10^{-7}	6.36×10^{-3}
Xylenes (total isomers)	5.00×10^{-1}	Not carcinogenic	2.75×10^{-5}
		$\sum$ Risk = 2×10^{-5}	HI = 1.4×10^{-1}

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Reference dose (RfD) is not available.

[c] Slope factor is not available.

Table C-16. Predicted incremental lifetime cancer risk and HI attributable to recreational use of contaminated ground water from well CARNRW2. Exposure-point concentrations of contaminants are equal to the LOD.

Chemical	LOD concentration[a] (µg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1}	3.82×10^{-8}	Not available[b]
1,1,1-Trichloroethane	5.00×10^{-1}	Not carcinogenic	1.09×10^{-5}
1,2-Dichloroethylene	5.00×10^{-1}	Not carcinogenic	9.80×10^{-5}
Acetone	1.00×10^{1}	Not carcinogenic	1.96×10^{-4}
Bis(2-ethylhexyl)phthalate	2.00×10^{1}	2.35×10^{-7}	1.96×10^{-3}
Butylbenzyl phthalate	1.00×10^{1}	Not available[c]	9.80×10^{-5}
Carbon disulfide	5.00×10^{-1}	Not carcinogenic	9.80×10^{-6}
Chloroform	5.00×10^{-1}	1.30×10^{-8}	9.80×10^{-5}
Ethylbenzene	5.00×10^{-1}	Not carcinogenic	9.80×10^{-6}
Methylene chloride	5.00×10^{-1}	5.87×10^{-9}	1.63×10^{-5}
Phenolics	1.00×10^{1}	Not carcinogenic	3.27×10^{-5}
Tetrachloroethylene (PCE)	5.00×10^{-1}	2.18×10^{-8}	9.80×10^{-5}
Toluene	5.00×10^{-1}	Not carcinogenic	4.90×10^{-6}
Trichloroethylene (TCE)	5.00×10^{-1}	6.29×10^{-9}	1.33×10^{-4}
Xylenes (total isomers)	5.00×10^{-1}	Not carcinogenic	4.90×10^{-7}
		Σ Risk = 3×10^{-7}	HI = 2.8×10^{-3}

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Reference dose (RfD) is not available.

[c] Slope factor is not available.

Table C-17. Comparison of cancer risk estimates for the baseline case (residential use) to cancer risks for which exposure-point concentrations at well CARNRW2 are equal to the LOD.

	Cancer risk associated with baseline contaminant concentrations		Cancer risk associated with contaminant concentrations at the LOD	
Chemical	Concentration (µg/L)	Cancer risk	LOD concentration[a] (µg/L)	Cancer risk
1,2-Dichloroethane	3.86×10^{-3}	1.50×10^{-8}	5.00×10^{-1}	1.94×10^{-6}
1,1,1-Trichloroethane	8.77×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
1,2-Dichloroethylene	4.37×10^{-2}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Acetone	2.43×10^{-2}	Not carcinogenic	1.00×10^{1}	Not carcinogenic
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	1.47×10^{-7}	2.00×10^{1}	1.22×10^{-5}
Butlybenzyl phthalate	1.67×10^{-1}	Not available[b]	1.00×10^{1}	Not available[b]
Carbon disulfide	2.91×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Chloroform	3.00×10^{-3}	8.02×10^{-9}	5.00×10^{-1}	1.34×10^{-6}
Ethylbenzene	2.10×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Methylene chloride	6.40×10^{-3}	1.89×10^{-9}	5.00×10^{-1}	1.47×10^{-7}
Phenolics	2.75×10^{-1}	Not carcinogenic	1.00×10^{1}	Not carcinogenic
Tetrachloroethylene (PCE)	9.27×10^{-3}	2.15×10^{-8}	5.00×10^{-1}	1.16×10^{-6}
Toluene	1.01×10^{-2}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Trichloroethylene (TCE)	9.00×10^{-1}	4.26×10^{-7}	5.00×10^{-1}	2.36×10^{-7}
Xylenes (total isomers)	9.97×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
		Σ Risk = 6×10^{-7}		Σ Risk = 2×10^{-5}

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Slope factor is not available.

Table C-18. Comparison of HI estimates for the baseline case (residential use) to HIs for which exposure-point concentrations at well CARNRW2 are equal to the LOD.

	Hazard index associated with baseline contaminant concentrations		Hazard index associated with contaminant concentrations at the LOD	
Chemical	Concentration (μg/L)	Hazard quotient	LOD concentration[a] (μg/L)	Hazard quotient
1,2-Dichloroethane	3.86×10^{-3}	Not available[b]	5.00×10^{-1}	Not available[b]
1,1,1-Trichloroethane	8.77×10^{-3}	5.07×10^{-6}	5.00×10^{-1}	2.89×10^{-4}
1,2-Dichloroethylene	4.37×10^{-2}	4.54×10^{-4}	5.00×10^{-1}	5.20×10^{-3}
Acetone	2.43×10^{-2}	1.84×10^{-5}	1.00×10^{1}	7.57×10^{-3}
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	1.29×10^{-3}	2.00×10^{1}	1.08×10^{-1}
Butylbenzyl phthalate	1.67×10^{-1}	2.95×10^{-5}	1.00×10^{1}	1.77×10^{-3}
Carbon disulfide	2.91×10^{-3}	3.32×10^{-6}	5.00×10^{-1}	5.71×10^{-4}
Chloroform	3.00×10^{-3}	2.88×10^{-5}	5.00×10^{-1}	4.81×10^{-3}
Ethylbenzene	2.10×10^{-3}	2.27×10^{-6}	5.00×10^{-1}	5.40×10^{-4}
Methylene chloride	6.40×10^{-3}	1.15×10^{-5}	5.00×10^{-1}	8.97×10^{-4}
Phenolics	2.75×10^{-1}	1.42×10^{-5}	1.00×10^{1}	5.14×10^{-4}
Tetrachloroethylene (PCE)	9.27×10^{-3}	9.74×10^{-5}	5.00×10^{-1}	5.26×10^{-3}
Toluene	1.01×10^{-2}	5.10×10^{-6}	5.00×10^{-1}	2.53×10^{-4}
Trichloroethylene (TCE)	9.00×10^{-1}	1.14×10^{-6}	5.00×10^{-1}	6.36×10^{-3}
Xylenes (total isomers)	9.97×10^{-3}	5.49×10^{-2}	5.00×10^{-1}	2.75×10^{-5}
		HI = 1.3×10^{-2}		HI = 1.4×10^{-1}

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Reference dose (RfD) is not available.

Table C-19. Comparison of cancer risk estimates for the baseline case (recreational use) to cancer risks for which exposure-point concentrations at well CARNRW2 are equal to the LOD.

	Cancer risk associated with baseline contaminant concentrations		Cancer risk associated with contaminant concentrations at the LOD	
Chemical	Concentration (µg/L)	Cancer risk	LOD concentration[a] (µg/L)	Cancer risk
1,2-Dichloroethane	3.86×10^{-3}	2.95×10^{-10}	5.00×10^{-1}	3.82×10^{-8}
1,1,1-Trichloroethane	8.77×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
1,2-Dichloroethylene	4.37×10^{-2}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Acetone	2.43×10^{-2}	Not carcinogenic	1.00×10^{1}	Not carcinogenic
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	2.82×10^{-9}	2.00×10^{1}	2.35×10^{-7}
Butylbenzyl phthalate	1.67×10^{-1}	Not available[b]	1.00×10^{1}	Not available[b]
Carbon disulfide	2.91×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Chloroform	3.00×10^{-3}	7.80×10^{-11}	5.00×10^{-1}	1.30×10^{-8}
Ethylbenzene	2.10×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Methylene chloride	6.40×10^{-3}	7.52×10^{-11}	5.00×10^{-1}	5.87×10^{-9}
Phenolics	2.75×10^{-1}	Not carcinogenic	1.00×10^{1}	Not carcinogenic
Tetrachloroethylene (PCE)	9.27×10^{-3}	4.04×10^{-10}	5.00×10^{-1}	2.18×10^{-8}
Toluene	1.01×10^{-2}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
Trichloroethylene (TCE)	9.00×10^{-1}	1.13×10^{-8}	5.00×10^{-1}	6.29×10^{-9}
Xylenes (total isomers)	9.97×10^{-3}	Not carcinogenic	5.00×10^{-1}	Not carcinogenic
		$\sum \text{Risk} = 2 \times 10^{-8}$		$\sum \text{Risk} = 3 \times 10^{-7}$

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Slope factor is not available.

Table C-20. Comparison of HI estimates for the baseline case (recreational use) to HIs for which exposure-point concentrations at well CARNRW2 are equal to the LOD.

	Hazard index associated with baseline contaminant concentrations		Hazard index associated with contaminant concentrations at the LOD[a]	
Chemical	Concentration (µg/L)	Hazard quotient	LOD concentration (µg/L)	Hazard quotient
1,2-Dichloroethane	3.86×10^{-3}	Not available[b]	5.00×10^{-1}	Not available[b]
1,1,1-Trichloroethane	8.77×10^{-3}	1.91×10^{-7}	5.00×10^{-1}	1.09×10^{-5}
1,2-Dichloroethylene	4.37×10^{-2}	8.56×10^{-6}	5.00×10^{-1}	9.80×10^{-5}
Acetone	2.43×10^{-2}	4.77×10^{-7}	1.00×10^{1}	1.96×10^{-4}
Bis(2-ethylhexyl)phthalate	2.40×10^{-1}	2.36×10^{-5}	2.00×10^{1}	1.96×10^{-3}
Butylbenzyl phthalate	1.67×10^{-1}	1.64×10^{-6}	1.00×10^{1}	9.80×10^{-5}
Carbon disulfide	2.91×10^{-3}	5.71×10^{-8}	5.00×10^{-1}	9.80×10^{-6}
Chloroform	3.00×10^{-3}	5.88×10^{-7}	5.00×10^{-1}	9.80×10^{-5}
Ethylbenzene	2.10×10^{-3}	4.12×10^{-8}	5.00×10^{-1}	9.80×10^{-6}
Methylene chloride	6.40×10^{-3}	2.09×10^{-7}	5.00×10^{-1}	1.63×10^{-5}
Phenolics	2.75×10^{-1}	8.99×10^{-7}	1.00×10^{1}	3.27×10^{-5}
Tetrachloroethylene (PCE)	9.27×10^{-3}	1.82×10^{-6}	5.00×10^{-1}	9.80×10^{-5}
Toluene	1.01×10^{-2}	9.88×10^{-8}	5.00×10^{-1}	4.90×10^{-6}
Trichloroethylene (TCE)	9.00×10^{-1}	2.40×10^{-4}	5.00×10^{-1}	1.33×10^{-4}
Xylenes (total isomers)	9.97×10^{-3}	9.77×10^{-9}	5.00×10^{-1}	4.90×10^{-7}
		$HI = 2.8 \times 10^{-4}$		$HI = 2.8 \times 10^{-3}$

---

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Reference dose (RfD) is not available.

Table C-21. Parameters used to calculate the exposure-point concentrations, Ca_{sw}, when the VOC concentrations in surface water at spring 7 are equal to the LOD.

Chemical	Cw (µg/L)[a]	Nw (g/cm^2•s)[b]	Qw (g/s)[c]	Ca_{sw} (mg/m^3)[d]
1,2-Dichloroethane	5.00×10^{-1}	1.36×10^{-12}	1.90×10^{-7}	2.85×10^{-4}
cis-1,2-Dichloroethylene	5.00×10^{-1}	1.55×10^{-12}	2.16×10^{-7}	3.24×10^{-4}
trans-1,2-Dichloroethylene	5.00×10^{-1}	1.58×10^{-12}	2.20×10^{-7}	3.30×10^{-4}
Chloroform	5.00×10^{-1}	1.39×10^{-12}	1.94×10^{-7}	2.91×10^{-4}
Tetrachloroethylene (PCE)	5.00×10^{-1}	1.22×10^{-12}	1.70×10^{-7}	2.55×10^{-4}
Trichloroethylene (TCE)	5.00×10^{-1}	1.36×10^{-12}	1.90×10^{-7}	2.85×10^{-4}
Xylenes (total isomers)	5.00×10^{-1}	1.50×10^{-12}	2.09×10^{-7}	3.13×10^{-4}

[a] Cw (µg/L) is the concentration of VOC in spring 7 surface water, and represents a potential remediation level.

[b] Nw (g/cm^2•s) is the calculated volatilization flux rate of VOC from surface water.

[c] Qw (g/s) is the calculated emission rate of VOC from surface water.

[d] Ca_{sw} (mg/m^3) is the calculated concentration of VOC in air in the vicinity of spring 7.

Table C-22. Parameters used to calculate the exposure point concentrations, Ca_{sw}, when the VOC concentrations in surface water at the SVRA residence pond are equal to the LOD.

Chemical	Cw (µg/L)[a]	Nw ($g/cm^2 \cdot s$)[b]	Qw (g/s)[c]	Ca_{sw} (mg/m^3)[d]
1,2-Dichloroethane	5.00×10^{-1}	1.36×10^{-12}	1.10×10^{-5}	1.08×10^{-3}
1, 1,1-Trichloroethane	5.00×10^{-1}	1.36×10^{-12}	1.10×10^{-5}	1.08×10^{-3}
1,2-Dichloroethylene	5.00×10^{-1}	1.55×10^{-12}	1.25×10^{-5}	1.22×10^{-3}
Acetone	1.00×10^{1}	7.02×10^{-12}	5.68×10^{-5}	5.58×10^{-3}
Bis(2-ethylhexyl)phthalate	2.00×10^{1}	2.50×10^{-12}	2.00×10^{-5}	1.96×10^{-3}
Butylbenzyl phthalate	1.00×10^{1}	1.69×10^{-13}	1.36×10^{-6}	1.34×10^{-4}
Carbon disulfide	5.00×10^{-1}	1.62×10^{-12}	1.31×10^{-5}	1.29×10^{-3}
Chloroform	5.00×10^{-1}	1.39×10^{-12}	1.12×10^{-5}	1.10×10^{-3}
Ethylbenzene	5.00×10^{-1}	1.51×10^{-12}	1.22×10^{-5}	1.20×10^{-3}
Methylene chloride	5.00×10^{-1}	1.56×10^{-12}	1.26×10^{-5}	1.24×10^{-3}
Phenolics	1.00×10^{1}	7.82×10^{-14}	6.32×10^{-7}	6.21×10^{-5}
Tetrachloroethylene (PCE)	5.00×10^{-1}	1.22×10^{-12}	9.86×10^{-6}	9.69×10^{-4}
Toluene	5.00×10^{-1}	1.61×10^{-12}	1.30×10^{-5}	1.28×10^{-3}
Trichloroethylene (TCE)	5.00×10^{-1}	1.36×10^{-12}	1.10×10^{-5}	1.08×10^{-3}
Xylenes (total isomers)	5.00×10^{-1}	1.50×10^{-12}	1.21×10^{-5}	1.19×10^{-3}

[a] Cw (µg/L) is the concentration of VOC in the surface water at the SVRA residence pond, and represents a potential remediation level.

[b] Nw ($g/cm^2 \cdot s$) is the calculated volatilization flux rate of VOC from surface water.

[c] Qw (g/s) is the calculated emission rate of VOC from surface water.

[d] Ca_{sw} (mg/m^3) is the calculated concentration of VOC in air in the vicinity of the residence pond.

Table C-23. Predicted incremental lifetime cancer risk and HI attributable to inhalation of VOCs that volatilize from the surface of spring 7. Exposure-point concentrations of contaminants are derived from the LOD.

Chemical	LOD concentration[a] (µg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1}	1.81×10^{-6}	Not available[b]
cis-1,2-Dichloroethylene	5.00×10^{-1}	Not carcinogenic	6.35×10^{-3}
trans-1,2-Dichloroethylene	5.00×10^{-1}	Not carcinogenic	3.23×10^{-3}
Chloroform	5.00×10^{-1}	1.65×10^{-6}	5.70×10^{-3}
Tetrachloroethylene (PCE)	5.00×10^{-1}	9.09×10^{-7}	5.00×10^{-3}
Trichloroethylene (TCE)	5.00×10^{-1}	1.99×10^{-7}	7.60×10^{-3}
Xylenes (total isomers)	5.00×10^{-1}	Not carcinogenic	3.07×10^{-5}
		$\sum$ Risk = 5×10^{-6}	HI = 2.8×10^{-2}

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Reference dose (RfD) is not available.

Table C-24. Predicted incremental lifetime cancer risk and HI attributable to inhalation of VOCs that volatilize from the surface of the SVRA residence pond (residential exposure). Exposure-point concentrations of contaminants are derived from the LOD.

Chemical	LOD concentration[a] (µg/L)	Cancer risk	Hazard quotient
1,2-Dichloroethane	5.00×10^{-1}	1.15×10^{-5}	Not available[b]
1,1,1-Trichloroethane	5.00×10^{-1}	Not carcinogenic	9.86×10^{-4}
1,2-Dichloroethylene	5.00×10^{-1}	Not carcinogenic	3.34×10^{-2}
Acetone	1.00×10^{1}	Not carcinogenic	1.53×10^{-2}
Bis(2-ethylhexyl)phthalate	2.00×10^{1}	1.93×10^{-6}	2.69×10^{-2}
Butylbenzyl phthalate	1.00×10^{1}	Not available[c]	1.84×10^{-4}
Carbon disulfide	5.00×10^{-1}	Not carcinogenic	3.53×10^{-3}
Chloroform	5.00×10^{-1}	1.04×10^{-5}	3.01×10^{-2}
Ethylbenzene	5.00×10^{-1}	Not carcinogenic	3.29×10^{-3}
Methylene chloride	5.00×10^{-1}	5.08×10^{-7}	5.66×10^{-3}
Phenolics	1.00×10^{1}	Not carcinogenic	2.84×10^{-5}
Tetrachloroethylene (PCE)	5.00×10^{-1}	5.78×10^{-6}	2.66×10^{-2}
Toluene	5.00×10^{-1}	Not carcinogenic	1.75×10^{-3}
Trichloroethylene (TCE)	5.00×10^{-1}	1.26×10^{-6}	4.03×10^{-2}
Xylenes (total isomers)	5.00×10^{-1}	Not carcinogenic	1.63×10^{-4}
		Σ Risk = 3×10^{-5}	HI = 1.9×10^{-1}

[a] The LOD is the limit of detection for EPA Method 601/8010 or 602/8020 currently reported by most analytic laboratories. The LOD is instrument-batch-specific and shall be determined in accordance with U.S. EPA (1986).

[b] Reference dose (RfD) is not available.

[c] Slope factor is not available.

Table C-25. Comparison of cancer risk estimates for the baseline case (residential use) to cancer risk for which exposure-point concentrations at the SVRA residence pond are derived from the LOD.

	Cancer risk associated with baseline contaminant concentrations		Cancer risk associated with contaminant concentrations at the LOD	
Chemical	Ca_{sw} Concentration[a] (mg/m^3)	Cancer risk	Derived from LOD Ca_{sw} concentration[b] (mg/lm^3)	Cancer risk
1,2-Dichloroethane	8.35×10^{-6}	8.89×10^{-8}	1.08×10^{-3}	1.15×10^{-5}
1,1,1-Trichloroethane	1.89×10^{-5}	Not carcinogenic	1.08×10^{-3}	Not carcinogenic
1,2-Dichloroethylene	1.07×10^{-4}	Not carcinogenic	1.22×10^{-3}	Not carcinogenic
Acetone	1.36×10^{-5}	Not carcinogenic	5.58×10^{-3}	Not carcinogenic
Bis(2-ethylhexyl)phthalate	2.36×10^{-5}	2.32×10^{-8}	1.96×10^{-3}	1.93×10^{-6}
Butylbenzyl phthalate	2.24×10^{-6}	Not available[c]	1.34×10^{-4}	Not available[c]
Carbon disulfide	7.48×10^{-6}	Not carcinogenic	1.29×10^{-3}	Not carcinogenic
Chloroform	6.61×10^{-6}	6.27×10^{-8}	1.10×10^{-3}	1.04×10^{-5}
Ethylbenzene	5.02×10^{-6}	Not carcinogenic	1.20×10^{-3}	Not carcinogenic
Methylene chloride	1.58×10^{-5}	6.48×10^{-9}	1.24×10^{-3}	5.08×10^{-7}
Phenolics	1.71×10^{-6}	Not carcinogenic	6.21×10^{-5}	Not carcinogenic
Tetrachloroethylene (PCE)	1.84×10^{-5}	1.10×10^{-7}	9.69×10^{-4}	5.78×10^{-6}
Toluene	2.58×10^{-5}	Not carcinogenic	1.28×10^{-3}	Not carcinogenic
Trichloroethylene (TCE)	1.94×10^{-3}	2.27×10^{-6}	1.08×10^{-3}	1.26×10^{-6}
Xylenes (total isomers)	2.38×10^{-5}	Not carcinogenic	1.19×10^{-3}	Not carcinogenic
		$\sum$ Risk = 3×10^{-6}		$\sum$ Risk = 3×10^{-5}

[a] Method used to derive baseline exposure-point concentrations, Ca_{sw}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in this Appendix C to this Feasibility Study.

[c] Slope factor is not available.

Table C-26. Comparison of HI estimates for the baseline case (residential use) to HIs for which exposure-point concentrations at the SVRA residence pond are derived from the LOD.

	Hazard index associated with baseline contaminant concentrations		Hazard index associated with contaminant concentrations at the LOD	
Chemical	Ca_{sw} concentration[a] (mg/m^3)	Hazard quotient	Derived from LOD Ca_{sw} concentration[b] (mg/m^3)	Hazard quotient
1,2-Dichloroethane	8.35×10^{-6}	Not available[c]	1.08×10^{-3}	Not available[c]
1,1,1-Trichloroethane	1.89×10^{-5}	1.73×10^{-5}	1.08×10^{-3}	9.86×10^{-4}
1,2-Dichloroethylene	1.07×10^{-4}	2.93×10^{-3}	1.22×10^{-3}	3.34×10^{-2}
Acetone	1.36×10^{-5}	3.72×10^{-5}	5.58×10^{-3}	1.53×10^{-2}
Bis(2-ethylhexyl)phthalate	2.36×10^{-5}	3.23×10^{-4}	1.96×10^{-3}	2.69×10^{-2}
Butylbenzyl phthalate	2.24×10^{-6}	3.07×10^{-6}	1.34×10^{-4}	1.84×10^{-4}
Carbon disulfide	7.48×10^{-6}	2.05×10^{-5}	1.29×10^{-3}	3.53×10^{-3}
Chloroform	6.61×10^{-6}	1.81×10^{-4}	1.10×10^{-3}	3.01×10^{-2}
Ethylbenzene	5.02×10^{-6}	1.38×10^{-5}	1.20×10^{-3}	3.29×10^{-3}
Methylene chloride	1.58×10^{-5}	7.23×10^{-5}	1.24×10^{-3}	5.66×10^{-3}
Phenolics	1.71×10^{-6}	7.80×10^{-7}	6.21×10^{-5}	2.84×10^{-5}
Tetrachloroethylene (PCE)	1.84×10^{-5}	5.05×10^{-4}	9.69×10^{-4}	2.66×10^{-2}
Toluene	2.58×10^{-5}	3.53×10^{-5}	1.28×10^{-3}	1.75×10^{-3}
Trichloroethylene (TCE)	1.94×10^{-3}	7.24×10^{-2}	1.08×10^{-3}	4.03×10^{-2}
Xylenes (total isomers)	2.38×10^{-5}	3.26×10^{-6}	1.19×10^{-3}	1.63×10^{-4}
		$HI = 7.7 \times 10^{-2}$		$HI = 1.9 \times 10^{-1}$

[a] Method used to derive baseline exposure-point concentrations, Ca_{sw}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in Appendix C to this Feasibility Study.

[c] Reference dose is not available.

Table C-27. Comparison of cancer risk estimates for the baseline case to cancer risks for which exposure-point concentrations at spring 7 are derived from the LOD.

	Cancer risk associated with baseline contaminant concentrations		Cancer risk associated with contaminant concentrations at the LOD	
Chemical	Concentration[a] (mg/m^3)	Cancer risk	Derived from LOD Ca_{SW} concentration[b] (mg/m^3)	Cancer risk
1,2-Dichloroethane	5.20×10^{-4}	3.31×10^{-6}	2.85×10^{-4}	1.81×10^{-6}
cis-1,2-Dichloroethylene	6.76×10^{-3}	Not carcinogenic	3.24×10^{-4}	Not carcinogenic
trans-1,2-Dichloroethylene	2.10×10^{-2}	Not carcinogenic	3.30×10^{-4}	Not carcinogenic
Chloroform	5.68×10^{-4}	3.22×10^{-6}	2.91×10^{-4}	1.65×10^{-6}
Tetrachloroethylene (PCE)	3.25×10^{-4}	1.16×10^{-6}	2.55×10^{-4}	9.09×10^{-7}
Trichloroethylene (TCE)	4.24×10^{-2}	2.96×10^{-5}	2.85×10^{-4}	1.99×10^{-7}
Xylenes (total isomers)	5.09×10^{-4}	Not carcinogenic	3.13×10^{-4}	Not carcinogenic
		Σ Risk = 4×10^{-5}		Σ Risk = 5×10^{-6}

[a] Method used to derive baseline exposure-point concentrations, Ca_{SW}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in Appendix B to this Feasibility Study.

Table C-28. Comparison of HI estimates for the baseline case to HIs for which exposure-point concentrations at spring 7 are derived from the LOD.

	Hazard index associated with baseline contaminant concentrations		Hazard index associated with contaminant concentrations at the LOD	
Chemical	Concentration[a] (mg/m^3)	Hazard quotient	Derived from LOD Ca_{SW} concentration[b] (mg/m^3)	Hazard quotient
1,2-Dichloroethane	5.20×10^{-4}	Not available[c]	2.85×10^{-4}	Not available[c]
cis-1,2-Dichloroethylene	6.76×10^{-3}	1.33×10^{-1}	3.24×10^{-4}	6.35×10^{-3}
trans-1,2-Dichloroethylene	2.10×10^{-2}	2.06×10^{-1}	3.30×10^{-4}	3.23×10^{-3}
Chloroform	5.68×10^{-4}	1.11×10^{-2}	2.91×10^{-4}	5.70×10^{-3}
Tetrachloroethylene (PCE)	3.25×10^{-4}	6.37×10^{-3}	2.55×10^{-4}	5.00×10^{-3}
Trichloroethylene (TCE)	4.24×10^{-2}	1.13×10^{0}	2.85×10^{-4}	7.60×10^{-3}
Xylenes (total isomers)	5.09×10^{-4}	4.99×10^{-5}	3.13×10^{-4}	3.07×10^{-5}
		HI = 1.5		HI = 2.8×10^{-2}

[a] Method used to derive baseline exposure-point concentrations, Ca_{SW}, is presented in the SWRI report (Webster-Scholten, 1994).

[b] Method used to derive exposure-point concentrations from the MCLs is presented in Appendix C to this Feasibility Study.

[c] Reference dose (RfD) is not available.

Table C-29. Calculated values of risk and hazard for potential adult on-site exposure in the vicinity of spring 7 for the baseline case (Webster-Scholten, 1994).

Chemical	Baseline chemical-specific risk ($RT_{(F)}$)[a]	Chemical-specific fraction, baseline total risk ($RT_{(F)}$)	Baseline hazard quotient (HQ)[a]	Chemical-specific fraction, baseline hazard index (HQ)
1,2-Dichloroethane	3.31×10^{-6}	88.8×10^{-2}	Not available[b]	Not available[b]
cis-1,2-Dichloroethylene	Not carcinogenic	NA	1.33×10^{-1}	8.95×10^{-2}
trans-1,2-Dichloroethylene	Not carcinogenic	NA	2.06×10^{-1}	1.39×10^{-1}
Chloroform	3.22×10^{-6}	8.64×10^{-2}	1.11×10^{-2}	7.47×10^{-3}
Tetrachloroethylene (PCE)	1.16×10^{-6}	3.11×10^{-2}	6.37×10^{-3}	4.29×10^{-3}
Trichloroethylene (TCE)	2.96×10^{-5}	7.94×10^{-1}	1.13×10^{0}	7.60×10^{-1}
Xylenes (total isomers)	Not carcinogenic	NA	4.99×10^{-5}	3.36×10^{-5}
	RT= 4×10^{-5}		HI = 1.5	

[a] Originally presented in Chapter 6 of the SWRI report (Webster-Scholten, 1994).

[b] Reference dose (RfD) is not available.

NA = not applicable.

Table C-30 Estimated allowable chemical-specific values of risk and hazard for potential remediation levels (RLs) of contaminants in surface water at spring 7. Values are based on potential adult on-site exposure in the vicinity of spring 7.

Chemical	$R_{t(RL)}$ (target risk = 1.0×10^{-4})	$R_{t(RL)}$ (target risk = 1.0×10^{-6})	Hazard quotient (target HI = 1.0)
1,2-Dichloroethane	8.88×10^{-6}	8.88×10^{-8}	Not available
cis-1,2-Dichloroethylene	Not carcinogenic	Not carcinogenic	8.95×10^{-2}
trans-1,2-Dichloroethylene	Not carcinogenic	Not carcinogenic	1.39×10^{-1}
Chloroform	8.64×10^{-6}	8.64×10^{-8}	7.47×10^{-3}
Tetrachloroethylene (PCE)	3.11×10^{-6}	3.11×10^{-8}	4.29×10^{-3}
Trichloroethylene (TCE)	7.94×10^{-5}	7.94×10^{-7}	7.60×10^{-1}
Xylenes (total isomers)	Not carcinogenic	Not carcinogenic	3.36×10^{-5}

Table C-31. Potential remediation levels, Cw (μg/L), and related parameters for VOCs in surface water at spring 7. Values are based on a target risk of 1×10^{-4} and potential exposure in the vicinity of spring 7.

Chemical	Ca_{sw} (mg/m^3)[a]	Qw (g/sec)[b]	Nw (g/cm^2•s)[c]	Cw (μg/L)[d]
1,2-Dichloroethane	1.39×10^{-3}	9.32×10^{-7}	6.69×10^{-12}	2.46×10^{0}
cis-1,2-Dichloroethylene	Not carcinogenic	NA	NA	NA
trans-1,2-Dichloroethylene	Not carcinogenic	NA	NA	NA
Chloroform	1.53×10^{-3}	1.02×10^{-6}	7.31×10^{-12}	2.63×10^{0}
Tetrachloroethylene (PCE)	8.72×10^{-4}	5.82×10^{-7}	4.18×10^{-12}	1.71×10^{0}
Trichloroethylene (TCE)	1.14×10^{-1}	7.58×10^{-5}	5.44×10^{-10}	2.00×10^{2}
Xylenes (total isomers)	Not carcinogenic	NA	NA	NA

[a] Ca_{sw} (mg/m^3) is the calculated concentration of VOC in air in the vicinity of spring 7.

[b] Qw (g/s) is the calculated emission rate of VOC from surface water.

[c] Nw (g/cm^2•s) is the calculated volatilization flux rate of VOC from surface water.

[d] Cw (μg/L) is the calculated concentration of VOC in spring 7 surface water associated with a specific target risk or hazard, and represents a potential remediation level.

NA = Not applicable.

Table C-32. Potential remediation levels, Cw (µg/L), and related parameters for VOCs in surface water at spring 7. Values are based on a target risk of 1×10^{-6} and potential exposure in the vicinity of spring 7.

Chemical	Ca (mg/m^3)[a]	Qw (g/sec)[b]	Nw (g/cm^2•s)[c]	Cw (µg/L)[d]
1,2-Dichloroethane	1.39×10^{-5}	9.32×10^{-9}	6.69×10^{-14}	2.46×10^{-2}
cis-1,2-Dichloroethylene	Not carcinogenic	NA	NA	NA
trans-1,2-Dichloroethylene	Not carcinogenic	NA	NA	NA
Chloroform	1.53×10^{-5}	1.02×10^{-8}	7.31×10^{-14}	2.63×10^{-2}
Tetrachloroethylene (PCE)	8.72×10^{-6}	5.82×10^{-9}	4.18×10^{-14}	1.71×10^{-2}
Trichloroethylene (TCE)	1.14×10^{-3}	7.58×10^{-7}	5.44×10^{-12}	2.00×10^{0}
Xylenes (total isomers)	Not carcinogenic	NA	NA	NA

[a] Ca_{sw} (mg/m^3) is the calculated concentration of VOC in air in the vicinity of spring 7.

[b] Qw (g/s) is the calculated emission rate of VOC from surface water.

[c] Nw (g/cm^2•s) is the calculated volatilization flux rate of VOC from surface water.

[d] Cw (µg/L) is the calculated concentration of VOC in spring 7 surface water associated with a specific target risk or hazard, and represents a potential remediation level.

NA = Not applicable.

Table C-33. Potential remediation levels, Cw (µg/L), and related parameters for VOCs in surface water at spring 7. Values are based on a target HI of 1.0 and potential exposure in the vicinity of spring 7.

Chemical	Ca_{sw} (mg/m^3)[a]	Qw (g/s)[b]	Nw (g/cm^2•s)[c]	Cw (µg/L)[d]
1,2-Dichloroethane	Not available	Not available	Not available	Not available
cis-1,2-Dichloroethylene	4.57×10^{-3}	3.05×10^{-6}	2.19×10^{-11}	7.08×10^{0}
trans-1,2-Dichloroethylene	1.42×10^{-2}	9.47×10^{-6}	6.79×10^{-11}	2.15×10^{-1}
Chloroform	3.81×10^{-4}	2.54×10^{-7}	1.83×10^{-12}	6.57×10^{-1}
Tetrachloroethylene (PCE)	2.19×10^{-4}	1.46×10^{-7}	1.05×10^{-12}	4.30×10^{-1}
Trichloroethylene (TCE)	2.85×10^{-2}	1.90×10^{-5}	1.36×10^{-10}	5.02×10^{1}
Xylenes (total isomers)	3.43×10^{-4}	2.29×10^{-7}	1.64×10^{-12}	5.47×10^{-1}

[a] Ca_{sw} (mg/m^3) is the calculated concentration of VOC in air in the vicinity of spring 7.

[b] Qw (g/s) is the calculated emission rate of VOC from surface water.

[c] Nw (g/cm^2•s) is the calculated volatilization flux rate of VOC from surface water.

[d] Cw (µg/L) is the calculated concentration of VOC in spring 7 surface water associated with a specific target risk or hazard, and represents a potential remediation level.

Appendix D

Remedial Technologies

Appendix D

Remedial Technologies

This section provides detailed descriptions of the remedial technologies presented in Chapter 3, with information sources referenced at the end of the descriptions. Some of these technologies have already been used in previous pilot studies involving the extraction and/or treatment of ground water and/or soil vapor at Site 300.

D-1. Surface Cover

A surface cover placed over buried waste or a contaminant plume limits or precludes surface water infiltration and minimizes the generation of a leachate. A surface cover also controls the emission of gases and odors, reduces erosion, and improves aesthetics. It provides a stable surface that prevents human exposure to wastes, and is necessary when contaminated materials are left in place at a site.. In situations where the waste is entirely above the ground water table, a properly designed cover can prevent the entry of water into the landfill or surface impoundment. Under CERCLA, capping is performed when extensive subsurface contamination at a site precludes excavation and removal of wastes due to potential hazards and/or high costs. Capping is often performed in connection with ground water extraction or containment technologies (i.e., physical barriers or hydraulic barriers) (U.S. EPA, 1991).

D-2. Induced Venting

Induced venting consists of applying a vacuum to one or more vadose-zone extraction wells to enhance volatilization and removal of high-volatility contaminants. Industry experience indicates that this process is very effective for remediating most chlorinated solvents and volatile fuel hydrocarbons. Venting can be used in conjunction with ground water extraction.

The properties of vadose-zone sediments, such as permeability and moisture content, and the areal extent and depth of contamination determine the design of a soil vapor well field. This technology is typically used in conjunction with vapor-phase GAC treatment to prevent the release of VOCs to the atmosphere. Induced venting can also be used to extract VOCs released in conjunction with ground water remediation using innovative *in situ* air sparging.

Drawbacks to this extraction technology include the uncertainty in predicting the time required to achieve the remedial objectives, and difficulties in extracting all hazardous materials from a heterogeneous subsurface environment. The treatment of air emissions can also be a significant operational expense (LLNL, 1991b).

D-3. Subsurface Containment Barriers

The purpose of subsurface barriers is to contain contaminant releases and to prevent ground water from contacting contaminants. The application of subsurface barriers can include any combination of vertical, horizontal, or inclined barriers. For example, vertical and horizontal barriers can be combined to encapsulate a portion of the subsurface, or intersecting inclined barriers could be used to create a subsurface trough-like containment system.

There are a variety of methods for installing subsurface barriers. Vertical subsurface barriers involve trenching and installing slurry or grout walls, or drilling a series of overlapping holes and backfilling with grout to create a continuous curtain. The objective is to create a low-permeability vertical wall or enclosure to prevent the migration of contaminants beyond its confines. Vertical curtains can be keyed into a natural impermeable barrier (e.g., low-permeability siltstone or claystone unit) if one exists. Keyed vertical barriers are also often combined with a surface cover or cap for complete isolation of contaminants.

Horizontal subsurface barriers can be installed using hydrofracturing or horizontal drilling. The objective is to create a low-permeability grout floor to prevent the vertical migration of contaminants. Controlled hydrofracturing can best be accomplished on a smooth contact between geologic formations or on a well defined bedding plan within a formation. Hydrofracturing can be risky; if the fracture is uncontrolled, it could direct itself through the buried debris or containment plume.

Inclined subsurface barriers can be installed using angled drilling and grout curtain techniques. The intersection of these inclined curtains creates a low-permeability subsurface containment barrier.

Another grouting method is jet grouting. This technique uses high pressure jets of water and grout to enlarge and fill a pre-drilled borehole. A variety of grout (aggregate or chemical) or barrier fluids can also be used in the construction of jet-grouted subsurface barriers.

D-4. Stabilization and Chemical Fixation

Stabilization/solidification refers to treatment processes that are designed to accomplish one or more of the following: (1) improve the handling and physical characteristics of the waste, as in the sorption of free liquids; (2) decrease the surface area of the waste mass across which transfer or loss of contaminants can occur; and (3) limit the solubility of any hazardous constituents of the waste, e.g., by pH adjustment or sorption phenomena.

The preliminary benefit of stabilization techniques is that they limit the solubility or mobility of the contaminants with or without changing or improving the physical characteristics of the waste. Stabilization usually involves adding materials to ensure that the hazardous constituents are maintained in their least mobile or toxic form.

Solidification implies that the beneficial results of treatment are obtained primarily, but not necessarily exclusively, through the production of a solid block of waste material with high structural integrity—a product often referred to as a "monolith." Solidification is often achieved by mixing grout and/or polymers with the source materials. (In many cases, a monolith is not the immediate end product of the stabilization/solidification process; however, after placement, the materials may continue to cure into a facsimile of a monolith.) The monolith can encompass the entire waste disposal site—called a "monofill"—or can be as small as the contents of a steel drum. The contaminants do not necessarily interact chemically with reagents. Instead, they are mechanically locked within the solidified matrix, or "microencapsulated." Contaminant loss is limited largely by decreasing the surface area exposed to the environment and/or isolating the contaminants from environmental influences by microencapsulating the waste particles. Wastes can also be "macroencapsulated," that is, bonded to or surrounded by an impervious covering. Macroencapsulation techniques are also considered to be stabilization/solidification processes (U.S. EPA, 1989).

Chemical fixation is an innovative process that is very similar to solidification, except that it alters complex organic compounds into simple nontoxic substances and incorporates them into a matrix. The end product can be a monolithic-type structure or a loose soil-like substance. This end product is designed to meet regulatory leachability standards and to bond the contaminant with the natural sediments. With the more traditional grout-type solidification, the grout matrix may not bond well with native materials and may be susceptible to slightly acidic ground water.

D-5. *In situ* Vitrification

Vitrification is the process of converting materials into a glass or glass-type substance, typically through a thermal process. However, heat is not required for vitrification. For example, vapor deposition, solution hydrolysis, and gel formation can also form glassy materials.

When accomplished through a thermal process, vitrification may destroy organic contaminants via pyrolysis or combustion. As a stabilization process, vitrification may immobilize inorganics by incorporating them into a glass structure or by encapsulating them in a product glass.

Many contaminated materials contain adequate quantities of the raw ingredients needed for forming glass. When such materials are heated, the ingredients fuse and form the glass in which the contaminants are immobilized. Because not all contaminated materials contain proper ratios of the materials required for the formation of a glass, additives may be required in some cases.

Vitrification has four major advantages over other methods of waste management. The primary advantage is the durable waste glass it produces. In most instances, this waste glass performs exceptionally well in leach tests. The second major advantage is the flexibility of the waste glass in incorporating a wide variety of contaminants and accompanying feed material in its structure without a significant decrease in quality. The third advantage is that vitrification processes can accommodate both organic and inorganic contaminants of various amounts. Lastly, vitrification may also reduce the volume of waste material.

Vitrification's major limitation is that it is energy intensive and, thus, may be more expensive when compared to other remedial technologies. A second limitation is the potential for some contaminants, both organic and inorganic, to volatilize. This limitation applies to both *ex situ* processes and *in situ* vitrification (ISV). For ISV, there is some concern that certain contaminants may migrate into the surrounding soil. Another limitation may be excessive void space, which limits the ability for uniform heat transfer (Hansen, 1993). These limitations may be amenable to modification of process parameters given site characteristics and management goals (U.S. EPA, 1992).

D-6. Ground Water Extraction from Wells

Ground water extraction wells may be either well points, naturally developed wells, or gravel-packed wells. Well points applied to shallow ground water (<30 ft) typically are manifolded to a header pipe and pumped with a suction system. Larger-diameter wells are pumped most commonly with submersible electric pumps, although vertical turbine or pneumatic positive displacement pumps may also be used. Extraction wells that are to be used in a ground water recirculation system would most likely be constructed near the leading edge of a plume and coupled with injection wells located upgradient of the source. Extraction wells to be used for hydraulic gradient control would probably be installed upgradient of the plume (U.S. EPA, 1991). Extraction wells can also be used for plume containment, and are often used in combination with ground water treatment systems.

D-7. Passive Venting

Passive remediation systems using barometric pumping to remove VOCs from the subsurface are being evaluated at the DOE's Hanford and Savannah River sites. These systems exploit naturally induced pressure gradients between surface and subsurface air to produce a flux of volatile contaminates from the subsurface to the surface.

Identical systems for passive remediation were installed on 4-in.-diam wells at both the Hanford and Savannah River sites. These systems consist of an instrument/treatment stack packed with GAC to remove VOCs in the air stream. Flow rates, temperature, and wind speed are monitored continuously during the period of operation. Removal rates ranging from 0.1 to 700 grams/day were achieved at the Hanford site, while removal rates of up to 2.5 kg/day were achieved at the Savannah River site. Although these rates are low compared to most active vacuum extraction systems, the passive extraction system requires less capital equipment, less operating capital, and will work for extended periods of time with only limited maintenance. When diminishing returns become an issue with active systems, the passive system can continue the remediation with minimal additional cost (Rossabi et al., 1993).

D-8. Drains

Drains (i.e., subdrains) are used to intercept and remove contaminated ground water. A drain is formed by placing a pipe in a trench, backfilling it with properly graded filter material, and protecting it against silting from above. The backfill material must be fine enough to keep the adjacent soil from entering the pipe and coarse enough not to enter the pipe perforations or joints. Soil that might enter the drain will clog it and reduce its efficiency. A *French drain* or blind drain is a drain interceptor trench without pipes. Drains can be actively pumped or designed with a slope to take advantage of gravity (Krynne and Judd, 1957).

D-9. Steam Flooding

Steam flooding is an adaptation of oil-field technology that uses steam injection to enhance the recovery of contaminants from the subsurface. Steam injected through multiple wells on the perimeter of a plume volatilizes the contaminants, thermally desorbs the contaminants in permeable zones, and displaces them toward one or more central recovering wells (Siegel et al., 1992). This technology has been combined with Joule heating at the LLNL Main Site to enhance volatilization in the low-permeability zones not penetrated by steam.

D-10. Joule Heating

Joule heating is an experimental remediation technology developed by LLNL to enhance the removal of VOCs from soil. An experiment using this method to remove TCE was conducted at the Building 834 operable unit in the summer of 1992. Six electrodes were buried in shallow boreholes heating an area approximately 7 m in diameter and 4 m deep. Large electrical alternating currents were passed through the soil, resulting in a decrease in TCE soil vapor concentrations from 130 $ppm_{v/v}$ to about 5 $ppm_{v/v}$ over a period of 25 days (Buettner, 1993).

D-11. Air Sparging

Air sparging consists of forcing air through coarse air bubble diffusers into large tanks filled with contaminated water. The agitation of the water and contact with forced air promotes the volatilization of VOCs. This technology would be used in conjunction with vapor phase GAC (LLNL, 1991b). High calcium and magnesium hardness, which occurs at Site 300, can clog the sparging tank components, reduce efficiency, and increase operating costs. Generally, air sparging has low energy efficiency than air stripping.

Air sparging can also be used *in situ.* It requires either trenching to lay a shallow network of air injection and extraction piping, and then backfilling; or vertical and/or horizontal drilling to construct a deep subsurface network of piping. The difficulty in using the *in situ* method is plume control. The air may diffuse away from collection points and mobilize the contaminants in an undesirable direction. This method is also expensive when horizontal drilling is used, because of the specialized nature of horizontal drilling. Generally, aboveground air sparging is cost effective for low flow rates and high VOC concentrations, unless mineral content causes operating problems.

D-12. Surfactant Flushing

Surfactant flushing is a relatively new, *in situ* technique for remediation of DNAPLs. The technique is applied by pumping water, with surfactants, into the ground water via injection wells. The surfactants increase the DNAPLs' aqueous solubility, by several orders of magnitude, by forming colloidal clusters in which the DNAPLs are solubilized. The resulting water/DNAPL/surfactant mixture can be removed by extraction wells without DNAPLs becoming sorbed by soil particles. The mixture is then treated with conventional ground water treatment systems (NETAC, 1992).

D-13. Bioremediation

Bioremediation involves the use of microbes to degrade organic compounds in contaminated ground water and/or soils. Under favorable conditions, microorganisms may be capable of completely degrading many organic compounds into carbon dioxide and water, or organic acids and methane.

The applicability of bioremediation depends on the nature of site contaminants. Petroleum compounds, such as gasoline and diesel fuel, are known to be readily biodegradable. Other biodegradable contaminants include alcohols, phenols, esters, and ketones. Chlorinated compounds become more difficult to biodegrade as the number of chlorine molecules increases. Bioremediation of large, heavily chlorinated compounds such as PCBs is slow and therefore impractical.

Bioremediation of contaminated soils is accomplished by the degradation of specific organic constituents, or "parent" compounds, to a number of intermediate compounds. It is a process that may involve many enzymes, many species of organisms, and many intermediate compounds before the parent compound is mineralized.

Mineralization is the complete degradation of organic compounds under aerobic conditions to carbon dioxide, water, inorganic compounds, and cell proteins or, under anaerobic conditions, to organic acids, methane, and/or hydrogen gas. Under normal degradation conditions, a constituent may not be completely mineralized but may be transformed into intermediate products, which may be just as hazardous as the parent compound. The goal of controlled on-site bioremediation is degradation of the parent compound to products that are not hazardous to human health or the environment.

Both aerobic and anaerobic processes are applicable to the degradation of hazardous materials. Aerobic biodegradation, which relies on the presence of oxygen, is applicable to the remediation of soils contaminated with nonchlorinated organics, such as fuel oil components, and some chlorinated materials.

Many chlorinated solvents, such as PCE, TCE, and TCA, are resistant to aerobic biodegradation. These compounds may, however, be degraded under anaerobic conditions. The degradation of these compounds involves reductive dehalogenation, in which chlorine is replaced with hydrogen, to form new compounds that may be more mobile and toxic than the original compound. Chlorinated alkenes have been mineralized by co-metabolism or methane-utilizing bacteria (methanotrophs). In other contaminated soil systems, some chlorinated compounds can be reductively dehalogenated to produce intermediate products that can then be degraded further using aerobic processes.

Enhanced in situ bioremediation of subsurface materials generally involves the stimulation of naturally occurring, or indigenous, microorganisms to degrade organic contaminants. The microorganisms are stimulated by the addition of agricultural fertilizers, such as manure; aqueous solutions of nutrients, such as ammonia and orthophosphate; and possibly an oxygen source, such as hydrogen peroxide. This is typically done by pumping ground water from the aquifer, treating it to remove contaminants, adding nutrients and an oxygen source, and then reinjecting it into the aquifer. Water is withdrawn faster than it is reinjected, creating a pressure sink at the withdrawal point. The pressure sink hydraulically contains the contamination and increases the flow rate of nutrients through the aquifer. In some cases, other environmental parameters, such as pH and temperature, can be optimized to stimulate biological activity.

Landfarming or enhanced soil bioremediation (ESB), a type of surface bioremediation, involves the surface aeration of soil and sludges containing oil and/or other hazardous materials by tilling or other cultivation methods, with the addition of nutrients. This method has been used by the oil refining industry for many years for the disposal of oily sludges. The method can also be applied *in situ*, where soil contamination is relatively shallow. Addition of microbial cultures can be used to augment the indigenous microbial population and speed up the rate of biodegradation. We are presently using ESB to reduce concentrations of diesel fuel in soil excavated during underground storage tank closure activities in the GSA. An ESB pilot study was conducted in 1990, and a full-scale ESB started in 1991 continues (Carlsen, 1991).

Bioremediation is often combined with other technologies, either by design as with pump-and-treat and *in situ* bioremediation, or as part of a treatment train, following soil flushing or vacuum extraction (U.S. EPA, 1991).

D-14. GAC—Ground Water Treatment

GAC adsorption is a well-established technology for ground water treatment that is generally effective for removing high-molecular-weight compounds and chlorinated solvents. Activated carbon removes contaminants from water by adsorbing them onto its surface. GAC units are made from a variety of carbonaceous materials. A GAC adsorption system consists of a packed column with a system to distribute the water evenly over the carbon bed. Organic compounds adsorb onto the surface of the GAC as the water flows through the fixed bed. The spent GAC may be thermally regenerated by heating the carbon in a natural gas-fired furnace, thereby completely desorbing the organic compounds from the surface of the GAC. The compounds can then be thermally oxidized or driven off and collected for reuse. After regeneration, the GAC is no longer considered a hazardous waste. The adsorptive capacity of GAC degrades from regeneration and the used material eventually must be disposed of and replaced. The cost is dependent upon flow rates and VOC concentrations. Generally, GAC is cost effective for low flow and low concentration applications (LLNL, 1991b).

D-15. Air Stripping

Air stripping is a process in which VOCs are removed from water by bringing VOC contaminated water into contact with air. This is commonly achieved with air stripping towers or trays. In conventional air strippers, ground water is sprayed into the top of an air stripping column. As water cascades down through packing material within the column, a blower forces an upward air stream through the water transferring VOCs from water to air.

Tray aeration is achieved by spraying extracted ground water into an inlet chamber. The water flows along baffled aeration trays and air is blown up through small-diameter holes in the trays. A froth forms, creating a large mass transfer surface. The high air-to-water ratio causes the organic contaminants to volatilize into air, leaving substantially reduced concentrations of VOCs in the water.

Air stripper design operation and maintenance must be tailored to the general water quality at the site. High calcium and magnesium hardness, which exists at Site 300, can clog the packed columns, reduce efficiency, and increase operating costs. To eliminate VOC discharge to the atmosphere, this technology would be used in conjunction with vapor-phase GAC.

The cost is dependent upon flow rates and VOC concentrations. Generally, air stripping is cost effective for high flow rates and high VOC concentrations, unless mineral content causes operating problems (LLNL, 1991b).

D-16. UV/Oxidation—Ground Water

UV/oxidation uses an oxidizing agent, such as hydrogen peroxide or ozone, and ultraviolet (UV) light as an agent to augment the dissociation of the oxidizing agent to a hydroxyl radical. By destroying the VOCs, UV/oxidation processes minimize the amount of waste that require further treatment or disposal (LLNL, 1991b).

A type of UV/oxidation technology is Perox-Pure™, a chemical oxidation technology that was demonstrated under EPA's Superfund Innovative Technology Evaluation (SITE) program at the Building 834 Complex. Over a three-week period in September 1992, about 40,000 gallons of VOC-contaminated ground water was treated in the Perox-Pure™ system. For the SITE demonstration, the Perox-Pure™ system achieved TCE and PCE removal efficiencies of about 99.7 and 97.1%, respectively. In general, the system produced an effluent that contained TCE, PCE, and 1,1-dichloroethane (DCA) below detection limits, and chloroform and 1,1,1-TCA slightly above detection limits. The system also achieved chloroform, DCA, and TCA removal efficiencies of 93.1, 98.3, and 81.8%, respectively. The treatment system effluent met California drinking water action levels and federal drinking water MCLs for TCE, PCE, chloroform, DCA, and TCA at the 95% confidence level (U.S. EPA, 1993).

D-17. Electron Acceleration

Electron acceleration is an innovative technology used for the radiolytic remediation of VOCs. In this process, a contaminated vapor stream is irradiated with a small electron accelerator, thereby reducing the concentration of the VOC. The level of contaminant irradiation in vapor is primarily a function of the power of the electron beam. In this process, organic by-products, such as chloromethane, dichloromethane, chloroform, acetone, and trimethylbenzene, may be formed at very low concentrations (Matthews et al., 1992).

This technology was tested at the Building 834 Complex in November and December 1991 to destroy TCE. In this experiment, 90% of the ingoing TCE was destroyed at a cost of approximately $15/kg (Webster-Scholten, 1994).

A similar technology is now being developed elsewhere for liquid phase contaminant destruction using electron acceleration. This technology is also considered innovative, and its cost effectiveness is also based on contaminant concentration levels.

D-18. GAC—Vapor Treatment

The use of GAC treatment for vapors is a well established technology for the removal of VOCs from air streams. With few exceptions, most VOCs can be effectively removed from the vapor exhaust of a soil vapor extraction system or a ground water air sparging/stripping treatment system, using a fixed-bed GAC system. The GAC is effective over a broad range of constituent concentrations in the air stream, although the mass of organic compounds that will be adsorbed per unit mass of GAC increases as the concentration of the compounds in the air to be treated increases. High moisture content in the vapor can limit the sorptive capacity of carbon. Spent GAC can be regenerated on site using steam, regenerated in an off-site kiln, or incinerated in an off-site furnace. The adsorptive capacity of GAC degrades from regeneration, and the used material eventually must be disposed of and replaced. Annual treatment costs associated with GAC can be quite high initially; costs decrease as VOC concentrations in the soil vapor decrease over time (LLNL, 1991b).

D-19. Thermal Oxidation

The vapor emissions produced by soil vapor extraction or extracted ground water treatment containing VOCs or fuel hydrocarbons can be controlled by passing the vapor through a thermal oxidation unit. There the air containing the organic vapors is heated to a temperature sufficient to completely oxidize the compounds. This technique is most easily applied to mixtures of air and fuel hydrocarbons in which the oxidation products consist of water and carbon dioxide. Chlorinated solvents, such as TCE, may also be thermally oxidized, although additional treatment of the exhaust gas from the thermal oxidation unit may be required to remove the hydrogen chloride produced. In most cases, the concentrations of organic compounds in the emissions from the soil vapor extraction operations will not be sufficient to maintain combustion, so an auxiliary source of fuel, such as propane or natural gas, must be supplied to produce enough heat. The major advantage of this system is that almost complete destruction (over 99%) of the VOCs or FHCs is achieved on site. In addition, this technology may be more economical than GAC treatment of the vapor phase for large quantities of vapor vented over extended periods. The disadvantages are the capital cost for the thermal oxidation system, and the expense associated with the need for an auxiliary fuel supply (LLNL, 1991b).

D-20. Catalytic Oxidation

Catalytic oxidation is a vapor treatment technology similar to the thermal oxidation process except that the oxidation occurs in the presence of a catalyst, commonly platinum or palladium metal, that allows the oxidation to occur at much lower temperatures. This has the advantage of reducing the quantity of auxiliary fuel required for the oxidation unit. However, the catalyst is susceptible to fouling and poisoning, particularly in the presence of chlorinated solvents. The capital cost for installation can be weighed against the lower operational costs for thermal oxidation. Close operator attention or automated protection is generally required to prevent catalyst damage.

Catalytic oxidation is commonly used for the destruction of fuel hydrocarbon vapors. This method is not applicable to chlorinated solvents because toxic daughter products are created in the process (LLNL, 1991b).

D-21. Resin Adsorption-Regeneration

Resin adsorption-regeneration is an innovative vapor treatment system that traps VOC vapors on an adsorbent resin bed. The advantage of this system is its on-site regenerative capacity. Typically, a resin adsorption-regeneration system consists of one or more resin beds that are on line while another bed is being regenerated in a desorption cycle. The resin beds are automatically switched between adsorption and desorption cycles. Desorption is accomplished using a combination of temperature, pressure, and a carrier gas. During the desorption cycle, the VOCs trapped in the adsorbent resin material are removed, condensed, and transferred in liquid phase to a storage tank.

The resin adsorption-regeneration system has two advantages over the conventional carbon treatment system. Because the adsorbent material can be regenerated on site, the cost is much lower than GAC, which typically must be transported off site as hazardous waste for disposal or treatment. Although on-site carbon regeneration is feasible, the carbon has limited reuse capacity before replacement. Carbon regeneration also produces acids when treated for VOCs, causing corrosion problems, and activated carbon's capacity to adsorb VOCs is significantly affected by moisture. The claim for the resin adsorption-regeneration system is that the adsorbent beds may be recycled in excess of 2,000 times with no measurable loss of adsorption capacity (Purus, 1993). They also have a high tolerance to water vapor, thereby allowing treatment of vapor streams that have relative humidity greater than 90% with minimal impact on adsorption efficiency. These two factors would lower the operation and maintenance treatment costs and would make the resin resorption-regeneration system more cost effective and efficient for long-term treatment.

D-22. UV/Oxidation—Vapor

A new UV/oxidation process has been developed for the photo-oxidation of VOCs in air using an advanced ultraviolet source, a Purus xenon flashlamp. The flashlamps have greater output at 200–250 nm than medium-pressure mercury lamps at the same power and therefore cause much more rapid direct photolysis of VOCs, including methylene chloride, chloroform, carbon tetrachloride (CCl_4), 1,2-dichloroethane (1,2 DCA), TCA, Freon 113, and benzene. The observation of quantum yields greater than unity indicate the involvement of chain reactions for TCE, PCE, 1,1-DCE, chloroform, and methylene chloride.

TCE was examined more closely because of its widespread occurrence and very high destruction rate. Two full-scale air emissions control systems for TCE were constructed by Purus and tested at a LLNL. The systems were operated at flash frequencies of 1–30 Hz, temperatures of 33–60 degrees Celsius, flows up to 300 scfm (260 ppmv TCE) and concentrations up to 10,600 ppmv (100 scfm). Residence times ranged from 5 to 75 seconds. In all cases, except at the lowest flash frequency, greater than 99% removal of TCE was observed. Careful attention was paid to product formation and mass balances. The main initial photo-oxidation product of TCE was dichloroacetyl chloride, which upon further photolysis was converted in part to dichlorocarbonyl (phosgene or DCC) and ultimately to hydrochloric acid, carbon dioxide, and possibly carbon monoxide. Further treatment of photo-oxidation products was recommended for full-scale operation (Johnson et al., 1992).

D-23. On-Site Surface Discharge

We are presently discharging treated ground water to the surface, under NPDES permit No. CA0082651 and RWQCB order No. 91-052, as part of an interim CERCLA removal action at the central GSA. The treated water is collected in a tank until 10,000 to 20,000 gallons have accumulated, then it is sprayed into a remote canyon at a rate of 100 gpm over an area of approximately 16,000 ft^2. This recharge rapidly infiltrates the exposed $Tnbs_1$ regional aquifer sandstone in the canyon.

D-24. Air Misting

Air misting is the atomization of treated ground water by forcing it through spray heads that separate the water into fine droplets as it is expelled into the air. This process allows maximum areal dispersion of discharge. This discharge process eliminates problems associated with surface discharge (e.g., erosion). Misting is applicable if flow rate is low enough. This process is being applied as part of the Site 300 Building 834 CERCLA removal action and is being used to discharge treated well development and sample purge water at Building 833.

D-25. Reinjection

Reinjection wells can function as a means to discharge treated ground water, hydraulically control plume movement, and reduce cleanup times. The reinjection of treated ground water can be an efficient cost-saving measure. However, the quality of this water is important because of potential for recontamination and potential scaling from precipitates, such as carbonate. Scaling and/or microbially-induced fouling can reduce the efficiency of the injection well and require periodic maintenance. For purposes of flow control, ground water reinjection would need to take place within the capture zones of ground water extraction wells.

D-26. References

Buettner, H. M. (1993), LLNL, personal communication with Laurene Green-Horner, Weiss Associates, July, 1993.

Carlsen, T. M., Ed. (1991), *LLNL Site 300 Environmental Investigations Quarterly, January–March 1991*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-10194-91-1).

Hansen, J. E. (1993), Geosafe Corporation, personal communication with R. Devany, Weiss Associates.

Johnson, M. D., W. Haag, P. G. Blystone, and P. F. Daley (1992), *Destruction of Organic Contaminants in Air Using Advanced Ultraviolet Flashlamps*, Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, Ohio (Contract No. 818209-01-1, July 1992).

Krynne, O. P., and W. R. Judd (1957), "Principles of Engineering Geology and Geotechnics," McGraw-Hill Book Company, Inc., New York, N.Y.

LLNL (1991b), *CERCLA Feasibility Study for the LLNL Livermore Site, Lawrence Livermore National Laboratory*, Livermore, Calif. (UCRL-AR-104040).

Matthews, S. M., A. J. Boegel, D. W. Camp, R. A. Caufield, J. O. Cunningham, P. F. Daley, J. J. Greci, J. A. Jovanovich, J. A. Loftis, and P. D. Soran (1992), "Remediation of a TCE Ground Spill Using an Electron Accelerator," in *Proceedings of the International Topical Meeting on Nuclear and Hazardous Waste Management, Spectrum '92*, August 23–27, 1992, Boise, Ida., published by the American Nuclear Society, Inc., La Grange Park, Ill.

NETAC (1992), "CESAR Process," *Environmental Product Profiles*, Vol. II, National Environmental Technology Applications Corporation, Austin, Tex.

Purus (1993), "PADRE™ Adsorption-Regeneration Systems," manufacturer's specifications and letter from Gerald Facino, Area Manager-West, Purus, San Jose, Calif.

Rossibi, J., G. Riha, B. B. Looney, V. J. Rohay, B. B. Peters, R. J. Cameron (1993), "Barometric Pumping for VOC Remediation," [abs.], in *Eos*, Transactions, Vol. 74, No. 43, October 26, 1993. American Geophysical Union, Washington, D.C.

Siegel, W. H., H. M. Buettner (LLNL), and K. S. Udell (Univ. of California, Berkeley) (1992), "Dynamic Underground Stripping Engineering Demonstration Project: Construction, Operation and Engineering Results," in *Proceedings of the International Topical Meeting on Nuclear and Hazardous Waste Management, Spectrum '92,* August 23–27, 1992, Boise, Ida., published by the American Nuclear Society, Inc., La Grange Park, Ill.

U.S. EPA (1989), *Stabilization/Solidification of CERCLA and RCRA Wastes*, U.S. Environmental Protection Agency, Center for Environmental Research Information, Cincinnati, Ohio (EPA/625/6-89/022).

U.S. EPA (1991), *Handbook, Stabilization Technologies for RCRA Corrective Actions,* U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. (EPA/625/6-91/026).

U.S. EPA (1992), *Vitrification Technologies for Treatment of Hazardous and Radioactive Waste,* U.S. Environmental Protection Agency, Office Research and Development U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. (EPA/625/R-92-002).

U.S. EPA (1993), *Application Analysis Report, Peroxidation Systems, Inc. Perox-Pure™ Chemical Oxidation Technology, Research and Development (RD 681),* U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio (Contract No. 68-C0-0047, May 1993).

Webster-Scholten, C. P., Ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-108131).

Appendix E

Source Removal Analysis

Appendix E

Source Removal Analysis

E-1. Introduction

In this appendix, we present an analysis of source removal as a potential remedial alternative at the Pit 6 operable unit. This analysis provides the basis for the screening comments in Chapter 3 on removal, treatment, and disposal of material contained in pit 6. Four source removal scenarios are described, and one potentially implementable scenario is discussed further. That scenario would require the following elements:

- Preparation of work and safety plans.
- Removal of rifle range and site grading.
- Preliminary borehole and geophysical surveys.
- Construction of a waste treatment/storage facility, and a general staging facility for decontamination, transportation, and administrative activities.
- Excavation of trench and animal pit contents.
- Waste characterization and separation.
- Temporary waste storage.
- On-site waste treatment.
- Transportation to disposal facility.
- Off-site treatment/destruction and/or disposal.
- Protection of the public, workers, and environment from chemical and physical hazards.

We also discuss the assumptions we used to prepare a cost estimate for removal, treatment, transportation, and disposal of material.

E-2. Screening of Scenarios and Selection of Treatment Options

We evaluated the following post-excavation scenarios:

1) Reburial of the waste at pit 6 after retrofitting the pit with an impermeable liner and a leachate collection system.
2) Reburial of the waste in a lined pit at a different Site 300 location.
3) Aboveground storage of the waste at Site 300.
4) Treatment of the waste at an on- or off-site facility and disposal off site.

As shown in Table E-1, three of the four scenarios are screened out because they are not implementable. Scenario 1 is screened out because the presence of a nearby Holocene fault prohibits retrofitting the old pit for proper reburial of the waste (22 CCR Section 66264.18[a]). Scenarios 2 and 3 are screened out since Site 300 is not permitted to permanently store or dispose of low-level radioactive waste (LLRW) or low-level mixed waste (LLMW) on site. The fourth scenario, treating the waste at an on- or off-site facility and disposing of the waste off site, appears to be implementable, although it is complex, as discussed below.

The selection of waste treatment options depends primarily on the contaminated medium and the chemical contaminants present. Basic treatment may involve decontamination of large debris by washing, recycling (when applicable), on- or off-site aeration or bioremediation, or stabilization at a permitted facility either on site or off site. Waste treatment/destruction options for pit 6 are shown in Figure E-1 and summarized in Table E-2.

E-3. Source Removal Tasks

A number of tasks would have to be completed to remove the source material under the one potentially implementable scenario described above. The tasks are discussed below.

E-3.1. Work and Safety Plans

All excavation, analytical, characterization, and disposal procedures would be described in detailed work plans. After the work plans were approved by regulatory agencies and the responsible parties, engineering design specifications would be developed and requests for bids would be solicited by the Plant Engineering and Procurement Divisions. The development of safety plans would follow and would require input from various LLNL departments: the Hazards Control, Plant Engineering, Fire Department, and Environmental Protection, etc.

E-3.2. Removal of Rifle Range and Site Grading

To access the trenches and animal pits for excavation, the existing rifle range would need to be dismantled and the site regraded.

E-3.3. Preliminary Borehole and Geophysical Surveys

Prior to excavation, we would conduct geophysical surveys, cone-penetrometer tests, and/or drilling to more accurately locate the trenches and animal pits, characterize their contents, and determine the possible extent of adjacent contamination. This may involve invasive methods such as drilling and sampling that would require extreme safety precautions. Because of potential worker and public exposure to hazards, comprehensive health and safety monitoring would take place during this phase.

E-3.4. Construction of Waste Treatment/Storage Facility

We would construct an enclosed waste storage facility to prevent wind and rain from coming into contact with the stored waste. A staging area would be outfitted with a decontamination facility consisting of a steam cleaner, showers, and containers for disposal of personal protection or other equipment. The decontamination facility would also need an effluent collection system to capture waste from steam cleaning, surfactant washing, and other decontamination procedures. A sufficient supply of water and power would be necessary for these operations. Administrative offices would be provided for on-site project management. A large paved area would be provided for preparing and loading excavated materials for transport off site. Improvements to the existing access road may be required.

E-3.5. Excavation

Excavation of the pit contents would only be conducted by trained and experienced crews. This effort would be slow and cautious due to uncertainties regarding the contents of the buried waste and the risks inherent in excavating these wastes. Excavation equipment required would depend on the proximity of the work to the buried waste. Digging along the former trench ramps and outlying areas could be accomplished with a backhoe. However, when buried debris is uncovered, manual excavation may be necessary to minimize potential releases. If contamination is discovered beyond the limits of the trenches, deeper excavation would be required.

E-3.6. Waste Characterization and Separation

Excavation of pit 6 contents would require that wastes be characterized and separated to select the proper treatment and/or disposal options. We would test the waste for various contaminants in a manner appropriate to the physical characteristics of the waste (e.g., contaminated soil versus glove boxes). Excavated soil and small debris would be sampled and placed into 55-gal. drums at the excavation site and then moved to the waste storage facility. Large debris would be wipe-sampled and stored in suitably sized roll-off containers.

E-3.7. Temporary Waste Storage

The storage facility would be used to temporarily store containerized waste while samples are being analyzed, and while the proper treatment/destruction or disposal and transportation methods are being determined and carried out.

E-3.8. On-Site Treatment/Destruction of Specific Waste Components

Table E-2 describes various media-specific treatment and destruction options. Steam-cleaning or surfactant washing and recycling might be used for non-soil solid components, such as large metal objects, and on-site aeration and/or bioremediation for soil contaminated exclusively with volatile nonradioactive compounds. Radioactive liquid wastes, if any, would require treatment by solidification and/or desiccation prior to off-site disposal.

E-3.9. Transportation

A licensed hazardous waste and/or radioactive waste hauler would be hired to transport characterized waste to a permitted disposal facility. Most of the waste would be transported in 4-ft by 8-ft by 4-ft metal containers. LLNL and the hauler would be required to manifest the waste.

E-3.10. Off-Site Treatment/Destruction and Disposal of Waste

Most of the contaminated waste would be treated and/or disposed of at an off-site facility, depending on applicable disposal requirements and regulations. Liquid waste would be stabilized (i.e., physically and/or chemically bound to a solid matrix) to meet leachability standards for disposal. Some waste such as PCBs may require incineration.

E-3.11. Protection of the Public, Workers, and the Environment

During the excavation, a temporary enclosed structure would be built over the excavation area to prevent rain or wind from coming into contact with the excavated waste. All workers would be required to wear at least level B personal protective equipment. Decontamination procedures would be strictly enforced to protect workers and the environment from exposure. Ongoing monitoring for VOCs, air-borne particulates, and radioactivity would also be conducted.

E-4. Cost Estimates

Table E-3 presents our cost estimates for the source removal action at pit 6 and includes:

- The excavation of waste from the three burial trenches, six animal pits, and adjacent soil in the Pit 6 operable unit.
- The separation and characterization of excavated waste and soil.
- The treatment/destruction of contaminants and/or off-site disposal of waste and soil.

E-5. Cost Assumptions

In this section we present the cost assumptions for general operations, treatment, transportation, and disposal. Because the contents of pit 6 are not completely characterized, costs are uncertain. We therefore make cost-conservative assumptions biased towards lower costs. Actual costs are likely to be higher than those presented here.

E-5.1. General Cost Assumptions

- The radioactive components of the buried debris are considered to be LLRW.
- All excavated material must initially be handled as LLMW.
- Debris described as "gas bottles" in the pit 6 disposal records do not contain pressurized gas. This is consistent with LLNL disposal protocol at the time of original disposal (Van Dyke, 1985).
- Disposal costs account for land disposal restrictions (LDR), treatment costs, site disposal fees, and any other fees or taxes.
- We assume the contaminated waste volume to be 3,000 yd^3 of material. To simplify the preparation of the disposal and transportation estimate, we assume that this material is all soil.

- Soil contaminated exclusively with volatile nonradioactive compounds would be treated on site by aeration or biodegradation methods.
- Post-disposal costs are excluded.

E-5.2. Site Reconnaissance and Preparation Assumptions

- Geophysical surveys and cone-penetrometer testing will adequately delineate the limits of the trenches to safely conduct drilling and sampling operations.
- Eighty boreholes will be drilled to a depth of 20 ft around the trenches.
- A total of 320 soil samples will be collected from these boreholes and analyzed for a full suite of analytes.

E-5.3. Waste Treatment/Storage Facility Construction Assumptions

- An Environmental Impact Report/Environmental Impact Study will be required.
- The facility will be completely enclosed to prevent accidental releases.
- A decontamination facility equipped with an effluent collection system will be included.

E-5.4. Excavation/On-Site Handling Assumptions

- An eight-man crew is capable of excavating, sampling, labeling, and containerizing 50 drums (about 12.5 yd^3) of waste per day.
- 13,000 yd^3 of soil will be excavated, of which 3,000 yd^3 will require treatment/disposal. Thirty percent of this volume is anticipated fluff (increased voids) in the soil.
- Construction of a temporary enclosure over the excavation area.
- All waste materials will be stored in 55-gal. drums until transfer for transport.
- Liquid effluent from decontamination activities will be LLRW requiring on-site solidification.
- This facility will be capable of processing all waste regardless of shape, size, or condition.

E-5.5. Waste Characterization Assumptions

- Four samples will be collected for every cubic yard of contaminated soil.
- One composite sample will be collected for every 50 yd^3 of prescreened uncontaminated soil.
- Samples will be analyzed for a suite of contaminants of concern (VOCs, metals, PCBs, and radionuclides). This requires four samples for the analysis of one suite.

E-5.6. Transportation Assumptions

- The density of buried debris is 1.5 ton/yd^3.
- Transportation costs include hauling and manifesting.

- All similarly contaminated soil will be transferred from 55-gal. drums to 4-ft by 8-ft by 4-ft metal boxes.
- Four boxes will be transported per trip for a total of 200 trips.
- The waste disposal facility is 1,000 miles away from Site 300.

E-5.7. Disposal Assumptions

- LDR stabilization and other treatments will meet all Federal, State, and local requirements.
- 1,000 yd^3 of the waste is LLRW, 1,000 yd^3 is LLMW, and 1,000 yd^3 will be treated on site using aeration and bioremediation, or steam-cleaning/surfactant washing.
- The 1,000 yd^3 of LLMW will require stabilization at the disposal facility.
- The 1,000 yd^3 of treated soil or debris will be used for on-site backfill (soil) or recycling after treatment.

E-5.8. Site Restoration Assumptions

- The waste storage facility will be dismantled.
- A closure plan will be required.
- The site will be regraded and the rifle range rebuilt.

E-5.9. Professional Environmental Services Assumptions

We assume the following professional environmental services will be needed to supplement LLNL's staff:

- Assistance with the preparation of work plans, standard operating procedures (SOPs), operational safety plans (OSPs), etc.
- Assistance with management of the project and coordination with regulatory agencies.

E-5.10. LLNL ERD Team

We assume that the LLNL ERD team will include the following:

- Project managers.
- Engineers.
- Geologists.
- Database management personnel.
- Administrative and clerical personnel.

E-5.11. LLNL Technical Support Assumptions

We assume that in addition to LLNL ERD's staff, the following LLNL technical support services will be used:

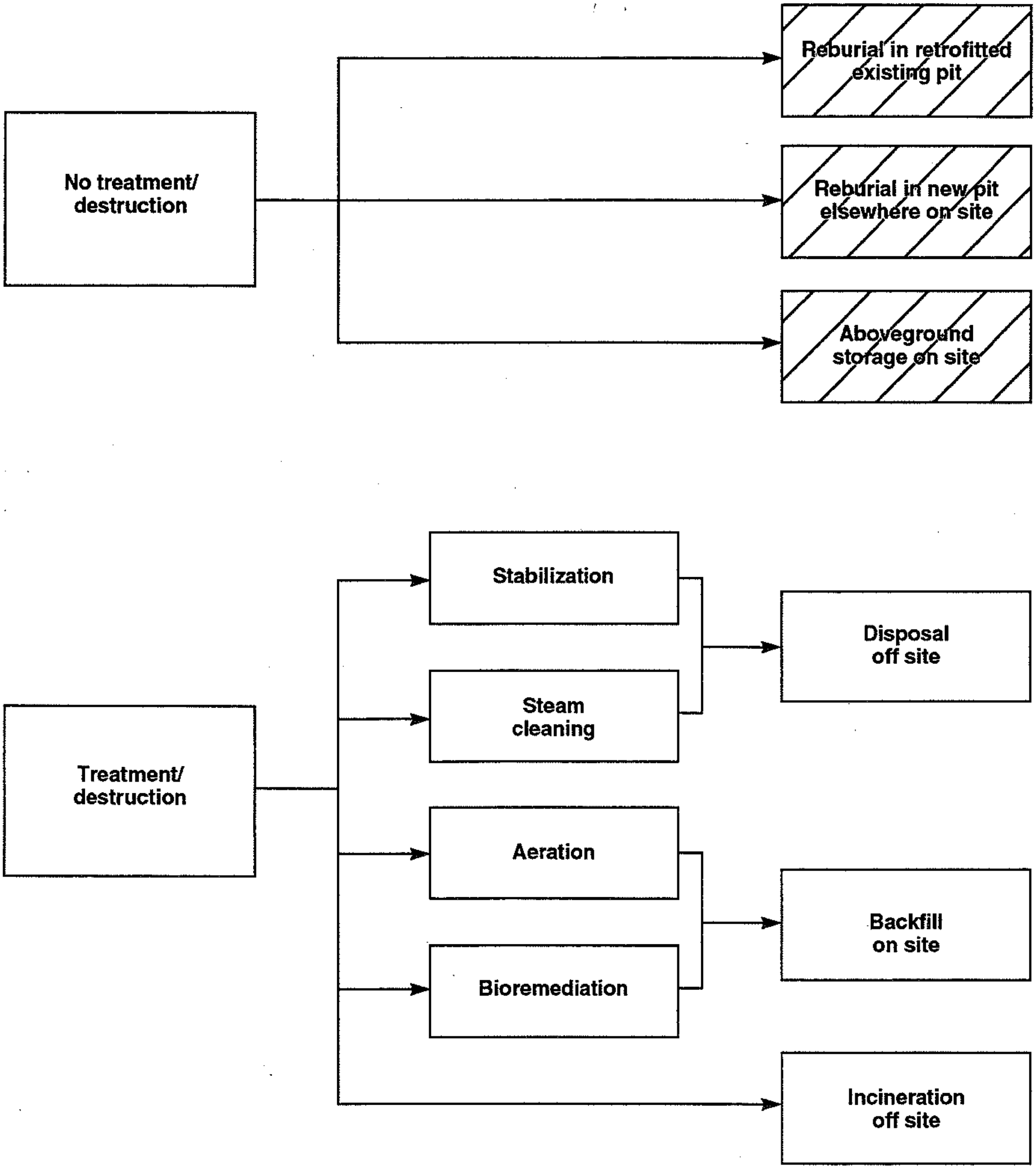
- LLNL Plant Engineering.
- Hazardous Waste Management.
- Hazards Control.
- Emergency Response Team.

E-6. Conclusions

As shown in Table E-3, the cost to remove and dispose of the contents of pit 6 approaches \$70 million. As a comprehensive remedial action, excavation and disposal would be coupled with long-term monitoring and possibly capping and ground water extraction, the total cost for which could easily exceed \$100 million. Although the removal process would employ significant safety and engineering controls, it would increase the potential for releases of hazardous materials to the environment.

E-7. Reference

Van Dyke, O. R. (1985), Memorandum to W. M. McConachie, LLNL Environmental Restoration Division, February 6, 1985.



Some steam-cleaned waste may be recycled

▨ **Screened out**

ERD-FS-PT6-3215

Figure E-1. Excavated waste process options.

Table E-1. Screening of post-excavation scenarios.

Scenario	Screening comments	Considered further
1) Retrofit old pit and replace waste	Too close to a Holocene fault. Site 300 not permitted for waste disposal.	No
2) Create new pit on site and fill with waste	Site 300 not permitted for waste disposal.	No
3) Store waste on site	Site 300 not permitted for waste storage.	No
4) Treat on site or off site and dispose of waste off site	Costly, complex, and could potentially increase risk.	Yes

Table E-2. Treatment/destruction options.

Treatment/ destruction process options	Applicable media			Comments
	Soil	Debris	Liquid	
Steam-cleaning/surfactant washing		√		Generates liquid waste that will need to be treated or destroyed. This may be done on site or at a permitted off-site facility.
Recycling	√	√	√	Remediated soil may be used as backfill.
Stabilization	√	√	√	A significant portion of the pit contents may be stabilized. This would probably be done off site at a permitted facility.
Incineration	√	√	√	This may be the best available treatment option for high concentration PCB waste. This would need to be done at an out-of-state, permitted facility.
Aeration	√			Aeration would be considered for soil contaminated with volatile compounds only. This would most likely be done on site.
Bioremediation	√			Bioremediation would be considered for soil contaminated with volatile compounds only. This would most likely be done on site.

Table E-3. Pit 6 source removal costs.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Site reconnaissance and preparation				
Dismantling of existing rifle range				20,000
Site surveys (ecological, trench location, radiometric)				40,000
Grading				60,000
Exploratory boreholes and soil analyses	80	each	8,500	680,000
Total site reconnaissance and preparation costs				**800,000**
Waste treatment and storage facility/staging area				
Construction of building (includes concrete floor, roll-up doors)	60,000	sq ft	50	3,000,000
Electrical connections				100,000
Decontamination facility (steam cleaning, showers, effluent collection system) and on-site administrative field office				85,000
Total waste treatment and storage facility construction costs				**3,185,000**
Excavation and on-site handling				
Fenced exclusion zone and tent enclosure over excavation area				120,000
Construction of drainage diversion system				50,000
Excavation/sampling/storage crew (8 persons; 2 years; 50 drums/day)	16	person-yr	140,000	2,240,000
Excavation/handling equipment (includes one backhoe and fork lift)	24	month	10,000	240,000
Metal box containers (large items) and 55-gal. drums				1,000,000
Safety monitoring and Level B protective personal equipment (PPE) (includes air monitoring and sampling, PPE coordination and inspections, safety supplies, and equipment maintenance/calibration)				360,000
Total excavation/on-site handling costs				**4,010,000**

Table E-3. Pit 6 source removal costs.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Waste characterization				
Sample containers (brass tubes)	50,000	each	2	100,000
Analyze samples (3,000 cu yd, trench volume; 4 samples/cu yd)	12,000	suite	1,500	18,000,000
Analyze samples (10,000 cu yd, non-trench volume; 1 composite sample/50 cu yd)	200	suite	1,500	300,000
Total waste characterization costs				**18,400,000**
Transportation				
Transportation containers, hauling, loading/unloading	2,000	cu yd	400	800,000
Total transportation costs				**800,000**
Treatment/Disposal				
Disposal of LLRW	1,000	cu yd	2,700	2,700,000
Stabilization and disposal of LLMW	1,000	cu yd	4,100	4,100,000
On-site aeration	1,000	cu yd	50	50,000
Disposal of liquid effluent and PPE				200,000
Total disposal costs				**7,050,000**
Site restoration				
Backfilling, compacting, regrading				100,000
Dismantling and decontamination of waste storage facility				500,000
Reconstruction of rifle range				60,000
Total site restoration costs				**660,000**
Subtotal field costs				**34,905,000**
Contractor overhead and profit (15% of subtotal field costs)				5,235,750
Subtotal contractor field costs				**40,140,750**
LLNL material procurement charge (MPC) (18% of contractor field costs)				7,225,335
Total field costs				**47,366,085**

Table E-3. Pit 6 source removal costs.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Professional environmental services				
Assistance with preparation of work plans, SOPs, OSPs, etc.				150,000
Assistance with preparation of EIR/EIS				350,000
Assistance with preparation of Closure Plan				350,000
Assistance with contract negotiation with disposal facility				100,000
Assistance with project management	3	person-yr	200,000	600,000
Subtotal professional environmental services				**1,550,000**
LLNL MPC (9.7% of professional environmental services)				150,350
Total professional environmental services				**1,700,350**
LLNL ERD team				
Project manager	3	person-yr	200,000	600,000
Engineer	3	person-yr	150,000	450,000
Geologist	3	person-yr	150,000	450,000
Database manager	6	person-yr	120,000	720,000
Administrative/clerical	3	person-yr	100,000	300,000
Total LLNL ERD team				**2,520,000**
LLNL technical support services				
LLNL Plant Engineering planning	1	person-yr	100,000	100,000
Hazardous Waste Management	2	person-yr	150,000	300,000
Hazardous Control	2	person-yr	150,000	300,000
Emergency Response Team (training/stand by)	1	person-yr	100,000	100,000
Total LLNL support services				**800,000**
Total capital costs				**49,866,435**
LLNL General & Administration Tax (7.5%)				3,739,983
Subtotal				**53,606,418**
LLNL Lab-Directed Research & Development Tax (6.0%)				3,216,385
Subtotal				**56,822,803**

Table E-3. Pit 6 source removal costs.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Contingency (20%)				11,364,561
Total cost for source removal				**68,187,363**

Appendix F

Analysis of Ground Water Capture

Appendix F

Analysis of Ground Water Capture

F-1. Introduction

This appendix presents the results of our analysis of ground water flow conditions in the Pit 6 operable unit, and the parameters influencing the capture and extraction of contaminated ground water for aboveground treatment. We used hydraulic head distribution and aquifer properties to estimate aquifer throughflow. Hydraulic capture zone widths were estimated from well yield estimates and aquifer properties. The objectives of our remedial design in Alternatives 3 and 4, based on these results, are to limit further migration of contaminated ground water and facilitate timely contaminant mass removal.

Figures F-1 and F-2 show ground water elevations for June 1992 and TCE ground water concentrations for May–July 1993, respectively. We used water elevation contours to calculate the aquifer throughflow south of pit 6, and the observed TCE distribution to determine the location of extraction wells. Ground water elevations from June 1992 were used because they are representative of recent flow conditions at the Pit 6 operable unit.

F-2. Ground Water Flow

North of the Corral Hollow-Carnegie fault zone ground water flow is generally towards the south. The flow is south-southeast in the fault zone area. Flow in the fault zone area is bounded to the north by the northern limit of the fault zone and to the south by south-dipping slopes where spring discharge and evapotranspiration take place. Figure F-1 shows a localized variation in the flow pattern that appears intermittently, where water elevations north of the fault zone are lower than water elevations in the southern part of pit 6.

F-2.1. Objectives

The objective of this analysis is to estimate aquifer discharge at various locations along the dominant south-southeast flow path, and to use these estimates to predict hydraulic capture near potential extraction wells.

F-2.2. Conceptual Model

We have estimated aquifer throughflow at two locations, south-southeast of pit 6 and further downgradient near Building 899. We used the following formulas to estimate flow through the Pit 6 operable unit:

Using the continuity equation for flow through a confined space,

$$Q = vA \tag{F-1}$$

we apply Darcy's Law,

$$v = Ki \qquad \text{(F-2)}$$

and the dimensions of our cross-sectional area,

$$A = wb \qquad \text{(F-3)}$$

and rewrite the continuity equation as,

$$Q = Kiwb \qquad \text{(F-4)}$$

where,

Q = flow through a cross-sectional area of the aquifer (ft^3/day),

v = specific discharge (ft/day),

A = cross-sectional area perpendicular to flow (ft^2),

K = saturated hydraulic conductivity (ft/day),

i = hydraulic gradient (ft/ft),

w = width of cross-sectional area (ft),

b = saturated thickness (ft).

Applying Equation F-4, and the values presented in Table F-1, we calculated aquifer throughflow the aquifer perpendicular to the 662-ft and 659-ft potentiometric surface lines (Fig. F-1). The input parameters and results are presented in Table F-1.

F-2.3. Parameter Selection

We used pump test data from well K6-22 to provide K, since it resides near the 662-ft potentiometric surface line (Table F-1). We assumed that the K from well K6-22 is also representative of the second cross-sectional area, because estimates of K are not available for wells existing on or near the 659-ft potentiometric surface line. This K is also within the same order of magnitude as the average K (logarithmic distribution) in the fault zone. We obtained an average hydraulic gradient from Figure F-1. To obtain the width of the cross-sectional areas we measured the length of the 662-ft and 659-ft ground water elevation lines from the northern limit of the Carnegie fault zone to the southern terrace outcrop. The saturated thickness was conservatively based on water level data obtained from monitor well EP6-09 following the 1992/1993 winter storms (Table F-1). This is the deepest Pit 6 operable unit well that contains VOCs.

F-2.4. Results

The ground water flow estimates, presented in Table F-1, show that flow decreases downgradient. Flow paths inferred from the potentiometric surface map (Fig. F-1) suggest that a significant portion of ground water never reaches the vicinity of well K6-23. Instead, ground water flows south towards the terrace outcrop and discharges from the water-bearing zone via springs and through evapotranspiration along the terrace slope. Flow patterns also show a flattening of the gradient between wells K6-18 and K6-23, indicative of a decrease in ground water velocity.

Because we do not have data for the southern portion of pit 6, we cannot calculate discharge for that location. However, the relatively higher water elevations and well yields immediately south of this area suggest that the aquifer throughflow may be higher than rates through the 662-ft water elevation line.

F-2.5. Sensitivity

The effects of variations in input parameters on estimated discharge are linear, due to the proportional nature of Equation F-4. An increase in velocity, conductivity, gradient, width of flow regime, or saturated thickness will produce a proportional increase in estimated discharge.

F-2.6. Conclusions

Our estimates suggest that ground water flow in the Pit 6 operable unit is on the order of 1,000 gpd south-southeast of pit 6. Ground water throughflow decreases downgradient due to a southerly flow component that directs some ground water south of the area to locations of spring discharge and evapotranspiration. We cannot use the above method to calculate flow in the southern portion of pit 6; therefore, we make the conservative assumption that the flow in this area is greater.

F-3. Capture Estimates

Figure F-1 shows the proposed locations for the four ground water extraction wells discussed in Chapter 4, which were selected based on the distribution of TCE in ground water. We positioned extraction wells K6-36, K6-37, and K6-48 to prevent further migration of the plume, extraction well K6-34 for use as an enhanced mass removal well, and K6-35 for use as a stagnation control well.

F-3.1. Objectives

Our objective in estimating the extraction well capture zones is to maximize the placement and effectiveness of the proposed extraction wells. We also compare our estimated aquifer flow to our expected well yields for the proposed well extraction scheme.

F-3.2. Conceptual Model

We base the following calculations on Darcy's Law, $Q = KiA$. The following then also applies:

$$Q = Kic_w b \qquad \text{(F-5)}$$

where

c_w = maximum capture zone width,

b = saturated thickness.

We take this approach to obtain an order-of-magnitude estimate of capture width.

F-3.3. Parameter Selection

To calculate extraction well capture widths, we used aquifer hydraulic properties presented in the SWRI report (Webster-Scholten, 1994), well yield estimates from nearby wells, and June 1992 water level data (Table F-2). We expect sustainable ground water extraction rates to be approximately 11 gpm, based on nearby well yields. We used data presented on Figure F-1 to obtain the hydraulic gradient (i).

F-3.4. Results

The modeling results are presented in Table F-2. The results show that the estimated maximum capture width is between 69 and 160 ft.

F-3.5. Sensitivity

The effects of input parameters on capture width are linear (Equation F-5). An increase in flow will produce a corresponding increase in capture width. An increase in hydraulic conductivity, hydraulic gradient, or saturated thickness will produce a corresponding decrease in capture width.

F-3.6. Conclusions

We expect sustainable ground water extraction rates to be about 15,000 gpd. These rates are sufficient to intercept the estimated aquifer flow east-southeast of pit 6, including a more than one order-of-magnitude-higher flow rate directly south of pit 6. The capture width estimates based on these flow rates indicate that the proposed wells can capture the plume inside the 5 µg/L (ppb) TCE concentration contour.

F-4. References

Freeze, R. A., and J. A. Cherry (1979), *Groundwater* (Prentice-Hall, Englewood Cliffs, N.J.).

Webster-Scholten, C. P., Ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-108131).

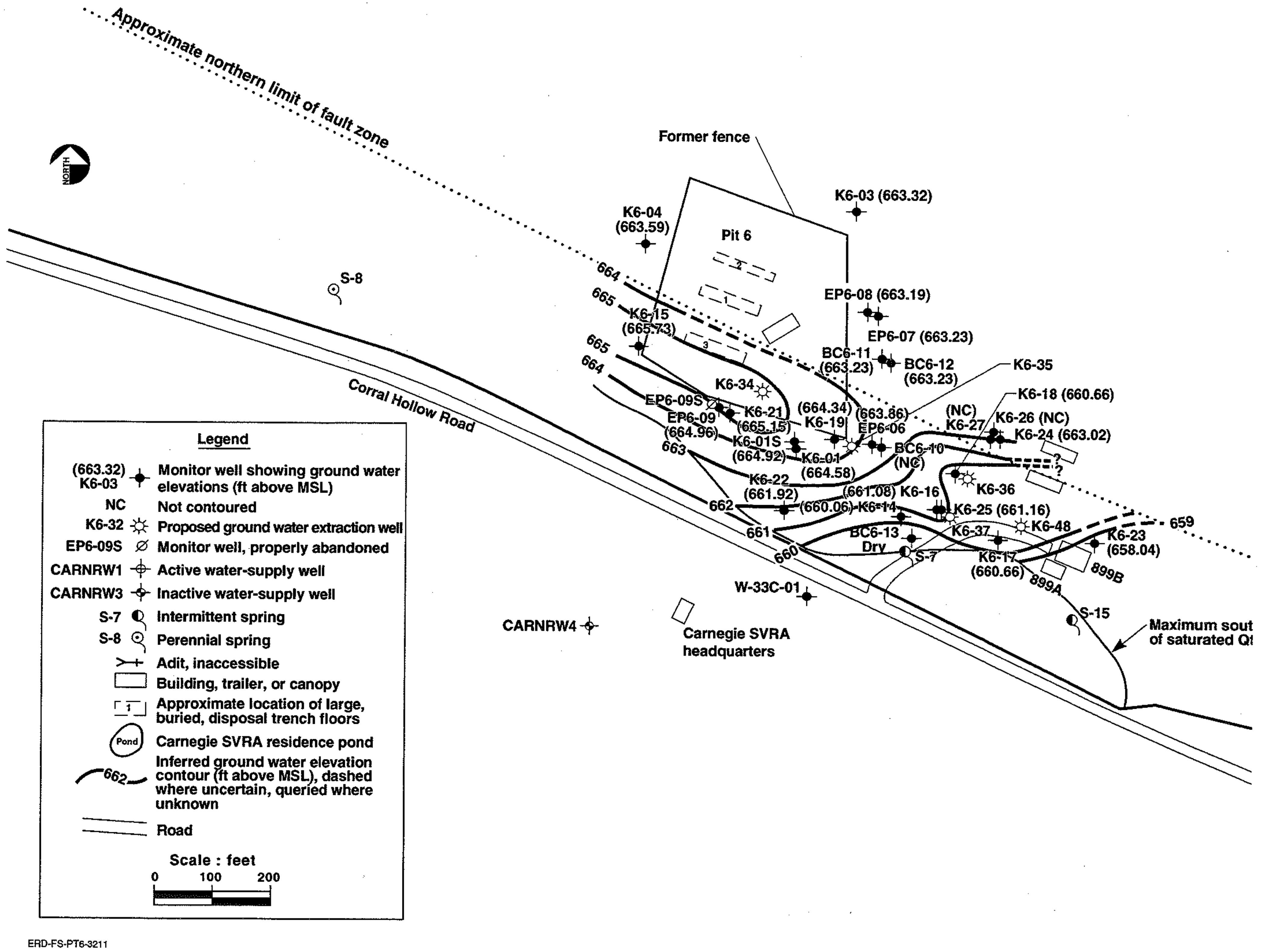


Figure F-1. Potentiometric surface map of Qt-Tmss hydrologic unit in the Pit 6 operable unit, June 1992.

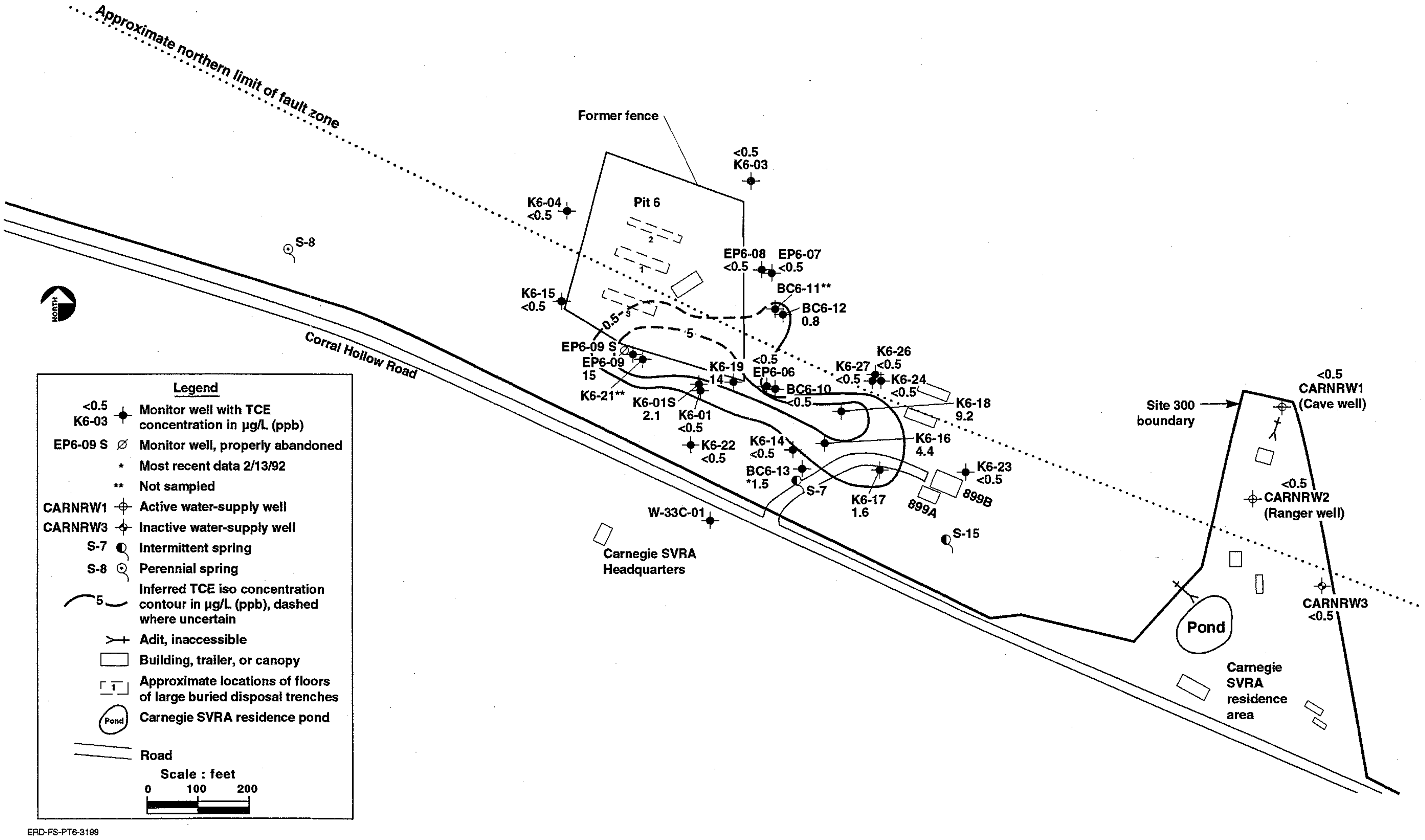


Figure F-2. Distribution of TCE in ground water of the Qt-Tmss hydrologic unit, Pit 6 operable unit, May–July 1993.

Table F-1. Modeling input parameters and estimated ground water flow south-southeast of pit 6.

Location	Length of potentiometric surface line (ft)	Saturated thickness (ft)[a]	Hydraulic gradient (ft/ft)	Saturated hydraulic conductivity (ft/d)[b]	Estimated flow (gpd) [ft³/d]
662-ft line	525	43	0.027	1.6×10^{-1}	728 [97.5]
659-ft line	280	43	0.04	1.6×10^{-1}	578 [77.1]

[a] From well EP6-09.

[b] From well KG-22.

Table F-2. Estimated maximum capture zone widths.

Proposed extraction well	Nearby representative well	Preliminary estimated yield (gpm) [ft³/d]	Approximate hydraulic conductivity (ft/d)	Approximate hydraulic gradient (ft/ft)	Approximate saturated thickness (ft)	Estimated maximum capture width (ft)
K6-34	EP6-09	10 [1,920]	13	0.027	40	137
K6-35	K6-01S	0.5 [96][a]	10	0.020	3	160
K6-36	K6-16	0.1 [19.2]	6	0.010	3	107
K6-37	K6-18	0.1 [19.2]	5	0.007	8	69
K6-48	K6-17	0.1 [19.2]	0.1	0.012	17	300[b]

[a] Estimated using one-half of the estimated sustainable yield to account for interference from extraction well K6-34.

[b] Estimate set at 300 ft (aquifer width), since calculated width exceeds the limit of the aquifer.

Appendix G

Cost Estimates and Design Assumptions for the Remedial Alternatives

Appendix G

Cost Estimates and Design Assumptions for the Remedial Alternatives

Cost estimates have been prepared for the four remedial alternatives described in Chapter 4. These estimates, and the assumptions we made in preparing them, are presented in this appendix. The assumptions discussed here are based on the conceptual remedial designs presented in Chapter 4.

We prepared comparative cost estimates for the purpose of analyzing and selecting the preferred remedial action alternative. These costs may be subject to:

- Changes in ARARs.
- Variations in specific assumptions such as alternative implementation, construction, effectiveness, and system life.
- Changes in dollar value at the time of construction.
- Changes in available equipment and technology at the time of construction.
- Changes in assumed discount rate used in present-worth calculations.
- Uncertainties associated with the hydrogeologic characteristics, subsurface heterogeneities, estimated contaminant mass and volume, and estimated life-cycle of remediation.
- Estimated cost accuracy of –30% to +50%.

Cost estimates were developed in accordance with U.S. EPA guidelines (U.S. EPA, 1987 and 1988), and are intended for evaluation of relative costs of remedial alternatives. Because detailed design is beyond the scope of this document and is required for actual cost analysis, costs presented here should not be used for budgetary purposes. A more detailed cost analysis of the selected remedial action alternative will be presented in the Remedial Design report, following the Record of Decision report.

G-1. Assumptions Used for Development of Remedial Alternative Cost Estimates

Assumptions about different kinds of costs are presented in the same order as costs are presented in Tables G-1 through G-4: capital costs, operation and maintenance costs, monitoring costs, and overhead and contingency costs.

G-1.1. Capital Cost Assumptions and Design Considerations

The following assumptions apply to the estimation of capital costs for all remedial alternatives:

1. Vendor/contractor quotes, vendor catalog prices, and/or LLNL cost experience are used to develop the costs for major construction work and purchase of equipment.
2. Full time employees (FTEs) are included as required at a rate of $120,000/year to cover potential additional work (such as extra reporting, system evaluation, modeling, etc.). We assume one person-year for Alternative 2, two person-years for Alternative 3, and three person-years for Alternative 4 to reflect the increasing complexity of each alternative.
3. LLNL Plant Engineering planning and Title I, II, and III services are assumed to be 33% of total field costs, which include materials and construction.
4. The LLNL material procurement charge on major equipment costs is estimated to be 18% for costs less than $500,000.
5. The LLNL material procurement charge on professional contract services is estimated to be 9.7% for services contracts greater than $500,000.
6. Installation costs for the remediation systems are estimated by applying a percentage, or factor, to the capital cost of major items of equipment. This is a technique commonly used in industry to develop conceptual cost estimates. These factors are used to determine labor and material for installation (58% major equipment costs), instrumentation and electrical components (20% of major equipment costs), and contractor's overhead and profit (15% of total field costs). Experience with the construction of similar remediation facilities is used to develop these factors. This procedure is considered adequate for alternative cost comparisons because it was applied in the same way to all alternatives.
7. Drill cuttings produced from ground water and vadose-zone well installation are assumed to be either clean or to contain low VOC concentrations that can be aerated on site. Cuttings will be disposed of at a Class III landfill at an estimated cost of $20/yd^3 (including transportation). We assume that 2.5 yd^3 of cuttings will be generated per well.
8. The cost for preparing the required Remedial Design (RD) report is estimated as follows:
   - $200,000 for Alternative 2 (POU treatment, pit cover, and monitoring system).
   - $400,000 for Alternative 3 (POU treatment, pit cover, monitoring system, and ground water extraction and treatment).
   - $500,000 for Alternative 4 (POU treatment, pit cover, monitoring system, ground water extraction and treatment system, and permeability reduction barriers).

   Each RD report includes engineering design specifications for remediation construction, construction specifications, treatment system drawings and descriptions, well designs, monitoring and construction schedules, costs estimates, and a Remedial Action Work Plan, which contains QA/QC plans, health and safety plans, and project closeout requirements. Costs for treatability studies and reports are also included.
9. Costs for implementing innovative technologies are not included in the cost estimates of any alternative because we do not have sufficient cost and/or performance data to estimate their cost.

10. LLNL Protective Service escorts are not required in the pit 6 area.

G-1.1.1. Pit Cover

1. The trench location investigation cost of $40,000 includes use of cone penetrometer, magnetic survey, and a radiometric survey.
2. Costs for pit cover materials assume covering an area of 63,000 ft^2. The thickness for each layer is as described in Chapter 4.
3. Costs for each cover layer and the test pit for infiltration tests include materials and installation.
4. The cost for the Construction Quality Assurance Closure (CQA) report is 10% of all pit cover capital costs except for remote sensing surveys and dismantling/restoring the rifle range. The CQA report cost includes construction inspections and having a CQA engineer on site during construction of the pit cover.
5. The cost for dismantling the rifle range includes labor and equipment rental, and assumes local Class III landfill disposal of debris. The new rifle range will be constructed on top of the new pit cover and will be of the same design and quality as the current facility. We also assume that during remediation construction, rifle range activities can continue at the existing facilities adjacent to the site at no additional cost to the project.

G-1.1.2. Ground Water Wells

1. The cost to install a ground water extraction or monitor well, up to 50-ft deep, is estimated to be $10,000. This includes labor and materials for soil boring, well construction, and well development.
2. An additional $1,000 is estimated for soil boring samples and initial ground water samples to be analyzed for VOCs.
3. Each new well will be fitted with a dedicated pump for either sample collection or extraction. We assume that extraction wells will be fitted with electric submersible pumps. Monitor wells may be fitted with either electric submersible or pneumatic-powered pumps, depending on well yield. Because prices vary between size and type of pump, we assume an average pump cost of $2,000 per well including wiring, controller, and installation.
4. Two-day pump tests are estimated to cost $5,000 for each new extraction well.
5. Half-day pump tests are estimated to cost $1,500 for each new monitor well.

G-1.1.3. POU Treatment Systems

1. Two POU treatment systems are designed to treat up to 50 gpm each.
2. Operational and installation costs are not included because the systems will only be installed and used if the ground water plume reaches the water-supply wells.

G-1.1.4. Spring 7 Exposure Control

1. We assume a chain-link fence will be needed to surround an area of 10 ft by 15 ft, a total of 50 linear ft. The fence will be 6 ft high.

G-1.1.5. Ground Water Extraction and Treatment System

1. We assume that locations for extraction wells and the treatment system are as shown in Figure 4-4.
2. Ground water treatment is as described in Chapter 4.
3. We assume that the electrical supply line will be routed overhead from existing facilities on site less than 500 ft away.
4. One-inch-diameter braided vinyl tubing is specified for conveyance of extracted ground water. The tubing will be contained in Schedule 40 PVC pipe and buried in trenches from the extraction wells to the treatment facility.
5. Costs are for all piping, fittings, valves, totalizing flow meters, gauges, and hardware for installation.
6. The 1,000-lb aqueous-phase carbon beds are designed to handle a flow up to 50 gpm, about 5 times the anticipated extraction rate. Under expected flow and contaminant concentrations, the treatment will reduce total VOCs to concentrations at or below 0.5 µg/L (ppb).
7. Because the specific discharge option is undetermined, we estimate a lump sum of $60,000 for purchase and installation of discharge equipment and materials. This cost includes discharge piping and either an infiltration trench, an air-misting array, or discharge to the gully west of pit 6.

G-1.1.6. Trenching

1. Costs for a 3-ft-deep trench for ground water extraction piping are estimated at $30/ft, which assumes that all trenching will be in unpaved areas.
2. We assume the exploratory trench for selecting the location of the ground water treatment system will be 430 ft long, 12 ft deep, and 3 ft wide. The cost for the exploratory trench includes excavation, shoring, and backfilling at $25,000, and geologic mapping at $25,000. Excavated soil will be field screened with a PID, but we do not anticipate detecting any contamination. Therefore, we assume that excavated soil will later be used to backfill the trench.

G-1.1.7. Structures

1. The ground water treatment system in Alternatives 3 and 4 will be housed in a building about 30 ft by 30 ft. The estimated cost for building construction is $300,000. About one-half of this cost is to provide the required utilities such as electrical, HVAC, water, etc.

2. The estimated cost for geotechnical studies required prior to building construction is $20,000.

G-1.1.8. Permeability Reduction Barriers

1. We assume that exploratory vertical boreholes will be drilled adjacent to the trenches to collect soil samples for characterization screening. The cost for each borehole is estimated at $2,500, assuming a 20-ft depth. Boreholes will be spaced every 20 ft for a total of 80 boreholes. We assume four samples will be collected from each borehole, with each sample analyzed for VOCs, metals, PCBs, radionuclides, and beryllium at a cost of $1,500 per suite of analyses.
2. A staging area adjacent to pit 6 will be constructed for storage of cuttings and decontamination of equipment. $50,000 is allotted for paving this area.
3. Barrier installation will consist of angled boreholes and vertical trenches. We assume 18-in.-diameter boreholes drilled/reamed on 1-ft centers to an average depth of 30 ft. About 1,300 boreholes will be required at this spacing. The cost of borehole drilling and slurry installation is estimated at $40/ft. Slurry wall trenches will be 18 in. wide with an average depth of 22 ft. The combined length of slurry walls is estimated at 280 ft. The cost for slurry wall trenching and installation is estimated at $5/vertical square ft.
4. About 2,500 yd^3 of soil will be removed during drilling and slurry wall installation. We assume a total of 3,750 yd^3 of waste to account for soil fluff, drilling fluids, and any bentonite/solidification material needed to dry out the cuttings. We assume results of the initial borehole characterization will indicate that 70% of the cuttings are clean and 30% contain VOCs. One composite sample will be analyzed per 50 yd^3 of clean soil, and one per 5 yd^3 of soil containing VOCs. Each sample will be analyzed for VOCs, metals, PCBs, radiolnuclides, and beryllium at a cost of $1,500 per suite of analyses. Soils with VOCs will be aerated on site until clean, to meet landfill requirements.
5. We assume one technician ($55/h) will be required for 6 months (1,000 h) for safety/air monitoring during construction.
6. Two time-weighted-average air samples (using personal sampling pumps with adsorptive tubes and/or particulate filters) will be collected and analyzed per day of construction for 130 days (6 months) of construction. The analytic cost is $50/sample.
7. We allotted $20,000 for either rental or purchase of air monitoring equipment for use during construction.
8. One clerical/technical staff member ($55/h) will be required for 6 months (1,000 h) for documentation and database management.

G-1.1.9. Professional Environmental Services

1. Design and plan review costs for each alternative are estimated as follows:
    - Alternative 2 = $50,000.
    - Alternative 3 = $100,000 (includes ground water extraction/treatment system).
    - Alternative 4 = $150,000 (includes ground water extraction/treatment system).

2. Coordination of ground water discharge permitting for Alternatives 3 and 4 is estimated at $10,000. We assume no other permits are required for construction and operation of any of the remedial actions.
3. Ground water extraction/treatment system startup for Alternatives 3 and 4 is estimated at $20,000 and includes coordination, field work, and initial sampling/analyses.

G-1.2. Operation and Maintenance Cost Assumptions

Operation and maintenance (O&M) costs include annual maintenance of the pit cover in Alternatives 2, 3, and 4, and O&M of the ground water extraction and treatment system in Alternatives 3 and 4. Maintenance of the ground water monitoring wells/pumps is included under monitoring costs. Costs for operating and maintaining innovative technologies are not included for any alternative.

A 3.5% discount rate was applied to calculate present-worth costs. This discount rate is based on the Office of Management and Budget estimate of government's long-term opportunity costs (OMB, 1992). Operating cost estimates are discounted to 1994 present-worth costs following procedures described in U.S. EPA (1987).

G-1.2.1. Pit Cover and Drainage Control

1. Pit cover maintenance costs for Alternatives 2, 3, and 4 are based on 120 hours of technician labor per year. This includes periodic inspections, annual cleaning of the drainage ditches and piping, and as-needed maintenance of the vegetative layer. Because the cover may show some slight differential settling, costs for periodic addition and compaction of soil onto the cover to maintain the proper drainage are included.
2. Costs for pit cover maintenance are presented for 30 years to be consistent with other components of the estimates.

G-1.2.2. Ground Water Extraction and Treatment

1. An operating factor of 90% is assumed for the ground water extraction and treatment system in Alternatives 3 and 4.
2. The cost for electricity is estimated at the rate of $0.07 per kW·h plus an annual connection fee of $36 per kW.
3. The following annual labor hours and hourly rates, including indirect labor costs, apply to operation of the ground water extraction and treatment system in Alternatives 3 and 4:
    - Project management labor: 200 h at $75/h.
    - Engineering labor (for system optimization): 300 h at $75/h.
    - Hydrogeologist labor (for system optimization): 300 h at $68/h.
    - Operating labor: 500 h at $55/h.
    - Clerical labor: 200 h at $45/h.
4. Water samples will be collected monthly at the treatment system influent, carbon midpoint, and effluent ports. An additional sample will be collected per event for

QA/QC. We assume that samples will be analyzed for VOCs by EPA Method 8010 at $50/sample.

5. The cost for replacement of spent liquid-phase GAC is based on vendor quotes for the treatment units used in the conceptual design. This cost estimate of $2.30/lb of GAC includes removal of spent unit, off-site thermal regeneration, and replacement with fresh GAC, as well as all freight and labor costs. The anticipated VOC mass removal rate is estimated at less than 0.002 lb/d based on a flow rate of 11 gpm and a TCE concentration of 15 µg/L (ppb). At a carbon adsorption capacity of 4%, carbon will be consumed at a rate of about 0.05 lb/d. Because this GAC consumption rate is negligible over the life-cycle of the alternatives, we include the cost of changing out both 1,000-lb beds every five years (an average of 400 lb/y) to account for possible bio-fouling or other precipitate clogging of the carbon.
6. We assume that the discharge permit will require monthly reporting of system analytic results and flow measurements. We allot $2,000 per report.
7. About 10% of the major equipment installed cost (MEIC) is included in the annual operating cost to cover routine equipment maintenance for the ground water extraction and treatment system in Alternatives 3 and 4.
8. Costs for ground water extraction and treatment O&M are included for years 6 through 30.

G-1.3. Monitoring Program Cost Assumptions

All four alternatives include a ground water monitoring program. The ground water monitoring program is different for each alternative because of varying numbers of new wells and the implementation of ground water extraction in Alternatives 3 and 4 only. The ground water monitoring program for each alternative is described in Chapter 4.

A 3.5% discount rate was applied to calculate present-worth costs. The discount rate is based on the Office of Management and Budget estimate of government's long-term opportunity costs (OMB, 1992). Monitoring cost estimates are discounted to 1994 present-worth costs following procedures described in U.S. EPA (1987).

G-1.3.1. Ground Water Monitoring

The ground water monitoring program for each alternative includes costs for water level measurements, sample collection and analysis, well and sampling pump maintenance, reporting, and project management. Other assumptions include:

1. Water level measurements will generally be taken quarterly. They may occasionally need to be taken more frequently to evaluate changing hydraulic conditions, such as during the initiation of ground water extraction. However, this does not significantly affect estimated costs.
2. Water samples will be collected using dedicated pumps installed in each well. The labor cost for sample collection is estimated to be two hours/sample at $55/h. Ground water monitoring costs also include labor for sample collection, purge water disposal, and

QA/QC. Maintenance of monitoring systems includes labor for pump repair and pump replacement.

3. Sampling frequency and analyses depend on well locations as presented in Table G-5.
4. Analytic costs are based on rates in existing contracts LLNL has with commercial analytical laboratories:

    VOCs by EPA Method 8010 = $50

    Inorganics = $35

    General minerals = $100

    Other analyses = $930 (includes analyses for PCBs, radionuclides, dissolved drinking water metals, and beryllium)

5. The cost for QA/QC analyses is 10% of total analytic costs.
6. Quarterly reports will be submitted to regulatory agencies for the first five years of each alternative and annually thereafter. We estimate a cost of $10,000 per report for Alternatives 1 and 2, and years 1 through 5 of Alternatives 3 and 4. We increased the cost to $15,000 per report for years 6 through 30 of Alternatives 3 and 4 to account for data collected from additional wells. Costs include analytic and water level data entry, interpretation, and reporting.
7. Well and pump maintenance is estimated at $430/y and includes labor and periodic pump replacement.
8. 500 hours of project management at $75/h is allotted per year for additional interpretation, meetings, and other tasks. When all sampling is reduced to annual frequency, we allot 250 hours per year for project management.

G-1.4. Overhead and Contingency Cost Assumptions

These assumptions apply to all four remedial alternatives:

1. A LLNL General and Administration (G&A) tax of 7.5% is applied to capital, O&M, and monitoring costs.
2. A LLNL Lab-Directed Research and Development (LDRD) tax of 6.0% is applied to capital, O&M, monitoring, and G&A costs.
3. A contingency of 20% is applied to the total cost estimate for each alternative.

G-2. Cost Summary

Summary costs for each alternative are summarized below, and are presented in detail in Tables G-1 through G-4. Additional cost information is presented in Chapter 5, in Figure 5-1 and Table 5-2. Cumulative costs, in five-year intervals, are shown in Figure G-1.

G-2.1. Alternative 1: No Action

The estimated costs for this alternative are presented in Table G-1. The present-worth cost of monitoring is $1,443,876. The total present-worth cost of the alternative, including overhead and contingency, is $1,974,536 for a 30-year project life.

G-2.2. Alternative 2: Risk Mitigation and Natural Attenuation

The estimated costs for this alternative are presented in Table G-2. The capital requirement for this alternative is $2,082,526. The present worth of the O&M cost is $121,374. Present-worth monitoring cost is $1,491,457. The total present-worth cost of the alternative, including overhead and contingency, is $5,053,030 for a 30-year project life.

G-2.3. Alternative 3: Risk Mitigation with Enhanced Mass Removal

The estimated costs for this alternative are presented in Table G-3. The capital requirement for this alternative is $4,015,022. Present worth of the O&M cost is $2,154,703. Present-worth monitoring cost is $2,058,952. The total present-worth cost of the alternative, including overhead and contingency, is $11,251,893 for a 30-year project life.

G-2.4. Alternative 4: Release Mitigation with Enhanced Mass Removal

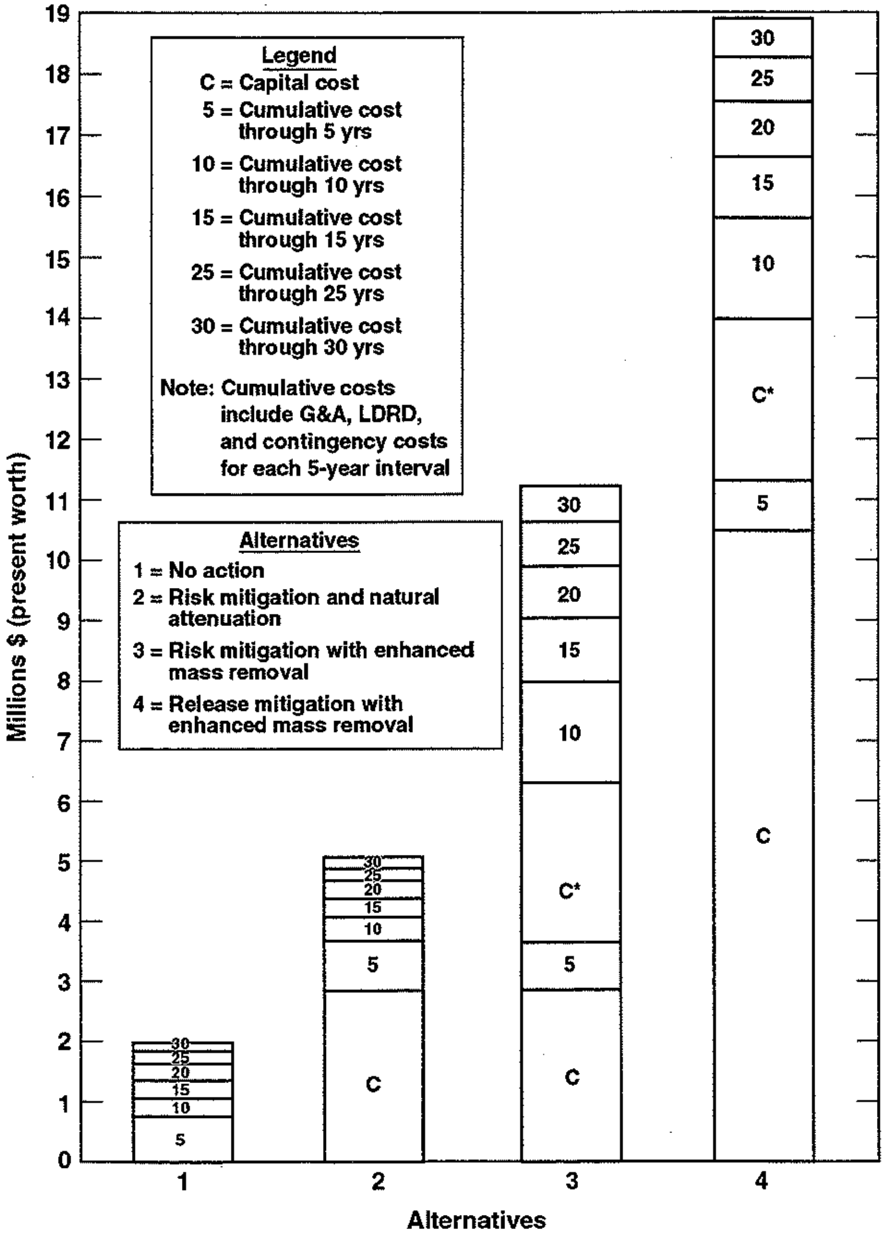
The estimated costs for this alternative are presented in Table G-4. The capital requirement for this alternative is $9,598,360. Present worth of the O&M cost is $2,154,703. Present-worth monitoring cost is $2,058,952. The total present-worth cost of the alternative, including overhead and contingency, is $18,886,549 for a 30-year project life.

G-3. References

Office of Management and Budget (1992), *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,* Washington, D.C. (OMB Circular A-94).

U.S. EPA (1987), *Remedial Action Costing Procedures Manual,* U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C. (EPA-600/8-87-049).

U.S. EPA (1988), *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA,* Interim Final, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. (EPA/540/G-89/004, OSWER Directive 9355.3-01, October 1988).



C* = Approximately $2.64 M capital cost for extraction and treatment of ground water may be incurred after 5 years of monitoring.

ERD-FS-PT6-3217

Figure G-1. Cumulative cost for Pit 6 operable unit remedial alternatives.

Table G-1. Alternative 1: No action.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Ground water monitoring				
Annual costs, years 1–5				
Quarterly water level measurements	27	well	55	1,485
Quarterly ground water sample collection (includes one spring)	9	well	440	3,960
Semiannual ground water sample collection	12	well	220	2,640
Annual ground water sample collection	7	well	110	770
VOC analysis	67	each	50	3,350
Inorganics analysis	17	each	35	595
General minerals analysis	4	each	100	400
Other analyses	17	suite	930	15,810
QA/QC analyses (10% of analytic costs)				2,016
Maintenance of ground water sampling system	27	well	430	11,610
Quarterly monitoring reports	4	report	10,000	40,000
Project management	500	hour	75	37,500
Total annual costs, years 1–5				**120,136**
Total present worth, years 1–5 years (factor = 4.52)				**543,012**
Annual costs, years 6–30				
Quarterly water level measurements	27	well	55	1,485
Annual ground water sample collection (includes one spring)	28	well	110	3,080
VOC analysis	28	each	50	1,400
Inorganics analysis	17	each	35	595
General minerals analysis	4	each	100	400
Other analyses	17	suite	930	15,810
QA/QC analyses (10% of analytic costs)				1,821
Maintenance of ground water sampling system	27	well	430	11,610
Annual monitoring reports	1	report	10,000	10,000
Project management	250	hour	75	18,750
Total annual costs, years 6–30				**64,951**
Total present worth, years 6–10 years (factor = 3.80)				**246,812**
Total present worth, years 11–15 years (factor = 3.20)				**207,842**

Table G-1. Alternative 1: No action.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Total present worth, years 16–20 years (factor = 2.69)				**174,717**
Total present worth, years 21–25 years (factor = 2.27)				**147,438**
Total present worth, years 26–30 years (factor = 1.91)				**124,055**
Total present worth of ground water monitoring for 30 years				**1,443,876**
Overhead and contingency				
LLNL General & Administrative Tax (7.5%)				108,291
Subtotal				**1,552,167**
LLNL Lab-Directed Research & Development Tax (6.0%)				93,130
Subtotal				**1,645,297**
Contingency (20%)				329,059
Total present worth of Alternative 1				**1,974,356**

Table G-2. Alternative 2: Risk mitigation and natural attentuation.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Capital costs				
Pit cover				
Trench location/investigation				40,000
Initial site grading				60,000
Foundation cover layer	4,700	cu yard	16	75,200
Low-hydraulic conductivity layer	3,500	cu yard	33	115,500
HDPE membrane layer (60 mil)	63,000	sq foot	0.60	37,800
Texture treatment to HDPE layer (two sides)	63,000	sq foot	0.06	3,780
Drainage layer (HDPE net and geotextile filter)	63,000	sq foot	0.55	34,650
Heat bonding of one geotextile layer	63,000	sq foot	0.02	1,260
Biotic barrier (cobble) layer	2,000	cu yard	25	50,000
Aggregate filter layers	2,000	cu yard	25	50,000
Topsoil layer	4,700	cu yard	5.50	25,850
Hydroseeding	1.45	acre	2,750	3,988
Engineered cover penetrations	14	each	500	7,000
Drainage diversion	1,400	linear foot	100	140,000
Construction Quality Assurance Closure (CQA) report				60,503
Dismantling of existing rifle range				20,000
Restoration of rifle range				60,000
Ground water wells				
Monitor well installation and development	8	each	10,000	80,000
Soil and initial ground water sample analysis	8	each	1,000	8,000
Soil disposal (Class III)	20	cu yard	20	400
Dedicated pump	8	each	2,000	16,000
Monitor well pump test	8	each	1,500	12,000
POU ground water treatment system for water-supply wells CARNRW1 and CARNRW2				
Wellhead modifications	2	each	1,000	2,000
Particulate filter	2	each	2,000	4,000
Aqueous-phase carbon beds (1,000 lb)	4	each	6,000	24,000
Double-containment skid (8' x 15')	2	each	4,000	8,000
System plumbing, totalizer, fittings	2	lot	2,000	4,000

Table G-2. Alternative 2: Risk mitigation and natural attentuation.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Contingency exposure control at spring 7				
Fencing	50	linear foot	40	2,000
Warning signs	1	lot	250	250
Subtotal field costs				**946,180**
Contractor overhead and profit (15% of subtotal field costs)				141,927
Subtotal contractor field costs				**1,088,107**
LLNL material procurement charge (MPC) (18% of contractor field costs)				195,859
Total field costs (TFC)				**1,283,967**
Professional environmental services				
Design				50,000
Subtotal professional environmental services				**50,000**
LLNL MPC (9.7% of professional environmental services)				4,850
Total professional environmental services				**54,850**
LLNL ERD team				
Full-time employee	1	person-yr	120,000	120,000
Total LLNL ERD team				**120,000**
LLNL technical support services				
LLNL Plant Engineering planning and Title I, II, and III services (33% of TFC)				423,709
Total LLNL support services				**423,709**
Remedial Design report				200,000
Total capital costs				**2,082,526**

Table G-2. Alternative 2: Risk mitigation and natural attentuation.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Operation and maintenance costs				
Annual pit cover/drainage control maintenance				
Inspections, drainage and cover maintenance	120	hour	55	6,600
Total annual costs for pit cover maintenance, years 1–30				**6,600**
Total present worth, years 1–5 (factor = 4.52)				**29,832**
Total present worth, years 6–10 (factor = 3.80)				**25,080**
Total present worth, years 11–15 (factor = 3.20)				**21,120**
Total present worth, years 16–20 (factor = 2.69)				**17,754**
Total present worth, years 21–25 (factor = 2.27)				**14,982**
Total present worth, years 26–30 (factor = 1.91)				**12,606**
Total present worth of pit cover maintenance costs for 30 years				**121,374**
Ground water monitoring				
Annual costs, years 1–5				
Quarterly water level measurements	35	well	55	1,925
Quarterly ground water sample collection (includes one spring)	17	well	440	7,480
Semiannual ground water sample collection	12	well	220	2,640
Annual ground water sample collection	7	well	110	770
VOC analysis	99	each	50	4,950
Inorganics analysis	13	each	35	455
General minerals analysis	10	each	100	1,000
Other analyses	13	suite	930	12,090
QA/QC analyses (10% of analytic costs)				1,850
Maintenance of ground water sampling system	35	well	430	15,050
Quarterly monitoring reports	4	report	10,000	40,000
Project management	500	hour	75	37,500
Total annual costs, years 1–5				**125,710**
Total present worth, years 1–5 years (factor = 4.52)				**568,207**

Table G-2. Alternative 2: Risk mitigation and natural attentuation.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Annual costs, years 6–30				
Quarterly water level measurements	35	well	55	1,925
Annual ground water sample collection (includes one spring)	36	well	110	3,960
VOC analysis	36	each	50	1,800
Inorganics analysis	13	each	35	455
General minerals analysis	10	each	100	1,000
Other analyses	13	suite	930	12,090
QA/QC analyses (10% of analytic costs)				1,535
Maintenance of ground water sampling system	35	well	430	15,050
Annual monitoring report	1	report	10,000	10,000
Project management	250	hour	75	18,750
Total annual costs, years 6–30				66,565
Total present worth, years 6–10 years (factor = 3.80)				**252,945**
Total present worth, years 11–15 years (factor = 3.20)				**213,006**
Total present worth, years 16–20 years (factor = 2.69)				**179,059**
Total present worth, years 21–25 years (factor = 2.27)				**151,101**
Total present worth, years 26–30 years (factor = 1.91)				**127,138**
Total present worth of ground water monitoring for 30 years				**1,491,457**
Subtotal present worth of Alternative 2				**3,695,356**
Overhead and contingency				
LLNL General & Administrative Tax (7.5%)				277,152
Subtotal				**3,972,508**
LLNL Lab-Directed Research & Development Tax (6.0%)				238,350
Subtotal				**4,210,858**
Contingency (20%)				842,172
Total present worth of Alternative 2				**5,053,030**

Table G-3. Alternative 3: Risk mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Capital costs				
Ground water extraction and treatment major equipment costs (MEC)				
Wellhead vaults, valves, sampling ports, gauges	5	well	1,500	7,500
4-in. PVC double-containment piping	650	foot	8.20	5,330
Braided vinyl tubing	800	foot	1.50	1,200
PVC pipe fittings, unistrut	1	lot	5,000	5,000
Particulate filter assembly	1	each	2,000	2,000
Aqueous-phase carbon beds (1,000 lb)	2	each	6,000	12,000
Manifold, piping, valves, gauges, sampling ports, totalizer, controllers	1	lot	10,000	10,000
Transfer tank	1	each	750	750
Transfer pump (1-1/2 hp)	1	each	500	500
Electrical supply line				20,000
Discharge system				60,000
Total ground water extraction and treatment MEC				**124,280**
Electrical components (20% of MEC)				24,856
Installation cost (58% of MEC)				72,082
Major equipment installed cost (MEIC)				**221,218**
Pit cover				
Trench location/investigation				40,000
Initial site grading				60,000
Foundation cover layer	4,700	cu yard	16	75,200
Low-hydraulic conductivity layer	3,500	cu yard	33	115,500
HDPE membrane layer (60 mil)	63,000	sq foot	0.60	37,800
Texture treatment to HDPE layer (two sides)	63,000	sq foot	0.06	3,780
Drainage layer (HDPE net and geotextile filter)	63,000	sq foot	0.55	34,650
Heat bonding of one geotextile layer	63,000	sq foot	0.02	1,260
Biotic (cobble) layer	2,000	cu yard	25	50,000
Aggregate filter layers	2,000	cu yard	25	50,000
Topsoil layer	4,700	cu yard	5.50	25,850
Hydroseeding	1.45	acre	2,750	3,988

Table G-3. Alternative 3: Risk mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Engineered cover penetrations	14	each	500	7,000
Drainage diversion	1,400	linear foot	100	140,000
Construction Quality Assurance Closure (CQA) report				60,503
Dismantling of existing rifle range				20,000
Restoration of rifle range				60,000
Trenching				
Trenching for extraction piping	600	linear foot	30	18,000
Exploratory trenching for treatment system location				50,000
Ground water wells				
Extraction well installation and development	5	each	10,000	50,000
Monitor well installation and development	18	each	10,000	180,000
Soil and initial ground water sample analysis	23	each	1,000	23,000
Soil disposal (Class III)	50	cu yard	20	1,000
Dedicated pump	23	each	2,000	46,000
Extraction well pump test	5	each	5,000	25,000
Monitor well pump test	18	each	1,500	27,000
Structure				
Ground water treatment system building	1	each	300,000	300,000
Geotechnical study	1	each	20,000	20,000
POU ground water treatment system for water-supply wells CARNRW1 and CARNRW2				
Wellhead modifications	2	each	1,000	2,000
Particulate filter	2	each	2,000	4,000
Aqueous-phase carbon beds (1,000 lb)	4	each	6,000	24,000
Double-containment skid (8' x 15')	2	each	4,000	8,000
System plumbing, totalizer, fittings	2	lot	2,000	4,000
Contingency exposure control at spring 7				
Fencing	50	linear foot	40	2,000
Warning signs	1	lot	250	250
Subtotal field costs				**1,790,999**
Contractor overhead and profit (15% of subtotal field costs)				268,650

Table G-3. Alternative 3: Risk mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Subtotal contractor field costs				**2,059,648**
LLNL material procurement charge (MPC) (18% of contractor field costs)				370,737
Total field costs (TFC)				**2,430,385**
Professional environmental services				
Design				100,000
Permitting				10,000
Start-up labor and analyses				20,000
Subtotal professional environmental services				**130,000**
LLNL MPC (9.7% of professional environmental services)				12,610
Total professional environmental services				**142,610**
LLNL ERD team				
Full-time employee	2	person-yr	120,000	240,000
Total LLNL ERD team				**240,000**
LLNL technical support services				
LLNL Plant Engineering planning and Title I, II, and III services (33% of TFC)				802,027
Total LLNL support services				**802,027**
Remedial Design report				400,000
Total capital costs				**4,015,022**

Operation and maintenance costs

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Annual pit cover/drainage control maintenance				
Inspections, drainage and cover maintenance	120	hour	55	6,600
Total annual costs for pit cover maintenance, years 1–30				6,600

Table G-3. Alternative 3: Risk mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Total present worth, years 1–5 (factor = 4.52)				**29,832**
Total present worth, years 6–10 (factor = 3.80)				**25,080**
Total present worth, years 11–15 (factor = 3.20)				**21,120**
Total present worth, years 16–20 (factor = 2.69)				**17,754**
Total present worth, years 21–25 (factor = 2.27)				**14,982**
Total present worth, years 26–30 (factor = 1.91)				**12,606**
Total present worth of pit cover maintenance costs				**121,374**
Annual ground water extraction and treatment O&M				
Electricity	38,000	kw·h	0.07	2,660
Electrical capacity charge	2.70	kw	36	97
Project management	200	hour	75	15,000
System optimization, engineer	300	hour	75	22,500
Well field optimization, hydrogeologist	300	hour	68	20,400
Operating labor	500	hour	55	27,500
Clerical	200	hour	45	9,000
Ground water treatment system analysis	12	event	200	2,400
Replacement of aqueous GAC	400	lb	2.30	920
Ground water discharge reporting (monthly)	12	report	2,000	24,000
Maintenance (10% of ground water extraction MEIC)				22,122
Total annual costs for ground water extraction and treatment O&M, years 6–30				**146,599**
Total present worth, years 6–10 (factor = 3.80)				**557,076**
Total present worth, years 11–15 (factor = 3.20)				**469,117**
Total present worth, years 16–20 (factor = 2.69)				**394,351**
Total present worth, years 21–25 (factor = 2.27)				**332,780**
Total present worth, years 26–30 (factor = 1.91)				**280,004**
Total present worth of ground water extraction and treatment O&M costs				**2,033,329**
Total present worth of O&M costs for 30 years				**2,154,703**

Table G-3. Alternative 3: Risk mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Ground water monitoring				
Annual costs, years 1–5				
Quarterly water level measurements	35	well	55	1,925
Quarterly ground water sample collection (includes one spring)	17	well	440	7,480
Semiannual ground water sample collection	12	well	220	2,640
Annual ground water sample collection	7	well	110	770
VOC analysis	99	each	50	4,950
Inorganics analysis	13	each	35	455
General minerals analysis	10	each	100	1,000
Other analyses	13	suite	930	12,090
QA/QC analyses (10% of analytic costs)				1,850
Maintenance of ground water sampling system	35	well	430	15,050
Quarterly monitoring reports	4	report	10,000	40,000
Project management	500	hour	75	37,500
Total annual costs, years 1–5				**125,710**
Total present worth, years 1–5 years (factor = 4.52)				**568,207**
Annual costs, years 6–10				
Quarterly water level measurements	50	well	55	2,750
Quarterly ground water sample collection (includes one spring)	38	well	440	16,720
Semiannual ground water sample collection	8	well	220	1,760
Annual ground water sample collection	5	well	110	550
VOC analysis	173	each	50	8,650
Inorganics analysis	16	each	35	560
General minerals analysis	10	each	100	1,000
Other analyses	16	suite	930	14,880
QA/QC analyses (10% of analytic costs)				2,509
Maintenance of ground water sampling system	50	well	430	21,500
Quarterly monitoring report	4	report	15,000	60,000
Project management	500	hour	75	37,500
Total annual costs, years 6–10				**168,379**
Total present worth, years 6–10 years (factor = 3.80)				**639,840**

Table G-3. Alternative 3: Risk mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Annual costs, years 11–30				
Quarterly water level measurements	50	well	55	2,750
Annual ground water sample collection (includes one spring)	51	well	110	5,610
VOC analysis	51	each	50	2,550
Inorganics analysis	16	each	35	560
General minerals analysis	10	each	100	1,000
Other analyses	16	suite	930	14,880
QA/QC analyses (10% of analytic costs)				1,899
Maintenance of ground water sampling system	50	well	430	21,500
Annual monitoring report	1	report	15,000	15,000
Project management	250	hour	75	18,750
Total annual costs, years 11–30				**84,499**
Total present worth, years 11–15 years (factor = 3.20)				**270,397**
Total present worth, years 16–20 years (factor = 2.69)				**227,302**
Total present worth, years 21–25 years (factor = 2.27)				**191,813**
Total present worth, years 26–30 years (factor = 1.91)				**161,393**
Total present worth of ground water monitoring for 30 years				**2,058,952**
Subtotal present worth of Alternative 3				**8,228,677**
Overhead and contingency				
LLNL General & Administrative Tax (7.5%)				617,151
Subtotal				**8,845,828**
LLNL Lab-Directed Research & Development Tax (6.0%)				530,750
Subtotal				**9,376,577**
Contingency (20%)				1,875,315
Total present worth of Alternative 3				**11,251,893**

Table G-4. Alternative 4: Release mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Capital costs				
Ground water extraction and treatment major equipment costs (MEC)				
Wellhead vaults, valves, sampling ports, gauges	5	well	1,500	7,500
4-in. PVC double-containment piping	650	foot	8.20	5,330
Braided vinyl tubing	800	foot	1.50	1,200
PVC pipe fittings, unistrut	1	lot	5,000	5,000
Particulate filter assembly	1	each	2,000	2,000
Aqueous-phase carbon beds (1,000 lb)	2	each	6,000	12,000
Manifold, piping, valves, gauges, sampling ports, totalizer, controllers	1	lot	10,000	10,000
Transfer tank	1	each	750	750
Transfer pump (1-1/2 hp)	1	each	500	500
Electrical supply line				20,000
Discharge system				60,000
Total ground water extraction and treatment MEC				**124,280**
Electrical components (20% of MEC)				24,856
Installation cost (58% of MEC)				72,082
Major equipment installed cost (MEIC)				**221,218**
Permeability reduction barriers				
Borehole installation	80	each	2,500	200,000
Initial borehole sample analysis	320	suite	1,500	480,000
Construct staging area				50,000
Borehole/slurry installation	39,000	foot	40	1,560,000
Slurry wall installation	6,160	sq foot	5	30,800
Cuttings characterization (2,625 cu yd of clean soil)	53	suite	1,500	79,500
Cuttings characterization (1,125 cu yd of soil with VOCs)	225	suite	1,500	337,500
Transportation/disposal (Class III)	3,750	cu yard	20	75,000
Safety monitoring	1,000	hour	55	55,000
Air monitoring equipment				20,000
Air sample analysis	260	each	50	13,000
Documentation/database management	1,000	hour	55	55,000

Table G-4. Alternative 4: Release mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Pit cover				
Trench location/investigation				40,000
Initial site grading				60,000
Foundation cover layer	4,700	cu yard	16	75,200
Low-hydraulic conductivity layer	3,500	cu yard	33	115,500
HDPE membrane layer (60 mil)	63,000	sq foot	0.60	37,800
Texture treatment to HDPE layer (two sides)	63,000	sq foot	0.06	3,780
Drainage layer (HDPE net and geotextile filter)	63,000	sq foot	0.55	34,650
Heat bonding of one geotextile layer	63,000	sq foot	0.02	1,260
Biotic (cobble) layer	2,000	cu yard	25	50,000
Aggregate filter layers	2,000	cu yard	25	50,000
Topsoil layer	4,700	cu yard	5.50	25,850
Hydroseed	1.45	acre	2,750	3,988
Engineered cover penetrations	14	each	500	7,000
Drainage diversion	1,400	linear foot	100	140,000
Construction Quality Assurance Closure (CQA) report				60,503
Dismantling of existing rifle range				20,000
Restoration of rifle range				60,000
Trenching				
Trenching for extraction piping	500	linear foot	30	15,000
Exploratory trenching for treatment system location				50,000
Ground water wells				
Extraction well installation and development	5	each	10,000	50,000
Monitor well installation and development	18	each	10,000	180,000
Soil and initial ground water sample analysis	23	each	500	11,500
Soil disposal (Class III)	50	cu yard	20	1,000
Dedicated pump	23	each	2,000	46,000
Extraction well pump test	5	each	5,000	25,000
Monitor well pump test	18	each	1,500	27,000
Structure				
Ground water treatment system building	1	each	300,000	300,000
Geotechnical study	1	each	20,000	20,000

Table G-4. Alternative 4: Release mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
POU ground water treatment system for water-supply wells CARNRW1 and CARNRW2				
Wellhead modifications	2	each	1,000	2,000
Particulate filter	2	each	2,000	4,000
Aqueous-phase carbon beds (1,000 lb)	4	each	6,000	24,000
Double-containment skid (8' x 15')	2	each	4,000	8,000
System plumbing, totalizer, fittings	2	lot	2,000	4,000
Contingency exposure control at spring 7				
Fencing	50	linear foot	40	2,000
Warning signs	1	lot	250	250
Subtotal field costs				**4,732,299**
Contractor overhead and profit (15% of subtotal field costs)				709,845
Subtotal contractor field costs				**5,442,143**
LLNL material procurement charge (MPC) (18% of contractor field costs)				979,586
Total field costs (TFC)				**6,421,729**
Professional environmental services				
Design				150,000
Permitting				10,000
Start-up labor and analyses				20,000
Subtotal professional environmental services				**180,000**
LLNL MPC (9.7% of professional environmental services)				17,460
Total professional environmental services				**197,460**
LLNL ERD team				
Full-time employee	3	person-yr	120,000	360,000
Total LLNL ERD team				**360,000**

Table G-4. Alternative 4: Release mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
LLNL technical support services				
LLNL Plant Engineering planning and Title I, II, and III services (33% of TFC)				2,119,171
Total LLNL support services				**2,119,171**
Remedial Design report				500,000
Total capital costs				**9,598,360**
Operation and maintenance costs				
Annual pit cover/drainage control maintenance				
Inspections, drainage and cover maintenance	120	hour	55	6,600
Total annual costs for pit cover maintenance, years 1–30				**6,600**
Total present worth, years 1–5 (factor = 4.52)				**29,832**
Total present worth, years 6–10 (factor = 3.80)				**25,080**
Total present worth, years 11–15 (factor = 3.20)				**21,120**
Total present worth, years 16–20 (factor = 2.69)				**17,754**
Total present worth, years 21–25 (factor = 2.27)				**14,982**
Total present worth, years 26–30 (factor = 1.91)				**12,606**
Total present worth of pit cover maintenance costs				**121,374**
Annual ground water extraction and treatment O&M				
Electricity	38,000	kw·h	0.07	2,660
Electrical capacity charge	2.70	kw	36	97
Project management	200	hour	75	15,000
System optimization, engineer	300	hour	75	22,500
Well field optimization, hydrogeologist	300	hour	68	20,400
Operating labor	500	hour	55	27,500
Clerical	200	hour	45	9,000
Ground water treatment system analysis	12	event	200	2,400
Replacement of aqueous GAC	400	lb	2.30	920

Table G-4. Alternative 4: Release mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Ground water discharge reporting (monthly)	12	report	2,000	24,000
Maintenance (10% of ground water extraction MEIC)				22,122
Total annual costs for ground water extraction and treatment O&M, years 6–30				**146,599**
Total present worth, years 6–10 (factor = 3.80)				**557,076**
Total present worth, years 11–15 (factor = 3.20)				**469,117**
Total present worth, years 16–20 (factor = 2.69)				**394,351**
Total present worth, years 21–25 (factor = 2.27)				**332,780**
Total present worth, years 26–30 (factor = 1.91)				**280,004**
Total present worth of ground water extraction and treatment O&M costs				**2,033,329**
Total present worth of O&M costs for 30 years				**2,154,703**
Ground water monitoring				
Annual costs, years 1–5				
Quarterly water level measurements	35	well	55	1,925
Quarterly ground water sample collection (includes one spring)	17	well	440	7,480
Semiannual ground water sample collection	12	well	220	2,640
Annual ground water sample collection	7	well	110	770
VOC analysis	99	each	50	4,950
Inorganics analysis	13	each	35	455
General minerals analysis	10	each	100	1,000
Other analyses	13	suite	930	12,090
QA/QC analyses (10% of analytic costs)				1,850
Maintenance of ground water sampling system	35	well	430	15,050
Quarterly monitoring reports	4	report	10,000	40,000
Project management	500	hour	75	37,500
Total annual costs, years 1–5				**125,710**
Total present worth, years 1–5 years (factor = 4.52)				**568,207**

Table G-4. Alternative 4: Release mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Annual costs, years 6–10				
Quarterly water level measurements	50	well	55	2,750
Quarterly ground water sample collection (includes one spring)	38	well	440	16,720
Semiannual ground water sample collection	8	well	220	1,760
Annual ground water sample collection	5	well	110	550
VOC analysis	173	each	50	8,650
Inorganics analysis	16	each	35	560
General minerals analysis	10	each	100	1,000
Other analyses	16	suite	930	14,880
QA/QC analyses (10% of analytic costs)				2,509
Maintenance of ground water sampling system	50	well	430	21,500
Quarterly monitoring report	4	report	15,000	60,000
Project management	500	hour	75	37,500
Total annual costs, years 6–10				**168,379**
Total present worth, years 6–10 years (factor = 3.80)				**639,840**
Annual costs, years 11–30				
Quarterly water level measurements	50	well	55	2,750
Annual ground water sample collection (includes one spring)	51	well	110	5,610
VOC analysis	51	each	50	2,550
Inorganics analysis	16	each	35	560
General minerals analysis	10	each	100	1,000
Other analyses	16	suite	930	14,880
QA/QC analyses (10% of analytic costs)				1,899
Maintenance of ground water sampling system	50	well	430	21,500
Annual monitoring report	1	report	15,000	15,000
Project management	250	hour	75	18,750
Total annual costs, years 11–30				**84,499**
Total present worth, years 11–15 years (factor = 3.20)				**270,397**
Total present worth, years 16–20 years (factor = 2.69)				**227,302**
Total present worth, years 21–25 years (factor = 2.27)				**191,813**

Table G-4. Alternative 4: Release mitigation with enhanced mass removal.

	Quantity	Unit type	Unit price (1994 $)	Total (1994 $)
Total present worth, years 26–30 years (factor = 1.91)				**161,393**
Total present worth of ground water monitoring for 30 years				**2,058,952**
Subtotal present worth of Alternative 4				**13,812,015**
Overhead and contingency				
LLNL General & Administrative Tax (7.5%)				1,035,901
Subtotal				**14,847,916**
LLNL Lab-Directed Research & Development Tax (6.0%)				890,875
Subtotal				**15,738,791**
Contingency (20%)				3,147,758
Total present worth of Alternative 4				**18,886,549**

Table G-5. Ground water monitoring program for Pit 6 operable unit remedial alternatives.

Analysis	VOCs by EPA 8010										Inorganics[a]						General minerals[b]				Other analyses[c]						
Alternative	1		2		3			4			1	2	3		4		1	2	3	4	1	2	3		4		
Monitoring Period (years)	1–5	6–30	1–5	6–30	1–5	6–10	11–30	1–5	6–10	11–30	1–30	1–30	1–5	6–30	1–5	6–30	1–30	1–30	1–30	1–30	1–30	1–30	1–5	6–30	1–5	6–30	Comments
Well ID																											
BC6-10	A	A	A	A	A	Q	A	A	Q	A	—	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Deep, clean monitor well
BC6-11	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Same screened interval as and adjacent to BC6-12
BC6-12	S	A	S	A	S	S	A	S	S	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
BC6-13	Q	A	Q	A	Q	Q	A	Q	Q	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	Spring 7 monitor well
CARNRW1	Q	A	Q	A	Q	Q	A	Q	Q	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	Active water-supply well
CARNRW2	Q	A	Q	A	Q	Q	A	Q	Q	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	Active water-supply well
CARNRW3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Inactive water-supply well
CARNRW4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Inactive water-supply well
EP6-06	S	A	S	A	S	Q	A	S	Q	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
EP6-07	S	A	S	A	S	S	A	S	S	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
EP6-08	S	A	S	A	S	S	A	S	S	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
EP6-09	S	A	S	A	S	S	A	S	S	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
K6-01	S	A	S	A	S	S	A	S	S	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
K6-01S	S	A	S	A	S	S	A	S	S	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
K6-03	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	—	—	—	—	A	A	A	A	A	A	Upgradient, clean monitor well
K6-04	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	—	—	—	—	A	A	A	A	A	A	Upgradient, clean monitor well
K6-14	Q	A	Q	A	Q	Q	A	Q	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Monitor well at southern edge of plume
K6-15	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	—	—	—	—	A	A	A	A	A	A	Upgradient, clean monitor well
K6-16	S	A	S	A	S	Q	A	S	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Monitor well within plume
K6-17	Q	A	Q	A	Q	Q	A	Q	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Monitor well at leading edge of plume
K6-18	S	A	S	A	S	Q	A	S	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	Monitor well within plume
K6-19	S	A	S	A	S	Q	A	S	Q	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
K6-21	S	A	S	A	S	S	A	S	S	A	A	—	—	—	—	—	—	—	—	—	A	—	—	—	—	—	Monitor well within plume
K6-22	Q	A	Q	A	Q	Q	A	Q	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Downgradient, clean monitor well
K6-23	Q	A	Q	A	Q	Q	A	Q	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Downgradient, clean monitor well
K6-24	S	A	S	A	S	S	A	S	S	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Cross-gradient monitor well
K6-25	A	A	A	A	A	Q	A	A	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Deep, clean monitor well
K6-26	A	A	A	A	A	A	A	A	A	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Deep, clean monitor well

Table G-5. (Continued)

Analysis	VOCs by EPA 8010										Inorganics						General minerals				Other analyses [a]						
Alternative	1		2		3			4			1	2	3		4		1	2	3	4	1	2	3		4		
Monitoring Period (years)	1–5	6–30	1–5	6–30	1–5	6–10	11–30	1–5	6-10	11-30	1–30	1–30	1–5	6–30	1–5	6–30	1–30	1–30	1–30	1–30	1–30	1–30	1–5	6–30	1–5	6–30	Comments
K6-27	A	A	A	A	A	A	A	A	A	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Deep, clean monitor well
Spring 15	Q	A	Q	A	Q	Q	A	Q	Q	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	Downgradient spring
W-33C-01	Q	A	Q	A	Q	Q	A	Q	Q	A	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	Clean, off-site monitor well
K6-32	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	—	—	—	—	—	NA	NA	—	—	NA	NA	—	—	—	—	Proposed downgradient, clean monitor well
K6-33	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	—	—	—	—	—	NA	NA	—	—	NA	NA	—	—	—	—	Proposed downgradient, clean monitor well
K6-34	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	A	NA	A	NA	NA	—	—	NA	NA	NA	A	NA	A	Proposed ground water extraction well
K6-35	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	A	NA	A	NA	NA	—	—	NA	NA	NA	A	NA	A	Proposed ground water extraction well
K6-36	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed ground water extraction well
K6-37	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed ground water extraction well
K6-38	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well at southern edge of plume
K6-39	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well at northern edge of plume
K6-40	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well at northern edge of plume
K6-41	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well at southern edge of plume
K6-42	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well at southern edge of plume
K6-43	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well at leading edge of plume
K6-44	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well within plume
K6-45	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well within plume
K6-46	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well within plume
K6-47	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	—	NA	—	NA	NA	—	—	NA	NA	NA	—	NA	—	Proposed monitor well within plume
K6-48	NA	NA	NA	NA	NA	Q	A	NA	Q	A	NA	NA	NA	A	NA	A	NA	NA	—	—	NA	NA	NA	A	NA	A	Proposed ground water extraction well
P6-01	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	A	A	A	A	A	NA	A	A	A	NA	A	A	A	A	A	Proposed monitor well adjacent to trench/pit

Table G-5. (Continued)

P6-02	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	A	A	A	A	A	NA	A	A	A	NA	A	A	A	A	A	**Proposed monitor well adjacent to trench/pit**
P6-03	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	A	A	A	A	A	NA	A	A	A	NA	A	A	A	A	A	**Proposed monitor well adjacent to trench/pit**
P6-04	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	A	A	A	A	A	NA	A	A	A	NA	A	A	A	A	A	**Proposed monitor well adjacent to trench/pit**
P6-05	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	A	A	A	A	A	NA	A	A	A	NA	A	A	A	A	A	**Proposed monitor well adjacent to trench/pit**
P6-06	NA	NA	Q	A	Q	Q	A	Q	Q	A	NA	A	A	A	A	A	NA	A	A	A	NA	A	A	A	A	A	**Proposed monitor well upgradient of trenches/pits**
Total samples																											
Quarterly	9	0	17	0	17	38	0	17	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Semiannually	12	0	12	0	1	8	0	12	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Annually	7	28	7	36	7	5	51	7	5	51	17	13	13	16	13	16	4	10	10	10	17	13	13	16	13	16	

[a] Inorganics = TDS, pH, and conductivity.

[b] General minerals = Bicarbonate, carbonate, hydroxide, total alkalinity, Al, Ca, Cl, Cu, methyl-blue active substances, nitrate, Fe, Mg, Mn, Ni, pH, K, Na, sulfate, conductivity, hardness, and Zn.

[c] Other analyses = PCBs, beryllium, radionuclides (gross alpha; gross beta; tritium; uranium 234, 235 and 238; radium 226 and 228) and dissolved drinking water metals (As, Ba, Cd, Cr, Pb, Hg, Se, Ag).

A = Annually.
NA = Not applicable; well not installed.
Q = Quarterly.
S = Semiannually.
— = No sampling.

Acronyms

Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ARARs	Applicable or Relevant and Appropriate Requirements
AVI SVS	Active Vacuum-Induced Soil Vapor Survey
BAAQMD	Bay Area Air Quality Management District
CAPCOA	California Air Pollution Control Officers Association
CDF	California Department of Forestry
CFR	Code of Federal Regulations
CEQ	Council of Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CQA	Construction Quality Assurance Closure
DCA	1,1-dichloroethane
DCE	1,2-dichloroethylene
DNAPLs	Dense Nonaqueous Phase Liquids
DOE	Department of Energy
DTSC	California Department of Toxic Substances Control
ESB	Enhanced Soil Bioremediation
EFA	East Firing Area
EPA	Environmental Protection Agency
ESB	Enhanced Soil Bioremediation
FFA	Federal Facility Agreement
FS	Feasibility Study
FTEs	Full Time Employees
G&A	General and Administration
GAC	Granular Activated Carbon
GPD	Gallons Per Day
GPR	Ground Penetrating Radar
GSA	General Services Area
GWTS	Ground Water Treatment System
HDPE	High-Density Polyethylene
HE	High Explosives

HE-OBTF	High-Explosives Open Burn Treatment Facility
HI	Hazard Index
ISV	*In situ* Vitrification
Kgv	Cretaceous Great Valley sequence
LLNL	Lawrence Livermore National Laboratory
LLRW	Low-Level Radioactive Waste
LLMW	Low-Level Mixed Waste
LDR	Land Disposal Restrictions
LDRD	Lab-Directed Research and Development
LOELs	Lowest Observable Effect Levels
LOD	Limit of Detection
MCLs	Maximum Contaminant Levels
MEIC	Major Equipment Installed Cost
NPDES	National Pollutant Discharge Elimination System
NCP	National Contingency Plan
NEPA	National Environmental Policy Act
NPL	National Priorities List
O&M	Operation and maintenance
OSPs	Operational Safety Plans
PCB	Polychlorinated Biphenyl
PCE	Tetrachloroethylene
PEFs	Pathway Exposure Factors
POU	Point of Use
Qt	Quaternary terrace deposits
RAOs	Remedial Action Objectives
REL	Reference Exposure Level
RfD	Reference Dose
RD	Remedial Design
RLs	Remediation Levels
ROD	Record of Decision
RQD	Rock Quality Designation
RWQCB	California Regional Water Quality Control Board

SARA	Superfund Amendments and Reauthorization Act of 1986
SDWA	Safe Drinking Water Act
SFTF	Small Firearms Training Facility
SITE	Superfund Innovative Technology Evaluation
SOPs	Standard Operating Procedures
STLC	Soluble Threshold Limit Concentration
SVRA	State Vehicular Recreation Area
SVS	Soil Vapor Surveys
SWRCB	State Water Resources Control Board
SWRI	Site-Wide Remedial Investigation
TBC	To Be Considered
TCA	1,1,1-trichloroethane
TCE	Trichloroethylene
TDS	Total Dissolved Solids
TEPH	Total-extractable-petroleum-hydrocarbons
TLV/TWA	Threshold Limit Value–Time Weighted Average
Tmss	Miocene Cierbo Formation
Tn	Miocene Neroly Formation
TOC	Total Organic Carbon
TOX	Total Organic Halides
TPA	Tracy Planning Area
Tps	Pliocene Nonmarine Unit
TQs	Toxicity Quotients
TRU	Transuranic
TSD	Treatment, Storage, or Disposal
TTLC	Total Threshold Limit Concentrations
Tts	Eocene Tesla Formation
UCRL	University of California Radiation Laboratory
UCL	Upper Confidence Limit
USDA	U.S. Department of Agriculture
UV	Ultraviolet
VOCs	Volatile Organic Compounds