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Engineering Evaluation/Cost Analysis for the Building 815 Operable Unit Lawrence Livermore National Laboratory Site 300

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December 1997

***Weiss Associates, Emeryville, California**

Environmental Protection Department
Environmental Restoration Division

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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
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Executive Summary

This Engineering Evaluation/Cost Analysis (EE/CA) report addresses the Building 815 operable unit (OU) at Lawrence Livermore National Laboratory (LLNL) Site 300 near Tracy, California. In the Building 815 OU, trichloroethylene (TCE) contamination has been identified in ground water in the Upper Neroly Formation ($Tnbs_2$) aquifer resulting from releases at Building 815. Ground water data indicate that the TCE is present in the $Tnbs_2$ aquifer at concentrations exceeding the 5.0 microgram/liter (µg/L), or parts per billion (ppb), Federal maximum contaminant level (MCL) and that the leading edge of the TCE plume is migrating. Additionally, a lifetime excess cancer risk of 1.0×10^{-5} was calculated based on residential use of ground water from the Building 815 OU at a hypothetical water-supply well located at the Site 300 boundary. This EE/CA evaluates these removal action alternatives for this TCE plume involving ground water extraction and treatment. These alternatives are designed to meet three removal action objectives (RAOs): 1) TCE plume migration control, 2) public health risk mitigation, and 3) TCE mass removal. To meet these objectives, ground water extraction and treatment will be implemented at the leading edge of the plume and within the plume interior.

The conceptual design for this removal action includes two separate extraction wellfields and treatment facilities. Aquifer testing and ground water modeling will be used to determine the final design of this removal action, which will be presented in a Removal Action Design Workplan (RADW). The ground water model will also be used as a decision-making tool to optimize and manage the extraction wellfields to ensure that the RAOs are being met. Ground water will be treated using aqueous-phase granular activated carbon (GAC) to remove TCE. Treated ground water will be discharged to the surface onsite or offsite in Corral Hollow Creek.

Ultimate cleanup of ground water in the Building 815 OU is beyond the scope of this removal action. Ground water extraction and treatment performance data will be collected during the implementation of this removal action to evaluate ground water cleanup goals for this OU that are technically and economically feasible. These cleanup goals will be presented in the Site-Wide Record of Decision (ROD).

Total present-worth cost for this removal action is $5.8M. This cost includes all direct capital, indirect capital, and 20 years of post-removal site control (PRSC).

Preface

This Engineering Evaluation/Cost Analysis (EE/CA) report evaluates three removal action alternatives to address ground water contamination in the Building 815 operable unit (OU) at Lawrence Livermore National Laboratory (LLNL) Site 300 near Tracy, California. The three alternatives were developed over a period of 1-1/2 years and were originally presented in two separate documents. This EE/CA consolidates these reports and presents all three alternatives for evaluation. Alternatives 1 and 3 were originally presented in the "Draft Evaluation of Remedial Alternatives for the Building 815 OU" (Madrid and Green-Horner, 1995) report, which was previously submitted to the regulatory agencies in December 1995. This report is presented as Attachment A. Alternative 2 was originally presented in the "Draft Engineering Evaluation/Cost Analysis for the Building 815 Operable Unit Lawrence Livermore National Laboratory Site 300" report, which was submitted to the regulatory agencies in July 1997. After significant discussions with the regulatory agencies, it was agreed to consolidate these three alternatives and two reports and submit them as one report. This EE/CA report reflects this consolidation.

Although all three alternatives have somewhat different scopes and objectives, they are all designed to mitigate any human health risk from ground water contaminants in the upper Neroly Formation ($Tnbs_2$) aquifer at the Building 815 OU.

The three removal action alternatives are:

Alternative 1. Monitoring of ground water contaminants and a contingency plan to implement ground water extraction and treatment, if necessary, to prevent offsite migration of trichloroethylene (TCE) at concentrations exceeding health-based standards.

Alternative 2. Ground water extraction and treatment to hydraulically control the leading edge of the TCE plume and remove TCE mass.

Alternative 3. Ground water extraction and treatment with the objective of restoring all contaminated ground water to concentrations not exceeding background levels.

As specified by Environmental Protection Agency (EPA) Guidance on Conducting Non-Time-Critical Removal Actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (1993), each removal action alternative was evaluated with respect to effectiveness, implementability, and cost. This evaluation, which is summarized in Table Pref-1, provides the basis for selecting and implementing a removal action for the Building 815 OU.

A public comment period, including a public workshop scheduled for March 1998, to allow the public to review and comment on the proposed alternative, will follow the submission of the Building 815 OU EE/CA. Public comments will be addressed in a Responsiveness Summary, included in the Action Memorandum, following the public comment period. The final design of the selected alternative will be presented in a Removal Action Design Workplan (RADW) following the Action Memorandum. Final ground water cleanup standards for the Building 815 OU will be presented in the Site-Wide Record of Decision (ROD).

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Table Pref-1. Comparison of Building 815 OU removal action alternatives based in the three EE/CA criteria.

Alternative	Effectiveness	Implementability	Cost (present-worth in 1997 dollars)
1. *Monitoring with contingency plume containment*			
Monitoring of ground water contaminants with a contingency plan to implement ground water extraction and treatment, if necessary, to prevent offsite migration of TCE at concentrations exceeding health-based standards. (Presented as Alternative A in Attachment A of this EE/CA).	• Protective of human health through ground water monitoring with contingencies. • Meets RAO of preventing human ingestion of ground water contaminants. • Relies on natural attenuation to comply with offsite ARARs. • Will not increase RDX plume mobilization unless contingency plan is triggered. • If the contingency plan is implemented, TCE toxicity, volume and mobility will be reduced through ground water extraction and treatment.	• Long-term ground water monitoring is readily implementable. • Equipment and materials are readily available for ground water extraction and injection. • If the contingency plan is triggered, injection wells may be required. Long-term maintenance of injection wells presents scaling and plugging problems.	\$2.0 million[a] for 20 years of monitoring only. \$4.9 million[a] for 10 years of monitoring only and 10 years of ground water extraction and treatment. \$6.8 million[a] for 10 years of monitoring only and 45 years of ground water extraction and treatment for clean-up to MCLs.
2. *Hydraulic control of the TCE plume*			
Ground water extraction and treatment to hydraulically control the leading edge of the TCE plume and to remove TCE mass. (Presented as the removal action in this EE/CA).	• Protects human health and environment by preventing further migration of TCE plume. • Meets all ARARs offsite. • May increase migration of RDX and nitrate plumes. • Reduction of toxicity, mobility and volume of TCE through extraction and treatment of ground water.	• Equipment and materials are readily available for ground water extraction. • Ground water extraction for plume control is technically feasible. • TCE mass removal may increase migration of RDX. • If injection wells are required, long-term maintenance of injection wells presents scaling and plugging problems. • Treatment of RDX-laden ground water would require an innovative on-site technology.	\$5.8 million for twenty years of extraction and treatment.

Table Pref-1. (Continued)

Alternative	Effectiveness	Implementability	Cost (present-worth in 1997 dollars)
3. *Clean-up of aquifer to background levels*			
Ground water extraction and treatment to restore ground water to background levels. (Presented as Alternative B in Attachment A of this EE/CA).	• Protects human health and the environment by cleaning up the ground water to background levels for TCE, RDX and nitrates. • Meets all ARARs. • May dewater the $Tnbs_2$ aquifer if treated ground is not reinjected. • Reduction of toxicity, mobility and volume of all contaminants.	• Equipment and materials are readily available for ground water extraction and treatment. • Long-term ground water monitoring for evaluation of the extraction system is readily implementable. • Treatment of RDX-laden ground water would require an innovative technology. • Reinjection of treated ground water may be required to prevent dewatering the $Tnbs_2$ aquifer.	$8.0 million[a] for twenty years of ground water extraction and treatment. $21.7 million[a] for total clean-up of ground water to background levels requiring 115 years of treatment.

[a] Discounted costs originally presented in 1995 dollars and subsequently recalculated to 1997 dollars using a 3% rate of inflation.

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1. Introduction

This Engineering Evaluation/Cost Analysis (EE/CA) report addresses the Building 815 operable unit (OU) at Lawrence Livermore National Laboratory (LLNL) Site 300 near Tracy, California. In the Building 815 OU, trichloroethylene (TCE) contamination has been identified in ground water in the Neroly Formation upper blue sandstone ($Tnbs_2$) aquifer resulting from releases at Building 815. The regulatory agencies and the U.S. Department of Energy (DOE) have agreed that a non-time-critical removal action is warranted to address the Building 815 OU TCE ground water plume (Proposed Regulatory Pathway Letter for the Building 815 OU, November 14, 1996). This EE/CA report evaluates a proposed remedial strategy for this ground water plume. It will be followed by a public comment period, including a public workshop. Public comments on this removal action will be addressed in the Responsiveness Summary of the Action Memorandum. The final extraction and treatment system design will be presented in a Removal Action Design Workplan (RADW) following the Action Memorandum. The final cleanup standard will be presented in the Site-Wide Record of Decision (ROD).

Chapter 1 of this report is a brief summary of relevant characterization and risk assessment data. The Removal Action Objectives (RAOs) and Applicable or Relevant and Appropriate Requirements (ARARs) are presented in Chapter 2. The main components of the removal action are presented in Chapter 3. Chapter 4 contains an evaluation of the removal action with respect to effectiveness, implementability, and cost, which provide the basis for determining whether this removal action adequately meets the RAOs. A conceptual contaminant hydrogeologic model for the Building 815 OU is presented in Appendix A, along with recent data on ground water monitoring and physical properties of the $Tnbs_2$ aquifer. An evaluation of remedial technologies considered for this removal action is presented in Appendix B. Information regarding innovative technologies that could potentially be used for this removal action are presented in Appendix C. Procedures used to estimate extraction well capture zones, TCE plume mass, and TCE retardation factor are presented in Appendix D. An evaluation of the Pliocene (Tps) perched water-bearing zone is presented in Appendix E. Appendix F contains removal action cost estimates and design assumptions.

1.1. Purpose and Scope

Data presented in the Final Site-Wide Remedial Investigation (SWRI) report (Webster-Scholten, 1994) indicate that TCE and nitrates are present in ground water in the Building 815 OU at concentrations exceeding Federal Maximum Contaminant Levels (MCLs). A high explosive (HE) compound, RDX, is also present in ground water at concentrations exceeding the 1996 U.S. Environmental Protection Agency (EPA) Region IX Preliminary Remediation Goal (PRG) of 0.61 micrograms per liter (µg/L) or parts per billion (ppb) for drinking water. The PRG is referenced as the health-based standard for RDX because no MCL exists for this compound.

Statistical evaluation of ground water monitoring data indicate that the leading edge of the Building 815 TCE plume appears to be migrating, further degrading ground water. For the SWRI baseline human health risk assessment, a lifetime excess cancer risk of 1.0×10^{-5} was calculated based on residential use of ground water from the $Tnbs_2$ aquifer at a hypothetical water-supply well located at the site boundary.

The purpose of this EE/CA report is to present a non-time-critical removal action that achieves the RAOs for the Building 815 TCE plume. The RAOs for this removal action are to: 1) hydraulically control further migration of the Building 815 TCE plume in the $Tnbs_2$ aquifer, 2) mitigate human health risk associated with migration of this plume, and 3) remove TCE mass from ground water. Given our conceptual hydrogeologic model of the $Tnbs_2$ aquifer, the most practicable and readily implementable removal action involves conventional ground water extraction and treatment. Currently, other technologies such as *in situ* treatment and physical containment are too costly, difficult to implement, and/or ineffective to be considered as part of this removal action. The extraction and treatment system proposed in this EE/CA is based on the assumption that the Building 815 TCE plume has been adequately characterized at concentrations above the MCL. Additional offsite monitor wells will be installed to further characterize the extent of detectable TCE concentrations at the leading edge of the plume. The extraction and treatment system will be designed after these wells have been installed and additional aquifer testing and ground water modeling are completed.

Remediation of contaminants in a perched Tps water-bearing zone beneath Building 815, and remediation of RDX and nitrate in the $Tnbs_2$ aquifer, are not within the scope of this removal action. However, nitrates at concentrations exceeding the MCL could be captured during this removal action. The treatment systems will be designed to meet nitrate discharge requirements as specified by the Central Valley Regional Water Quality Control Board (CVRWQCB) Substantive Requirements.

1.2. Description of the Building 815 OU

The Building 815 OU is located in the southeast part of the HE Process area study area (Fig. 1). The HE Process area study area occupies approximately 934 acres in the southeastern part of Site 300. As described in Chapter 13 of the SWRI report (Webster-Scholten, 1994), this area has a steep, hilly terrain with deep northwest-southeast-trending canyons and ravines that drain into Corral Hollow Creek. The HE Process area was established in the mid- to late-1950s to chemically formulate and mechanically press and machine HE compounds into detonation devices.

The Building 815 OU is located west of Building 832 Canyon and north of Corral Hollow Creek. As shown in Figure 2, several former and currently operational Site 300 water-supply wells are located in the southern part of the Building 815 OU. One of the privately owned parcels located south of the Building 815 OU is owned by the Gallo family. The Gallo family operates the water-supply well, Gallo-1, located about 2,000 ft southwest of Building 815.

1.2.1. Building 815 Facilities

Building 815 was constructed as a central steam plant in 1958 to supply steam to nearby facilities involved in the processing and formulation of HE compounds. The steam was supplied to these facilities via buried pipelines. Between 1959 and 1986, steam was generated using a diesel-powered steam boiler, and steam boiler blowdown (condensate) was discharged to a dry well located approximately 50 ft north of Building 815. The TCE was used to periodically clean organic scale buildup in the steam boiler system and was stored in 55-gallon drums approximately 50 ft southeast of the building.

1.2.2. Chemical Releases

During steam boiler cleaning activities, TCE may have spilled or leaked to the ground. The steam boiler blowdown that was discharged to the Building 815 dry well provided a mechanism for mobilizing TCE and created a saturated pathway in the vadose zone for TCE migration to the $Tnbs_2$ aquifer. Concurrent pumping from a former water-supply well (well 6), located approximately 2,000 ft south of Building 815, accelerated migration of dissolved TCE in the $Tnbs_2$ aquifer.

1.2.3. History of Environmental Investigations

Since 1981, many environmental investigations have been conducted in the HE Process area study area to identify sources of soil and ground water contamination. Table 1 presents a list of reports summarizing these findings. These investigations focused primarily on chemical releases resulting from discharges of HE Process wastewater to rinsewater lagoons, surface impoundments, and dry wells. As part of these investigations, LLNL collected and analyzed surface soil; subsurface soil and rock; water from springs, open boreholes, and monitor wells; and soil vapor from passive and active vacuum-induced (AVI) soil vapor surveys (SVS). Most of the investigations and monitor well installations were completed between 1984 and 1991 and summarized in the SWRI report. Additional characterization completed after the SWRI report is summarized in this chapter and Appendix A.

1.2.4. Corrective Actions and Facility Upgrades

All activities that led to TCE ground water contamination in the Building 815 OU have been discontinued. These corrective actions included:

- Removing the steam boilers and the TCE hardstand from Building 815.
- Sealing and abandoning water-supply wells 4 and 6.
- Closing the Building 815 dry well.
- Rerouting any liquid discharges from Building 815 to an engineered percolation pit.

1.3. Hydrogeology

This section summarizes the geologic and hydrogeologic data collected in the Building 815 OU relevant to this removal action. We discuss primary stratigraphic and structural features that influence ground water flow and contaminant transport in the Building 815 OU. A more detailed description of the hydrogeology can be found in the SWRI report.

1.3.1. Geology

A generalized geologic map showing the major stratigraphic units and geologic structures in the Building 815 OU is presented in Figure 3. This map shows the location of cross sections A-A' and B-B' (Figs. 4 and 5).

1.3.1.1. Stratigraphy

Most of the Building 815 OU is covered by Pleistocene – Holocene terrace (Qt), alluvium (Qal), and the Pliocene Tps unit (Dibblee 1980; Carpenter et al., 1991). The Tps unit is exposed at the surface near Building 815 and consists of interbedded silt and clay with discontinuous sand and gravel. The Tps is overlain by Quaternary terrace deposits east and west of Building 815; Quaternary terrace and alluvium overlie the Tps south of Building 815. The Tps and Quaternary units in the area are generally flat-lying, with dip magnitudes < 4 degrees to the south.

The uppermost water-bearing zone in the Neroly Formation is the $Tnbs_2$ aquifer. The $Tnbs_2$ is a 60-ft-thick, fine- to medium-grained, moderately to well sorted sandstone aquifer. In core and outcrop samples, this aquifer exhibits a distinctive blue color and a moderate estimated primary permeability. The blue color is related to the presence of an iron-rich smectite clay. The $Tnbs_2$ aquifer is overlain and underlain by fine-grained sediments of the Tps and the Neroly Formation siltstone/claystone ($Tnsc_1$) confining units, and generally dips 4–6 degrees, south-southwest to south-southeast.

1.3.1.2. Structure

The Lone Tree syncline and the Spring 5 fault are the primary geologic structures in the Building 815 OU that could potentially influence ground water flow in the $Tnbs_2$ aquifer (Fig. 3). The Lone Tree syncline is a south-southeast plunging syncline, and it's axis is located west of Building 815. This syncline controls the bedding orientation of the $Tnbs_2$ aquifer in this area. The $Tnbs_2$ aquifer dips 4–6 degrees south-southwest to south-southeast toward the axis of the syncline. Because the overlying Quaternary and Tps units are essentially flat-lying in this area, an angular unconformity exists between the $Tnbs_2$ aquifer and the shallower units. This angular unconformity is visible on cross section B-B', which shows the $Tnbs_2$ aquifer in contact with Quaternary alluvium along the east flank of the syncline. The Spring 5 fault is oriented southwest-northeast and is located approximately 600 ft southeast of Building 815 (Fig. 3). Geologic units are offset down to the south along this fault, based on exposures in Building 832 Canyon. The influence of these geologic structures on ground water flow is discussed in Section 1.3.2 and Appendix A.

1.3.2. Ground Water

Ground water beneath the Building 815 OU occurs primarily in the lower Neroly Formation blue sandstone ($Tnbs_1$) and $Tnbs_2$ aquifers. Because ground water extraction and treatment in the $Tnbs_2$ aquifer is the objective of this removal action, this section focuses primarily on the hydrogeology of that aquifer. The deeper $Tnbs_1$ aquifer is the primary water-supply aquifer for Site 300, but it is not impacted by TCE released at Building 815. The $Tnbs_1$ aquifer is hydraulically isolated from the $Tnbs_2$ aquifer by a 100-foot-thick confining layer, the $Tnsc_1$ unit.

1.3.2.1. Description of the $Tnbs_2$ Aquifer

The extent of ground water saturation in the $Tnbs_2$ aquifer is presented in Figure 6. The $Tnbs_2$ saturated thickness ranges from 0 ft north of the Building 815 OU, to 70 ft near Site 300 boundary. Between Building 815 and the Site 300 boundary, hydraulic conditions range from unconfined to confined and flowing-artesian. The top of the $Tnbs_2$ aquifer ranges from the ground surface to more than 100 ft below ground surface (bgs) within the Building 815 OU. This aquifer is believed to be naturally recharged along southeast-trending canyons that drain into Corral Hollow Creek. The $Tnbs_2$ aquifer is underlain by the 90- to 100-ft-thick $Tnsc_1$ confining unit. The $Tnsc_1$ hydraulically separates the $Tnbs_2$ aquifer from the underlying $Tnbs_1$ aquifer.

Physical property data for the $Tnbs_2$ aquifer are presented in Appendix A. These data indicate an average core porosity of 0.32, an average clay content of 2% by weight (primarily smectite), and an organic carbon content of 0.1% or lower. The laboratory-measured TCE partitioning coefficient (K_d) is 0.54. This relatively high K_d may be related to the presence of an iron-rich smectite clay.

Based on aquifer test results, the hydraulic conductivity ranges from 1.5×10^{-3} to 9.5×10^{-5} cm/sec. The estimated ground water flow velocity is about 20 meters/year. In properly constructed water-supply wells, the $Tnbs_2$ aquifer yields more than 50 gallons per minute (gpm). Ground water produced from the $Tnbs_2$ aquifer contains total dissolved solids (TDS) generally ranging from 700–1,500 ppm. The main inorganic constituents include sodium, sulfate, chloride, and bicarbonate. The range of dissolved oxygen content is 1.0–7.0 milligrams per liter (mg/L), indicating predominantly aerobic conditions. The $Tnbs_2$ aquifer was formerly used as a water-supply aquifer at Site 300, and it is currently used by the Gallo family (Gallo-1) primarily for irrigation and livestock watering.

1.3.2.2. Potentiometric Surface of the Tnbs2 Aquifer

As shown by the potentiometric surface map in Figure 6, the direction of the $Tnbs_2$ aquifer ground water gradient is generally south to southeast, and the magnitude of the gradient ranges 0.025–0.050. This change in gradient magnitude near the Spring 5 fault is due to a 25-ft decrease in ground water elevation. This decrease in hydraulic head suggests that the fault represents a "leaky" barrier to ground water flow.

In the southeast part of the Building 815 OU, the ground water gradient changes to a more easterly direction. A comparison of ground water elevation data between the $Tnbs_2$ aquifer and the overlying Quaternary aquifer indicates that an upward hydraulic gradient exists in the area where the gradient direction changes. This comparison is shown in cross section B-B', where the ground water elevation in $Tnbs_2$ monitor well W-880-01 is higher than in the adjacent alluvial well W-880-02. An upward hydraulic gradient causes ground water from the $Tnbs_2$ aquifer to flow into the overlying alluvial aquifer. This flow occurs where the two aquifers are in hydraulic communication along the eastern flank of the Lone Tree syncline near the Site 300 southern boundary. The influence of this upward gradient on ground water flow and contaminant transport is discussed further in Appendix A.

1.4. Nature and Extent of Ground Water Contamination

As a result of environmental investigations in the HE Process Area study area, 87 potential release sites were identified. Of the 87 potential areas, 20 were confirmed as chemical release sites. In the Building 815 OU, only TCE, RDX, and nitrate are considered chemicals of concern. Ground water plume maps for TCE, RDX, and nitrate (as NO_3) in the $Tnbs_2$ aquifer are presented in Figures 7–9, respectively. Table 2 summarizes the health-based standards, detection limits, and background concentrations for these chemicals.

Among the confirmed release sites, the former TCE hardstand, located near Building 815, is considered to be the primary source of ground water contamination by volatile organic compounds (VOCs). TCE is the most widespread VOC detected in ground water in the Building 815 OU. The Building 815 TCE plume is relatively large (58 acres) and dilute (< 65 ppb).

Prior to 1984, wastewater containing RDX was discharged to former unlined rinsewater lagoons. These lagoons are believed to be the primary source of HE compounds in ground water. The most widespread HE compound detected in ground water is RDX. Because RDX has a low aqueous solubility (42 mg/L, or parts per million [ppm]) and a low subsurface mobility, the dissolved RDX ground water plume is relatively small (15 acres). RDX has been detected above the 0.61 ppb PRG in seven $Tnbs_2$ ground water monitor wells.

Although nitrate was not considered a chemical of concern in the SWRI report, nitrate has been detected in ground water at concentrations exceeding the 45 ppm Federal MCL for nitrate (as NO_3). Wastewater that was discharged to the former HE rinsewater lagoons may have also contained dissolved nitrate compounds at sufficient concentrations to impact ground water in the $Tnbs_2$ aquifer.

1.4.1. Building 815 TCE plume

Figure 2 is a map showing the location and completion zone for all monitor wells located in the Building 815 OU. These monitor wells were installed to help define the extent of the Building 815 TCE plume and develop our conceptual contaminant hydrogeologic model, which is presented in Appendix A. A TCE isoconcentration contour map is presented in Figure 7 showing the distribution of TCE in ground water in the $Tnbs_2$ aquifer based on second quarter 1996 analytical results.

1.5. Human Health Risk Assessment Summary

The following is a brief summary of the human health risk assessment that was presented in the SWRI report based on residential exposure to ground water contaminants in the Building 815 OU. A more detailed discussion is presented in Chapter 6 and summarized in Appendix P, Table P-27-5, of the SWRI report. Human health risk from ground water contaminants in the Building 815 OU has not been reassessed since the SWRI report.

1.5.1. Estimation of Exposure-Point Concentrations

Using the two-dimensional saturated flow model PLUME, exposure-point concentrations for TCE and RDX in ground water were estimated at a hypothetical water-supply well completed in the $Tnbs_2$ aquifer located at the Site 300 boundary. These exposure-point concentrations were used in the SWRI baseline risk assessment to estimate additional lifetime cancer risk resulting from residential use of $Tnbs_2$ ground water. Modeling results indicate that TCE would reach the Site 300 boundary at a concentration exceeding the 5.0 ppb MCL in about 10 years, and would reach an average maximum concentration of about 6.0 ppb at 20 years. Modeling results also indicate that RDX would reach the Site 300 boundary at a maximum concentration of 1.32 ppb in about 600 years.

1.5.2. Human Health Assessment Results for TCE

The SWRI baseline human health risk assessment for the HE Process area was based on conservative estimates of additional lifetime cancer risk associated with residential use of TCE-contaminated ground water. The estimated incremental cancer risk is 1.0×10^{-5}. This risk assumes residential use of TCE-contaminated ground water in the $Tnbs_2$ aquifer from a hypothetical water-supply well, located at the Site 300 boundary.

The Environmental Protection Agency (EPA, 1991a) indicates that where cumulative potential carcinogenic risk to an individual based on reasonable maximum exposure for both current and future land use is less than 10^{-4}, and the hazard index (HI) is < 1, remedial action is generally not warranted unless adverse environmental impacts are indicated. If MCLs are exceeded, a remedial action is generally warranted. The 10^{-4} to 10^{-6} risk range is a target within which risks should be managed as part of a remedial action. Once a decision has been made to remediate, the preference is to achieve the more protective end of the range (10^{-6}).

2. Removal Action Objectives

The following three RAOs have been identified for this removal action.

1. Migration control—hydraulically control migration of the leading edge of the Building 815 OU TCE plume, preventing further degradation of ground water.
2. Risk mitigation—mitigate any public health risk associated with future offsite residential use of contaminated ground water from this plume.
3. Mass removal—remove TCE mass from the $Tnbs_2$ aquifer, without accelerating migration of the RDX plume.

2.1. Removal Action Scope

This EE/CA evaluates ground water extraction and treatment as a non-time-critical removal action to meet the above stated RAOs. Ground water extraction will be implemented at the leading edge of the plume to control offsite migration of TCE. Additionally, by intercepting the plume at this location, public health risk from potential future offsite residential use of ground water will decrease.

Whereas extraction of ground water at the leading edge of the plume will meet the RAO of removing TCE mass from the $Tnbs_2$ aquifer, mass removal could be increased by extracting ground water from areas of the TCE plume with higher concentrations. However, extraction from the TCE plume interior may accelerate RDX plume migration. This removal action includes additional aquifer testing and ground water modeling to determine how TCE mass removal from the $Tnbs_2$ aquifer will influence the RDX plume. Any influence of the RDX plume as a result of this removal action will be addressed in the RADW. A cleanup goal for RDX will be specified in the Site-Wide ROD.

The $Tnbs_2$ aquifer contains nitrates (as NO_3) at concentrations exceeding the 45 ppm Federal MCL. Though extraction of ground water containing nitrates is not an objective of this removal action, it is likely that some of the ground water extracted during this removal action will contain nitrates above the MCL. The treatment systems for this removal action will be designed to meet nitrate discharge requirements as specified by CVRWQCB Substantive Requirements.

2.2. ARARs

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, Section 121 (d)(2)(A) requires that removal actions meet any Federal, State, and local standards, requirements, criteria, or limitations that are determined to be legally applicable or relevant and appropriate. CERCLA Section 121 (d)(2)(A)(ii) requires that State ARARs be met if they are more stringent than Federal requirements.

Based on CERCLA guidance (EPA, 1991b), ARARs are divided into three categories:

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 or floodplains.
3. Action-specific requirements that may control activities and/or technology.

ARARs directly related to the removal action for the Building 815 OU TCE ground water plume are presented in Table 3. These ARARs cite the most appropriate requirements related to this removal action and provide a mechanism to enforce standards. When State ARARs are more stringent than Federal requirements, only the State ARAR is listed.

2.2.1. Chemical-Specific ARARs

State Water Resources Control Board (SWRCB) Resolution No. 92-49 (Policies and Procedures for Investigation and Cleanup and Abatement of Discharges Under Water Code Section 13304) is a chemical-specific ARAR that provides general policies on ground water investigation, remediation, monitoring, and reporting. All ground water cleanup activities associated with this removal action will be conducted under the supervision of the CVRWQCB and in accordance with Resolution 92-49. In addition, Resolution 92-49 authorizes the CVRWQCB to determine cost-effective and technically feasible cleanup standards. Ultimate cleanup of ground water in the Building 815 OU is not within the scope of this removal action, but will be specified in the Site-Wide ROD.

SWRCB Resolution No. 88-63 (Sources of Drinking Water Policy) designates all ground water and surface water of the State as drinking water except where:

1. TDS is > 3,000 ppm,
2. The water source does not provide sufficient water to supply a single well more than 200 gallons per day (gpd),
3. The water is a geothermal resource or in a waste water conveyance facility, or
4. The water cannot reasonably be treated for domestic use by employing Best Management Practices or best economically achievable treatment practices. Ground water in the Tnbs_2 aquifer qualifies as a source of drinking water under State Board Resolution No. 88-63.

SWRCB Resolution No. 68-16 (Anti-degradation Policy) is a chemical-specific ARAR intended to protect all waters of the State from degradation. Resolution 68-16 applies to this removal action because any effluent generated during this removal action will be discharged in accordance with this policy.

2.2.2. Location-Specific ARARs

Location-specific ARARs are restrictions placed on the concentration of chemicals or conduct of operations based on the location of a site. Potential location-specific ARARs for this removal action include the protection of:

- Wetlands.
- Floodplains.
- Historic landmarks.
- Coastal zones.
- Coastal barriers.
- Rare and endangered species.
- Cultural resources.

The Building 815 OU does not contain any historic landmarks, coastal zones, or coastal barriers. No wetlands have been identified within the area of this removal action. Although the Building 815 OU is located adjacent to the 100-year floodplain of Corral Hollow Creek, no portion of Site 300 lies within the floodplain.

Archaeologic and ecologic surveys conducted in the HE Process Area are described in Chapter 13 of the SWRI report (Webster-Scholten, 1994) and the 1992 Environmental Impact Report/Environmental Impact Statement (U.S. DOE and University of California, 1992), respectively. Additional surveys to identify potential cultural resources and the presence of sensitive (rare, threatened, or endangered) species will be conducted, as necessary, to mitigate any adverse impacts from any ground-breaking activities associated with this removal action.

2.2.3. Action-Specific ARARs

Most action-specific ARARs address treatment, transportation, and disposal of hazardous waste~~s~~. All hazardous waste generated as the result of this removal action, primarily spent granular-activated carbon (GAC), will be handled in accordance with the requirements of

California Code of Regulations (CCR), Title 22, Chapter 30, and the Health and Safety Code (HSC), Sections 25100-25395.

3. Removal Action

This removal action is designed to achieve the RAOs defined in Chapter 2. This removal action will be implemented in phases to allow for additional data collection and a public comment period. The final design of this removal action will be presented in a RADW report. The primary components of this removal action are:

- Additional characterization.
- Extraction wellfield design.
- Treatment facility design, construction, and operation.
- Monitoring and reporting.
- Contingency Plan.

Each of these components is discussed below.

3.1. Additional Characterization

Additional characterization work is necessary to define the extent of detectable TCE in ground water and to design and manage the extraction wellfield. This work includes:

- Installing two offsite ground water monitor well clusters downgradient of the leading edge of the TCE plume.
- Performing additional aquifer tests to evaluate capture zones, help design the extraction wellfield, and provide input parameters for a ground water flow and transport model.
- Developing a ground water flow and transport model to optimize the extraction wellfield and for use as an ongoing decision-making tool.

3.1.1. Offsite Monitor Wells

Two offsite ground water monitor well clusters will be installed on the Gallo Ranch property to further define the leading edge of the TCE ground water plume and to monitor the performance of the ground water extraction wellfield. Approximate locations of the proposed well clusters are shown in Figure 10. Each cluster will have a maximum of three wells with completion zones in the alluvial aquifer and two separate intervals within the $Tnbs_2$ aquifer, respectively.

3.1.2. Aquifer Tests

Aquifer tests will be performed to help design the extraction wellfields and provide input parameters for the ground water model. Data from these tests will be used to evaluate sustainable pumping rates, measure drawdown in nearby wells, refine plume capture zones, and evaluate potential influence on the RDX plume. Tests will be performed on wells located near the leading edge of the plume to help design the extraction wellfield to achieve migration control (RAO 1) and risk mitigation (RAO 2). Wells considered for aquifer testing include W-6ER, W-35C-04, W-4A, and W-4B. Additional aquifer tests will be performed on plume interior wells to help design the extraction wellfield to achieve mass removal (RAO 3). The plume interior wells considered for aquifer testing include W-6K, W-6L, W-818-06, and W-818-08. Aquifer test results combined with the ground water model will be used to determine whether new extraction well(s) are needed to achieve the RAOs.

3.1.3. Ground Water Flow and Transport Model

A ground water flow and transport model will be developed for use as a decision-making tool throughout this removal action. The model will be based on the conceptual contaminant hydrogeologic model presented in Appendix A. Other data to be used for input parameters and model calibration include:

- Porosity measurements from core.
- Laboratory-measured TCE partitioning coefficient.
- Hydraulic conductivity.
- Ground water elevation data.
- TCE and RDX analytical data.
- Data obtained during aquifer testing and extraction wellfield operations.

The calibrated flow and transport model will be used to:

- Manage and optimize the extraction wellfields to achieve the RAOs.
- Predict TCE and RDX plume migration under natural and pumping conditions.
- Evaluate and predict the performance of the removal action.

3.2. Extraction Wellfield Design

As presented in Figure 10, our conceptual design for this removal action includes two separate extraction wellfields and treatment facilities (Building 815 Treatment Facility 1 [B815-TF1 and Building 815 Treatment Facility 2 [B815-TF2]). The combined capture zone from both the B815-TF1 and B815-TF2 wellfields is presented in Figure D-1.

The proposed B815-TF1 extraction wellfield consists of wells W-6ER and W-35C-04. The B815-TF1 extraction wellfield is designed to hydraulically control the leading edge of the TCE plume to achieve RAOs 1 and 2. Our estimate of the capture zone for the B815-TF1 extraction wellfield is presented in Figure D-2.

Well W-818-06 is the proposed extraction well for B815-TF2. This well is designed to maximize TCE mass removal without accelerating RDX migration, achieving RAO 3. Aquifer test data and modeling results will be used to determine if additional wells, including new extraction well(s), can be added to the B815-TF2 extraction wellfield. Our estimate of the capture zone for well W-818-06 is presented in Figure D-3.

3.3. Facility Design

Figure 11 is a generalized schematic of a treatment facility for this removal action. The final treatment system design will be presented in the RADW report.

3.3.1. Building 815 Treatment Facility 1

B815-TF1 will be located near monitor wells W-6ER and W-35C-04 at the leading edge of the plume to control plume migration (RAO 1) and mitigate risk (RAO 2). Based on well yield data from these wells, we anticipate that the total influent flow rate to B815-TF1 will be about 40 gpm.

To remove TCE, the extracted ground water will be treated using two 1,000-lb GAC canisters in series. Extracted nitrate concentrations are expected to be below 10 ppm (as NO_3) based on ground water nitrate concentrations presented in Figure 9. Assuming treated water meets discharge limits, B815-TF1 effluent will be discharged to the surface, reinjected, or discharged offsite in Corral Hollow Creek. Discharge limits will be specified by RWQCB Substantive Requirements. The discharge requirements will be based on a number of factors including discharge location and chemistry of treated ground water. If the treated water does not meet the discharge limits, we will discharge effluent via a misting tower or into a constructed wetland as described below.

3.3.2. Building 815 Treatment Facility 2

B815-TF2 will be located north of B815-TF1 near well W-818-06. The purpose of B815-TF2 is to improve the effectiveness of this removal action for achieving mass removal (RAO 3). Based on the expected yield from well W-818-06, we anticipate that the influent flow rate to B815-TF2 will be about 15 gpm.

As with B815-TF1, extracted ground water will be treated at B815-TF2 for TCE using aqueous-phase GAC. To remove TCE, ground water will be pumped from the extraction wellfield and treated using three 1,000-lb GAC canisters in series. These canisters will be used at B815-TF2 to maximize GAC consumption efficiency because we anticipate detecting higher influent TCE concentrations.

Ground water effluent from the B815-TF2 treatment system may contain nitrate concentrations above discharge levels set for the B815-TF1. B815-TF2 effluent will be discharged and evaporated using a misting tower system. If the misting system is an inadequate discharge method, B815-TF2 effluent will be discharged to a constructed wetland or reinjected.

If RDX is extracted along with TCE at B815-TF2, contingencies for RDX treatment will be specified in the RADW.

3.4. Monitoring and Reporting

Ground water monitoring will be used to manage and optimize the extraction wellfields, demonstrate that the treatment systems are operating in regulatory compliance, and verify that the RAOs are being met. Reporting requirements for this removal action include quarterly ground water monitor reports and a CERCLA 5-Year Review report.

3.4.1. Ground Water Monitoring

The proposed ground water monitoring network is presented in Figure 12. Tables 4–7 present monitoring schedules, including analytes and monitoring frequency, based on the following categories:

- TCE plume leading-edge wells.
- TCE mass-tracking wells.
- RDX compliance wells.
- Tps monitoring wells.

To monitor influence of pumping on the RDX plume, certain wells have been designated as RDX compliance wells (Fig. 12). If RDX is detected and confirmed in any of the RDX compliance wells, a contingency action will be considered. As presented in Section 3.5, contingency actions for this removal action will be specified in the RADW.

3.4.2. Reporting Requirements

Reporting requirements for this removal action are summarized in Table 8. Removal action status and performance will be presented at Remedial Project Managers' (RPMs) meetings. Quarterly ground water monitor reports will be submitted to the regulatory agencies. These reports will include:

- Ground water analytical results and elevation data.
- Updated TCE, RDX, and nitrate plume maps.
- Potentiometric surface maps.
- Extraction system flow rates and volume data.
- Treatment system influent and effluent analytical results.
- Contaminant mass removal estimates.
- Receiving water monitoring results.

As required by CERCLA, a 5-Year Review report will be prepared to summarize the status of the RAOs, identify non-compliance areas, and make any necessary recommendations.

3.5. Contingency Plan

A contingency plan for this removal action will be presented in the RADW. It will describe how DOE/LLNL and the regulatory agencies plan to address foreseeable problems that may arise during this removal action. The plan will include technical and logistics contingencies. The technical contingencies will address uncontrolled plume migration, accelerated migration of the RDX plume, RDX treatment, and other foreseeable ground water problems. The logistics contingencies will address issues of personnel, funding, regulatory compliance, and land use.

3.6. Removal Action Schedule

The proposed schedule for this removal action, presented in Table 9, is dependent on DOE receiving adequate funding from Congress. DOE/LLNL will negotiate future schedule milestones with the regulatory agencies once this EE/CA document has been finalized. These schedule milestones will be included in the Action Memorandum.

4. Analysis of Removal Action

In this chapter we analyze this removal action for the Building 815 OU with respect to the following criteria:

- Effectiveness.
- Implementability.
- Cost.

4.1. Effectiveness

This section evaluates how effective this removal action is in protecting public health and the environment, and how effective it is at achieving the RAOs. This evaluation is based on :

- Overall protection of public health and the environment.
- Compliance with ARARs.
- Long-term effectiveness and permanence.
- Reduction of contaminant toxicity, volume, or mobility.
- Short-term effectiveness.

4.1.1. Overall Protection of Public Health and the Environment

The primary goal of this removal action is to protect public health and the environment. This goal will be accomplished by preventing further offsite migration of TCE-contaminated ground water through ground water extraction and treatment (RAOs 1 and 2). Ground water monitoring will be conducted to verify that these RAOs are being achieved. By adding the two offsite monitor well clusters downgradient of the TCE plume's leading edge, sufficient data can be collected to demonstrate the effectiveness of the removal action to prevent further migration of the TCE plume.

4.1.2. Compliance with ARARs

A discussion of ARARs related to this removal action is presented in Chapter 2 and summarized in Table 3. This removal action will achieve all of the ARARs at offsite locations by preventing TCE plume migration. However, ultimate cleanup of ground water is not part of the scope of this removal action; therefore, this removal action does not meet the requirements of the Safe Drinking Water Act, the CVRWQCB Basin Plan, or State Resolutions 68-16 and 92-49.

State Resolutions 68-16 and 92-49 contain provisions for establishing alternate cleanup standards above background levels, when economic or technical infeasibility is demonstrated. Recent studies of remediation progress at sites across the nation indicate that ground water extraction systems may not be able to reduce contaminant concentrations to Federal and State standards (NRC, 1994). Ground water extraction and treatment system performance data collected during this removal action will be used to evaluate technically and economically feasible cleanup standards for the Building 815 OU. These cleanup standards will be presented in the Site-Wide ROD.

4.1.3. Long-Term Effectiveness and Permanence

The long-term effectiveness of this removal action is dependent on the ability of the extraction wellfields to hydraulically control migration of the TCE plume and reduce its mass. During this removal action the extraction wellfields will be carefully managed to prevent any future public health risk associated with contaminants in extracted ground water. Ground water cleanup standards, which will be presented in the Site-Wide ROD, will be designed to protect public health from any TCE or RDX residual after ground water cleanup is completed.

Reinjection of treated ground water to the subsurface could potentially create a barrier to RDX plume migration, increase flow to the extraction well, and replenish ground water supply.

DOE will have long-term control of environmental restoration activities at Site 300 and will be responsible for providing sufficient funding to conduct this removal action. Ground water monitoring and regulatory oversight will be used to evaluate removal action performance and verify that all the RAOs have been achieved. Contingencies for long-term implementation of this removal action will be presented in the Building 815 RADW.

4.1.4. Reduction of Toxicity, Mobility, or Volume

This removal action will reduce toxicity, mobility, and TCE mass through ground water extraction and treatment. Toxicity will be reduced when TCE-contaminated ground water is extracted and treated using aqueous-phase GAC. The TCE will be thermally destroyed when the GAC is regenerated. Ground water extraction will also decrease TCE mobility and volume by controlling migration hydraulically and removing TCE mass by GAC treatment. RDX plume mobility may be increased, but monitoring will be conducted and appropriate actions will be taken to minimize this occurrence and to ensure no increased risk occurs to public health or the environment. To maximize TCE mass removal, aquifer testing and ground water modeling will be conducted to design the extraction wellfields while minimizing influence on the RDX plume.

Ground water extraction will increase nitrate plume migration, and ground water containing nitrate will, most likely, be extracted during this removal action. The final treatment system design for this removal action will include provisions necessary to meet nitrate discharge requirements. The final design will be presented in a RADW following the public comment period and the Action Memorandum.

4.1.5. Short-Term Effectiveness

By preventing further offsite migration of TCE, this removal action will be immediately effective in preventing public exposure to contaminated ground water. Potential exposure to onsite workers or the public will be mitigated through strict adherence to standard operating procedures, health and safety code regulations, and administrative controls. Strict adherence to these procedures, regulations, and controls will also mitigate any potential adverse environmental impacts during this removal action.

4.2. Implementability

This section evaluates the implementability of this removal action by considering the following criteria:

- Technical feasibility.
- Administrative feasibility.
- Availability of services and materials.
- State and community acceptance.

Technical feasibility includes the ability of the selected technology to implement the remedy, the reliability of the technology, and the flexibility of the removal action to allow future remedial actions, if necessary. Statutory limits, permitting, and siting problems are discussed in Section 4.2.2.

4.2.1. Technical Feasibility

This removal action uses conventional, industry-accepted technologies to achieve the RAOs. Ground water extraction and treatment is an effective and accepted method for treating ground water containing low concentrations (i.e., < 100 µg/L) of TCE. Use of aqueous-phase GAC is a treatment technology that has proven to effectively treat TCE-contaminated ground water in areas such as the eastern General Services Area (GSA) at Site 300.

Ground water extraction is technically feasible to hydraulically control TCE migration at the leading edge of the plume and mitigate potential public health risk. However, ground water extraction from the interior of the TCE plume will be necessary to increase the effectiveness of this removal action to achieve mass removal (RAO 3). The technical feasibility of TCE mass removal will be further evaluated as part of this removal action, using aquifer testing and ground water modeling. Aquifer testing and modeling results will be used to design an extraction wellfield to achieve TCE mass removal, while minimizing RDX plume migration. Continued ground water monitoring and modeling will be used to manage and optimize the extraction wellfield to verify that this RAO is being achieved.

The technical feasibility of reinjecting treated ground water or discharging it at the surface to recharge the $Tnbs_2$ aquifer will be evaluated by ground water modeling. Long-term maintenance of reinjection wells are subject to problems including scaling and plugging. The location of any reinjection well will be carefully selected to ensure efficient performance of the extraction wellfield.

Although aqueous-phase GAC treatment is effective for treating TCE-contaminated ground water, it is not recommended for treating nitrate because nitrate is not readily sorbed onto aqueous-phase GAC. Therefore, the final design for this removal action will include provisions for treating nitrate, if necessary, to meet nitrate discharge requirements as specified by CVRWQCB Substantive Requirements. Additional information regarding an innovative technology for nitrate treatment using a constructed wetland is presented in Appendix C. RDX is readily sorbed onto the aqueous-phase GAC. However, RDX-laden GAC poses a potential explosive hazard and many GAC disposal/regeneration facilities will not accept it. Therefore, using GAC for RDX treatment is inefficient and costly. This removal action is designed to achieve the RAOs while minimizing influence on the RDX plume. An innovative technology that could potentially be used for onsite treatment of RDX-laden GAC, if necessary, is presented in Appendix C.

If necessary, this removal action can be expanded by adding additional wells to the extraction wellfields, or adding technologies for nitrate and/or RDX treatment. Contingencies will be presented in the RADW for incorporating additional treatment technologies to achieve the RAOs for this removal action.

4.2.2. Administrative Feasibility

This project is not subject to the statutory limits of $2M or 12 months for conducting non-time-critical removal actions; therefore, the administrative feasibility of conducting this removal action is not constrained. We do not anticipate any difficulties in obtaining permits for installing offsite wells, meeting substantive requirements for treated ground water discharge, or coordinating efforts with other Site 300 activities. However, meeting Substantive Requirements for reinjection wells may present a problem.

Two offsite monitor well clusters will be installed on Gallo ranch property to monitor ground water downgradient of the TCE plume and verify that public health risk is being mitigated. Previously, the Gallo family has been cooperative in allowing the placement of monitor wells on their property, so no administrative problems are anticipated with this part of the removal action.

The two proposed treatment facility locations are relatively accessible and should not pose any significant facility placement problems. Any ground modification that might be needed for treatment facility siting or placement will be coordinated with Site 300 Planning and subject to their approval. If a constructed wetland is required for nitrate treatment, the location, design, and long-term management of such a facility will be presented in the RADW report. Siting and maintaining a constructed wetland will also be coordinated with Site 300 Planning. Additional information regarding constructed wetlands is presented in Appendix C.

4.2.3. Availability of Services and Materials

All of the services and materials required to implement this removal action are commercially available. Materials and services for monitor well installation; aquifer testing; ground water monitoring and modeling; treatment facility design, construction, and operation are all currently available. GAC canisters can be obtained from local vendors, and TCE-laden GAC canisters can be regenerated by one of several vendors.

4.2.4. State and Community Acceptance

It is anticipated that the State, regulatory agencies, and the public will view this removal action as a good balance of options, with respect to the evaluation criteria, and will accept this removal action as the best approach for achieving the RAOs. Comments submitted by the regulatory agencies will be addressed in the Final EE/CA report. The regulatory agencies will monitor and review the community acceptance of this removal action during a public comment period, which will include a public workshop. Appropriate public comments concerning this removal action will be considered and addressed in the Responsiveness Summary of the Action Memorandum.

4.3. Cost

Cost estimates were prepared for this removal action based on three cost categories: 1) direct capital, 2) indirect capital, and 3) post-removal site control (PRSC). Direct and indirect costs are presented in 1997 dollars. A 3.5% discount rate is applied to the PRSC costs presented as present-worth 1997 dollars. The estimated costs for each category, a description of each category, and the total costs for the removal action are presented below. The estimates and assumptions that were made in preparing these costs, along with a detailed costing table (Table F-1), are presented in Appendix F.

4.3.1. Direct Capital Costs

Direct capital costs for this project include:

- Installing offsite monitor well clusters.
- Material.
- Constructing treatment facilities.
- Installing additional extraction well, if necessary.

The direct capital cost including a 20% contingency is $577K.

4.3.2. Indirect Capital Cost

Indirect costs are these associated with engineering and design, licensing and permits, and startup. Indirect capital costs for this removal action include:

- Aquifer tests.
- Ground water flow and transport modeling.
- RADW report preparation.
- Activation.
- Permits for offsite wells and treated water discharge.
- Interim project management and document preparation.

The indirect capital cost including a 20% contingency is $377K.

4.3.3. Annual Post-Removal Site Cost

PRSC are costs incurred after the removal action has been completed. PRSC costs for this removal action include operations and maintenance, ground water monitoring and compliance, reporting, and project management. We assume that the ground water treatment facilities will be operating for 20 years. The actual removal action life-cycle will depend on cleanup standards to be presented in the Site-Wide ROD.

PRSC costs were calculated for 20 years including a 20% contingency. The PRSC present-worth cost for 20 years is $4.9M. PRSC costs for the 2 years before the Site-Wide ROD supercedes the removal action are $0.7M.

4.3.4. Total Cost

Total present-worth cost for all direct capital, indirect capital, and 20 years of PRSC costs is $5.8M. Total present-worth cost for all direct capital, indirect capital, and the 2 years of PRSC costs before the Site-Wide ROD supercedes the removal action is $1.6M.

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Figures

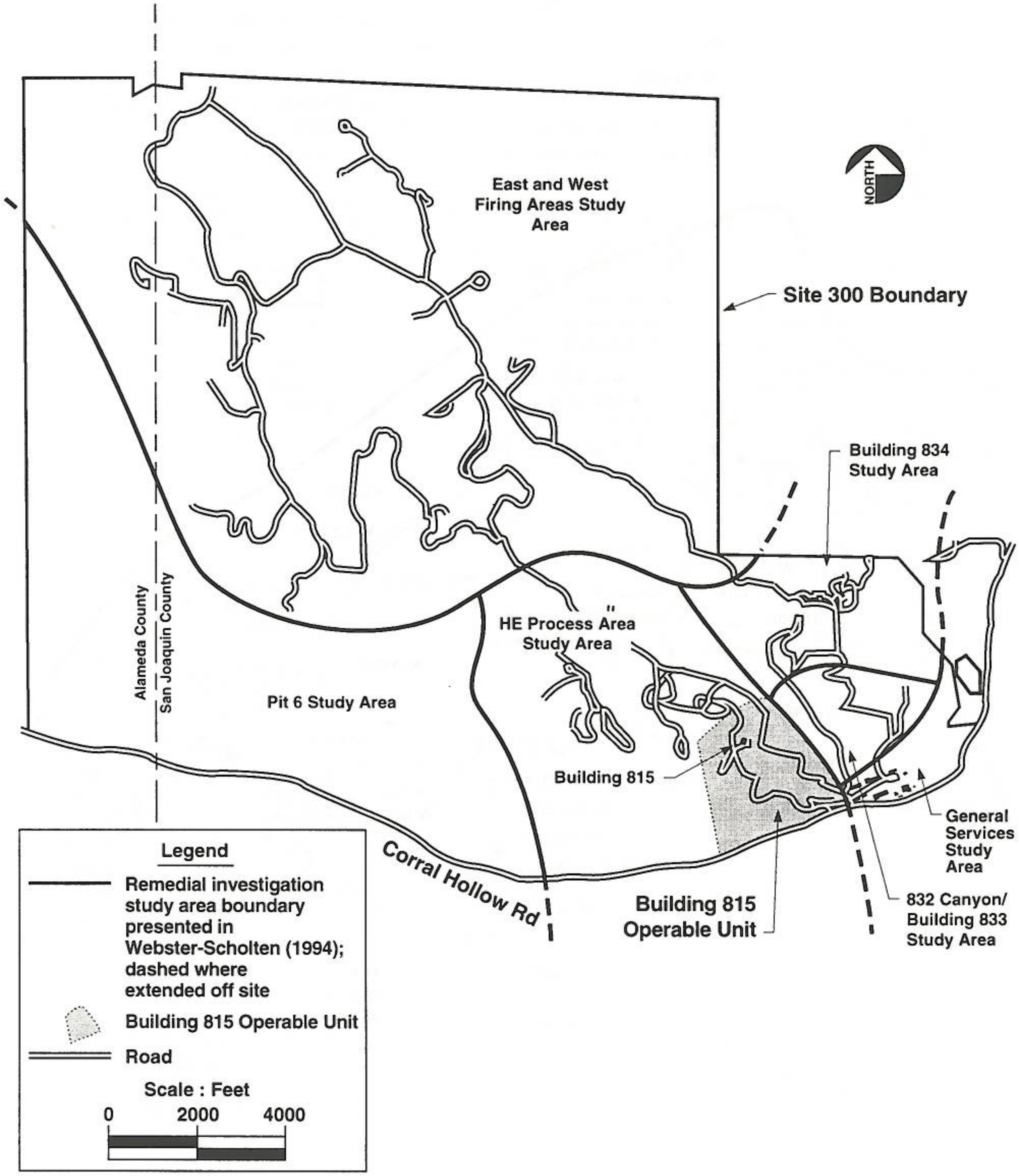

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Figure 1. Map of Site 300 showing location of the study areas and the Building 815 OU.

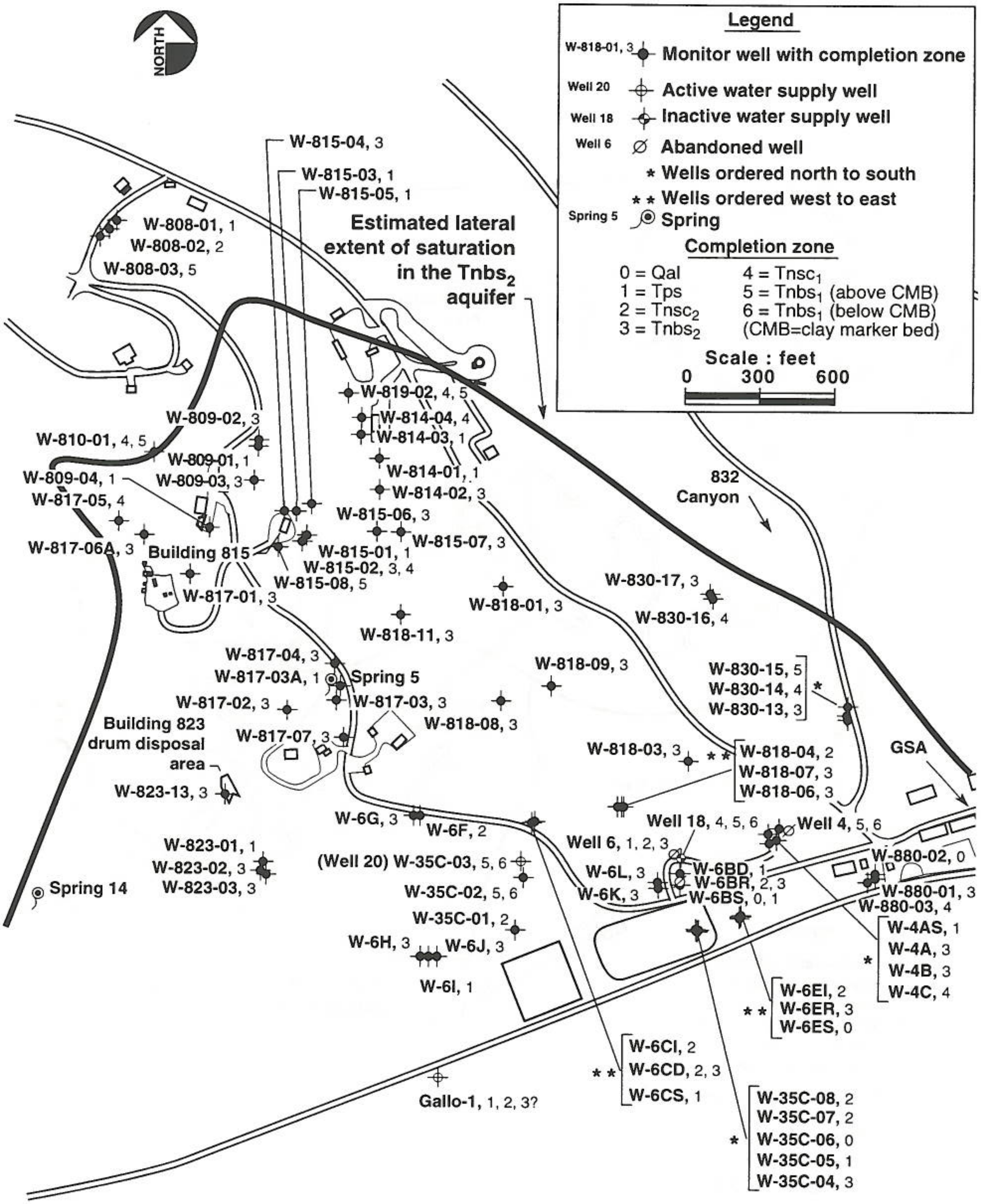

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Figure 2. Monitor well locations and completion zones in the Building 815 OU and vicinity.

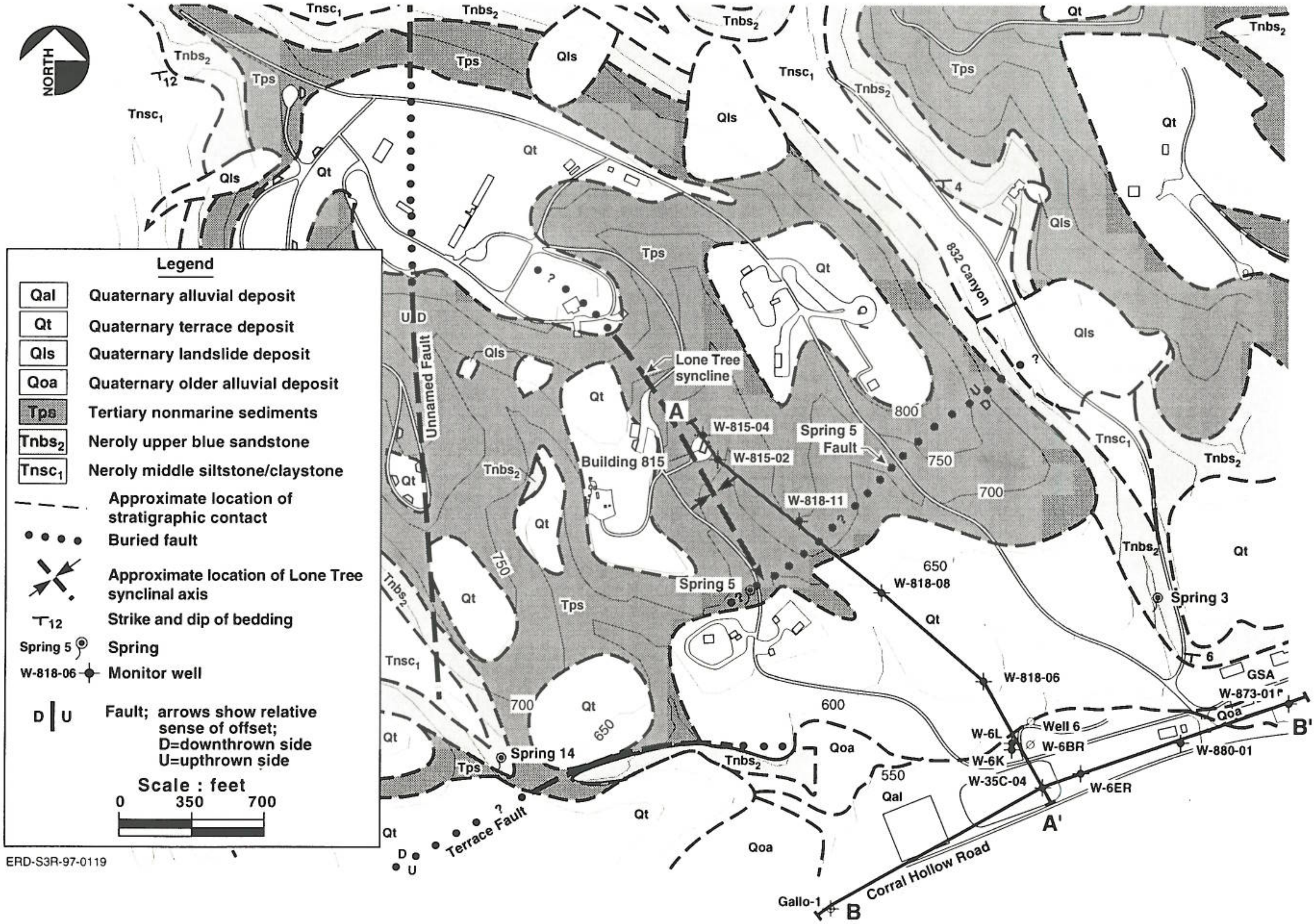

Figure 3. Geologic map of HE Process Area showing location of hydrogeologic cross sections A-A' and B-B'.

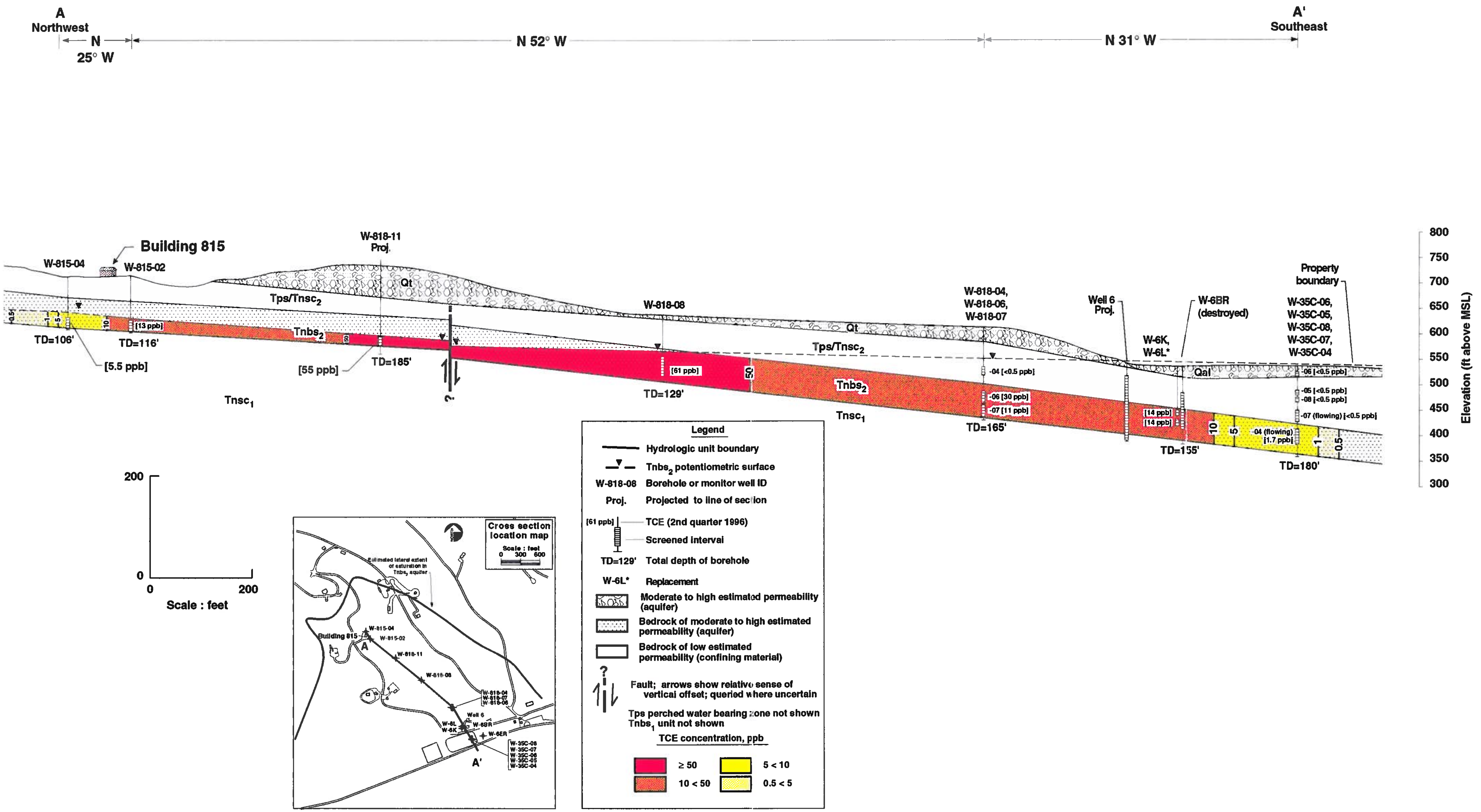

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Figure 4. Hydrogeologic cross section A-A'.

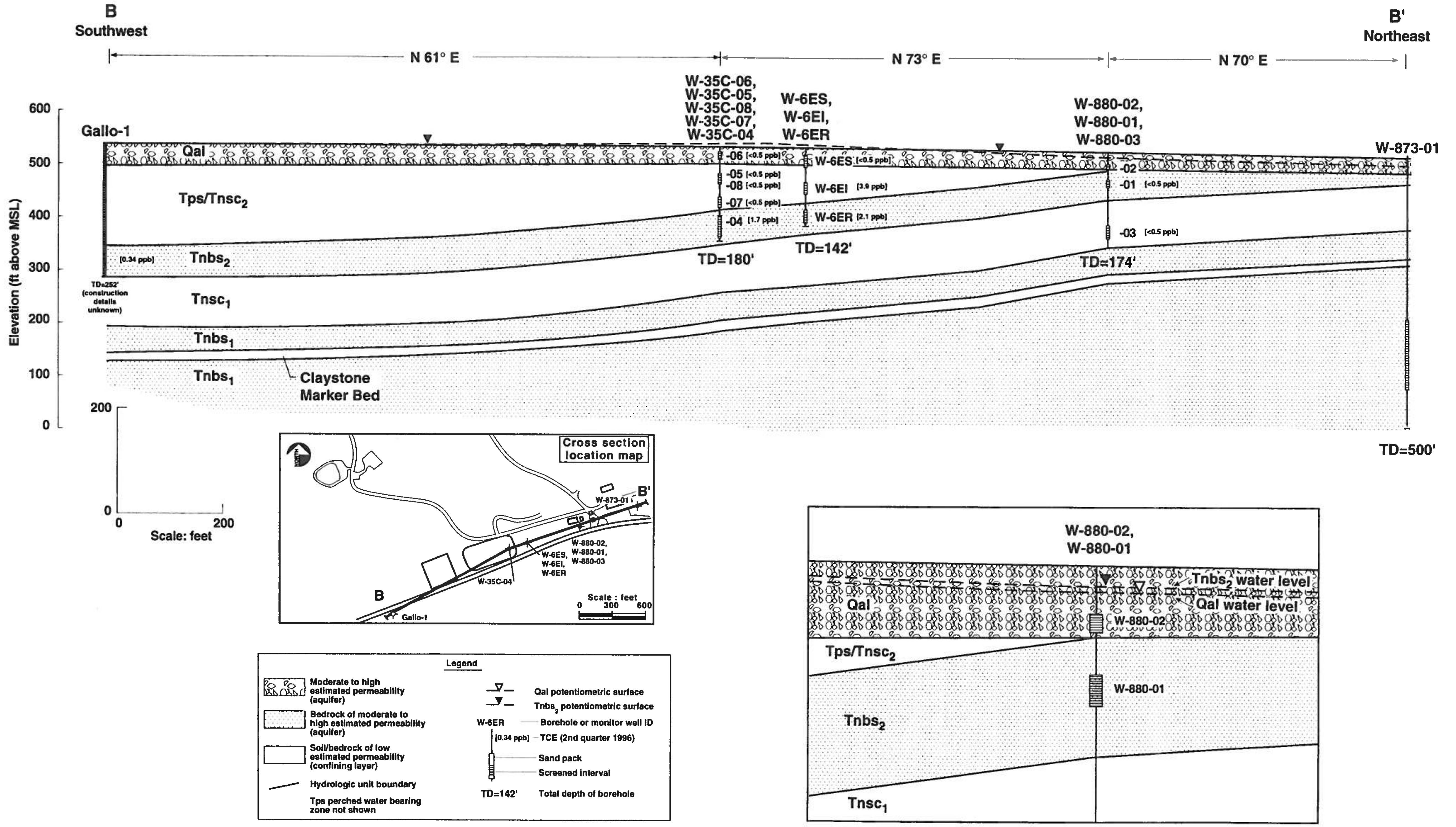

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Figure 5. Hydrogeologic cross section B-B'.

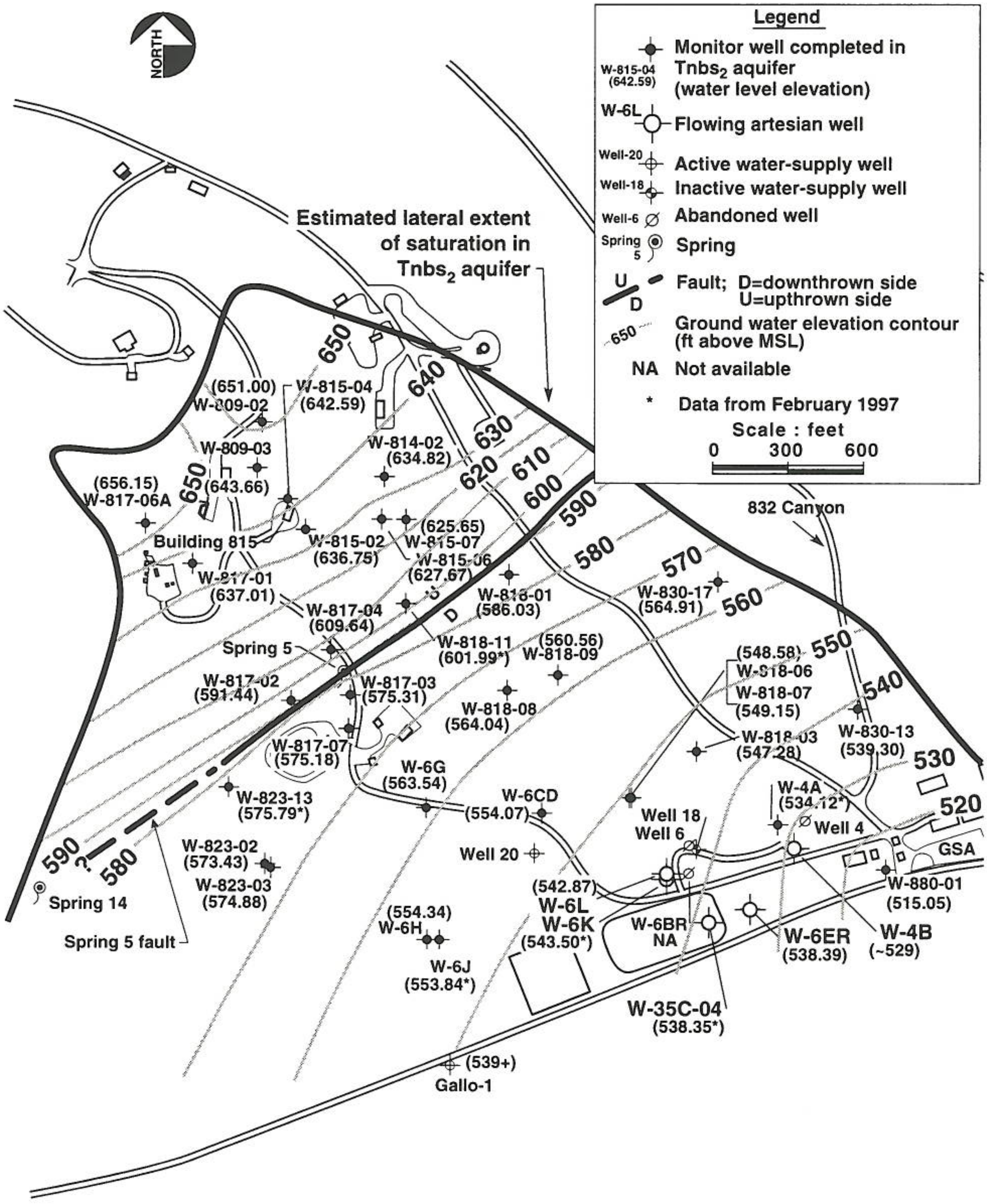

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Figure 6. Potentiometric surface map and extent of saturation in the Tnbs$_2$ aquifer, second quarter 1996.

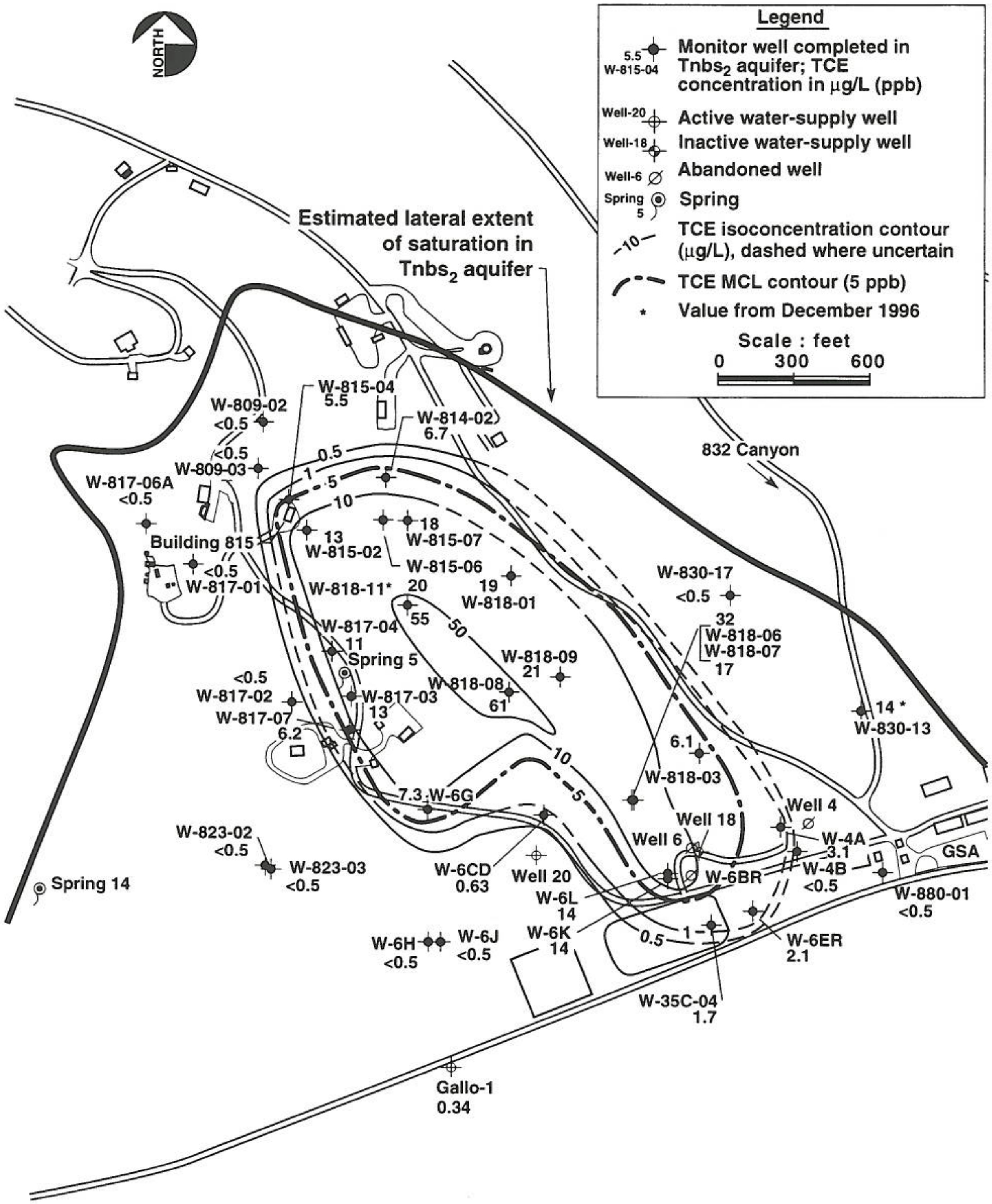

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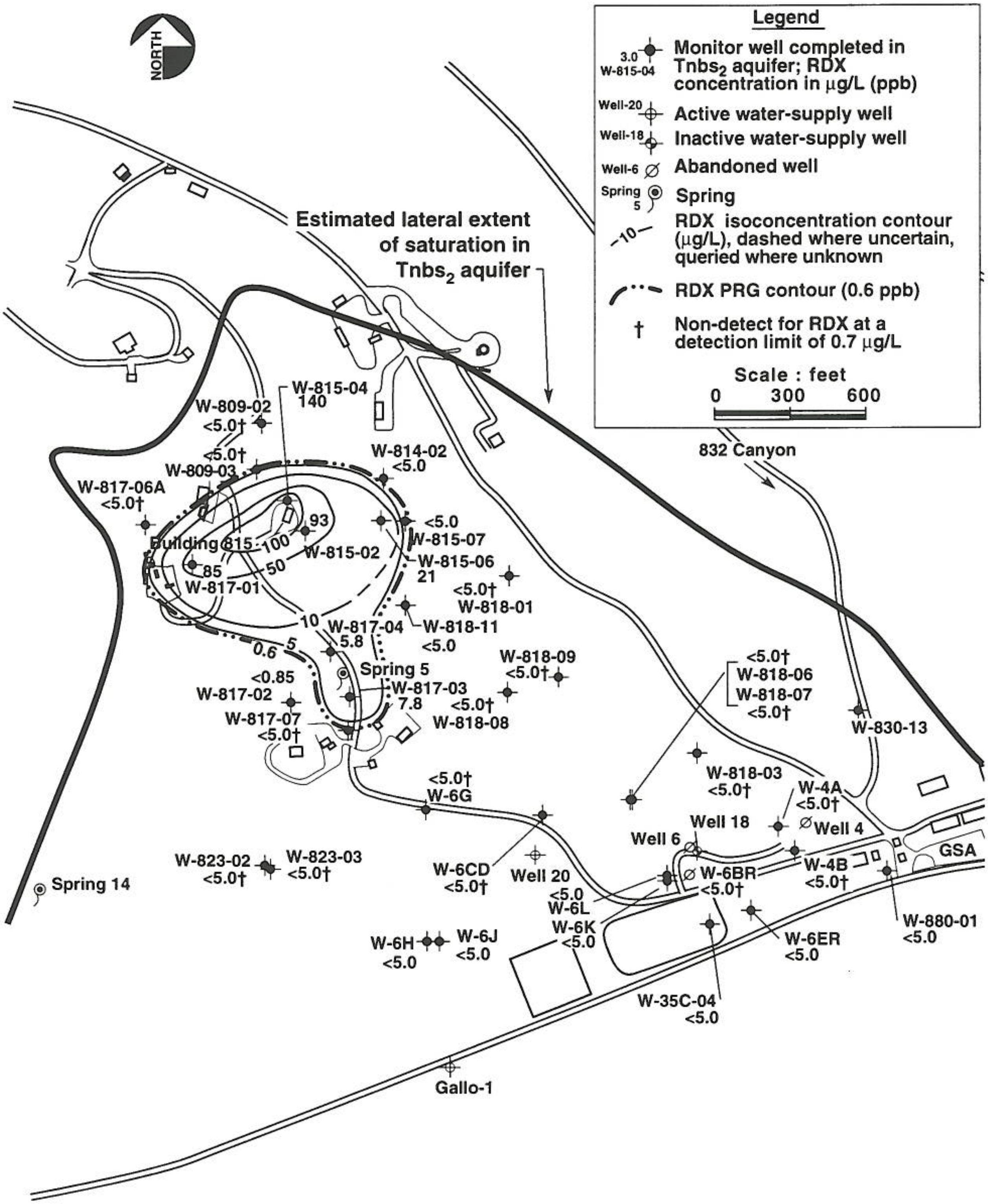
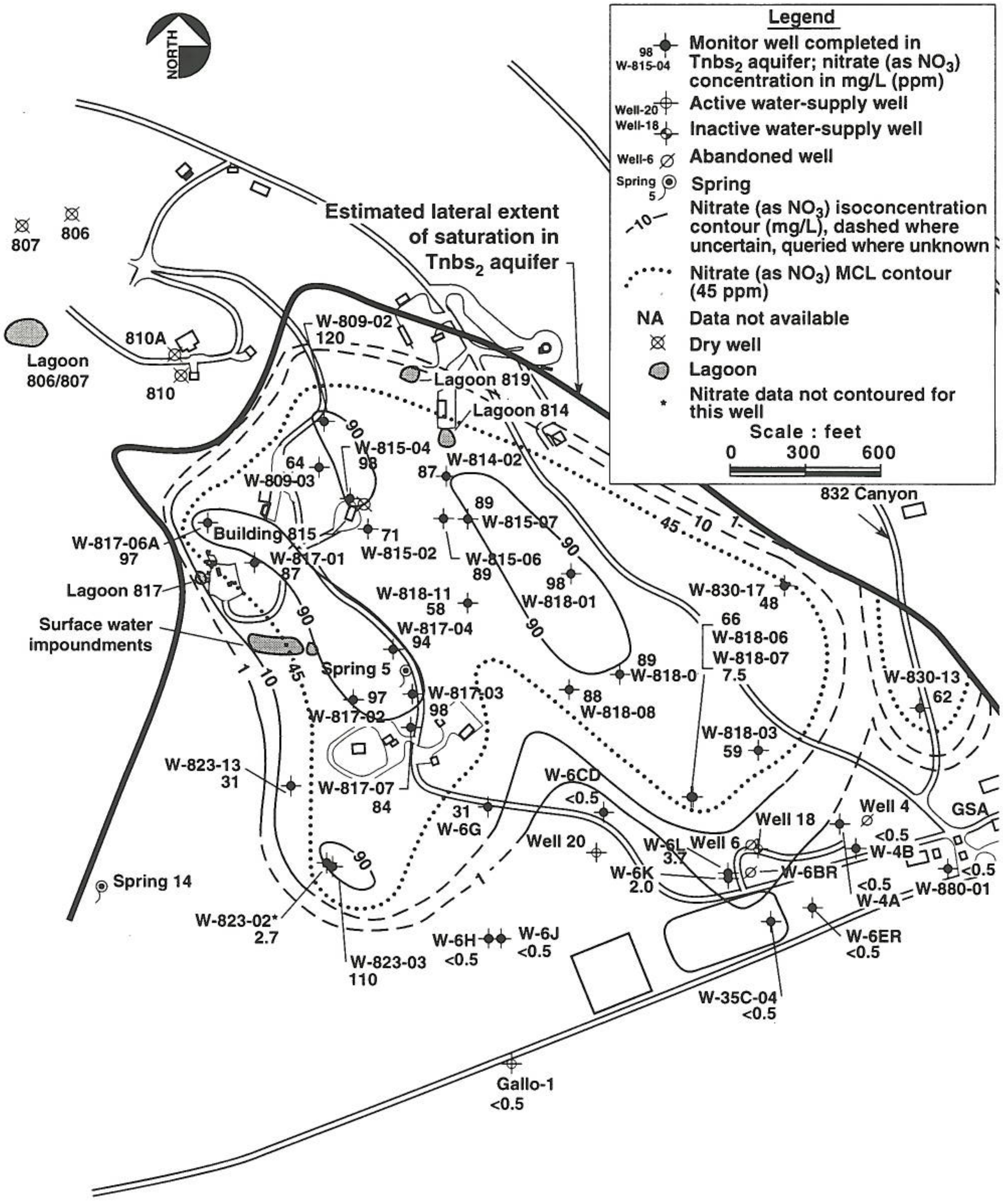
Figure 7. TCE isoconcentration contour map in the Tnbs$_2$ aquifer, second quarter 1996.



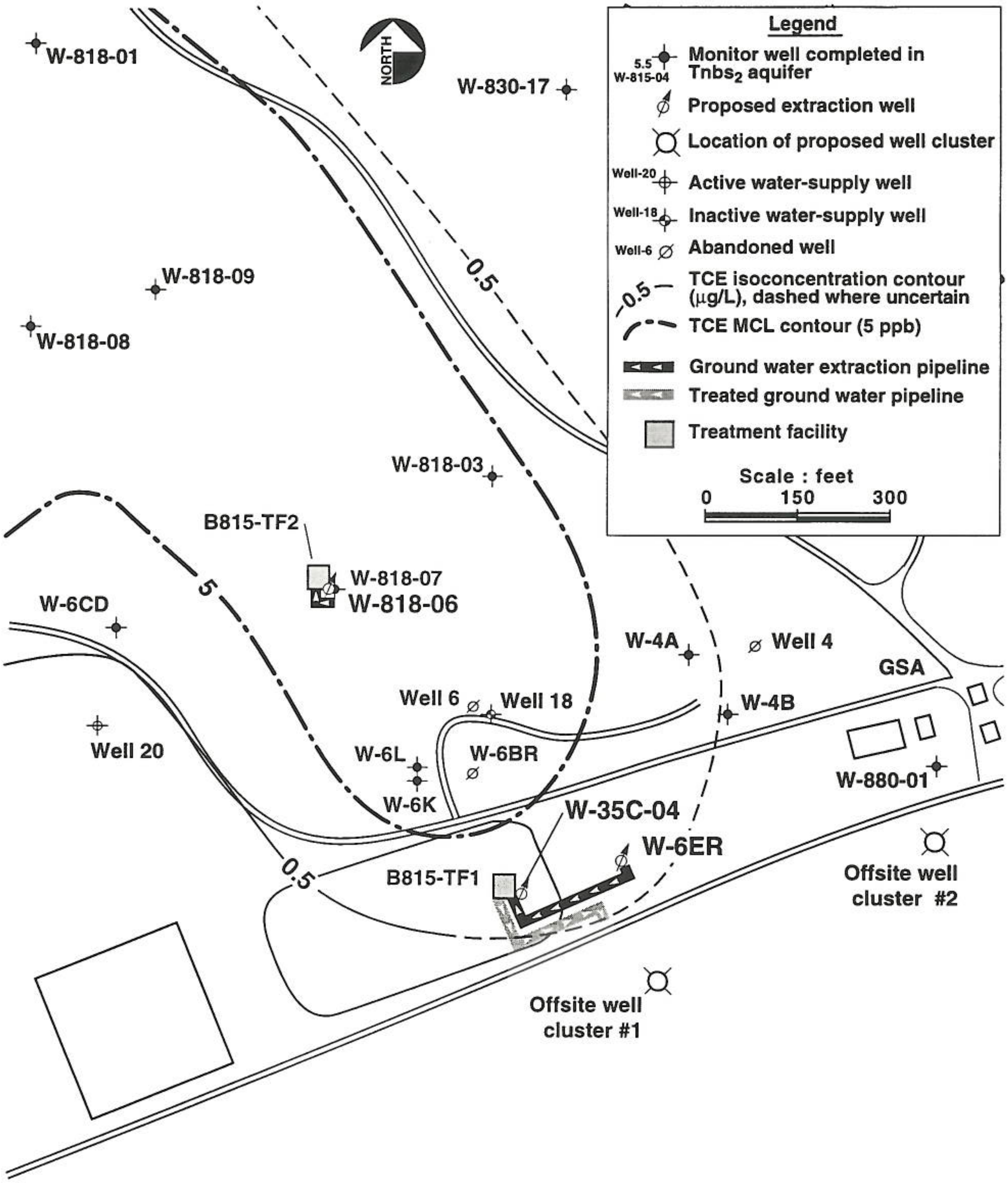
ERD-S3R-97-0124

Figure 8. RDX isoconcentration contour map in the Tnbs$_2$ aquifer, second quarter 1996.



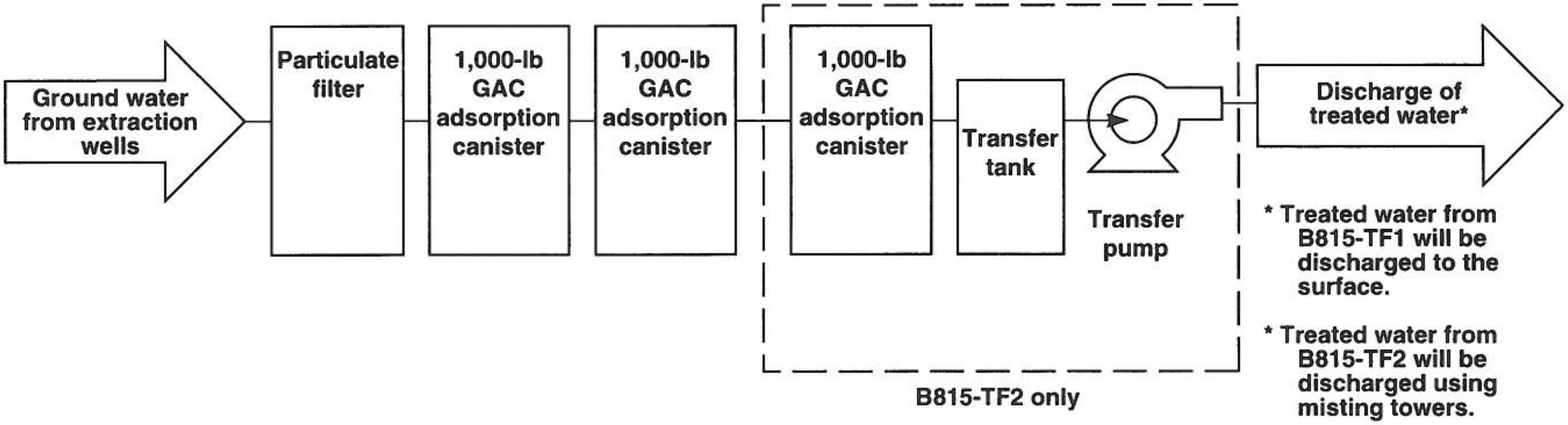
ERD-S3R-97-0125

Figure 9. Nitrate (as NO_3) isoconcentration contour map in the Tnbs$_2$ aquifer, second quarter 1996.



ERD-S3R-97-0126

Figure 10. Map showing location of extraction wells, offsite well clusters, and treatment systems for the Building 815 OU removal action.

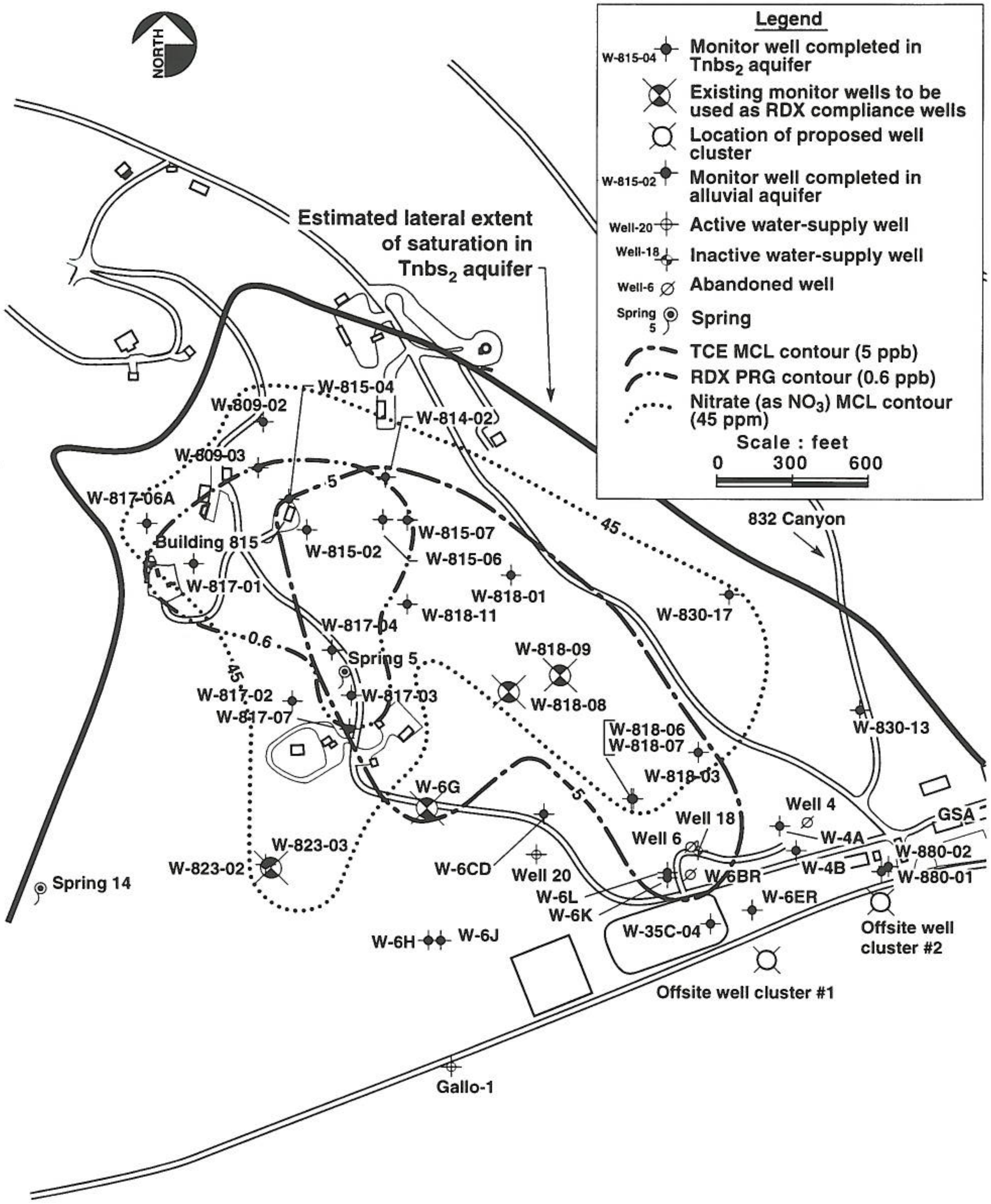


* Treated water from B815-TF1 will be discharged to the surface.

* Treated water from B815-TF2 will be discharged using misting towers.

ERD-S3R-97-0127

Figure 11. Schematic of a typical ground water treatment system for B815-TF1 and B815-TF2. (The third GAC canister and transfer pump are for B815-TF2 only).



ERD-S3R-97-0128

Figure 12. Map of proposed ground water monitoring network for the Building 815 OU showing location of RDX compliance wells, TCE and nitrate MCL contours, and RDX PRG contour.

Tables

Table 1. Chronology and brief summary of environmental restoration activities in the HE Process area and in the Building 815 OU.

Year	Activity
1953	Site 300 established.
Mid 1950s	HE Process area established to formulate and machine high-explosive compounds.
1957	Well 6 installed as a water-supply well. Pumped at approximately 50 gpm to supply water for Site 300 use.
1958	Building 815 constructed as a steam plant for neighboring buildings in the HE Process area. Cooling tower blowdown water was discharged to the Building 815 drywell.
1980	TCE contamination was detected in well 6; pumping discontinued.
1983	An investigation of the unlined surface water lagoons was begun in response to Federal and State laws concerning waste disposal and ground water protection. Lagoon water, existing water-supply wells, and springs were sampled for HE compounds, metals, and anions. Geophysical reconnaissance, percolation tests, and a water budget were performed for each lagoon. A recommendation to stop discharge to the lagoons and reroute the drainage to either a tank or a lined surface impoundment was made for each lagoon and reported in *Chemical and Hydrogeologic Evaluation of High-Explosive Process Wastewater Discharges at Site 300* (Raber, 1983).
1984	First ground water monitoring wells installed in HE Process area as part of the monitoring network for the HE surface impoundments located south of Building 817.
1985–1986	A study of HE compounds in soil was conducted as one of the activities leading to the closure of the nine unlined HE rinsewater lagoons. Study is reported in *Distribution of High Explosives Compounds in Soil and Water at the 806/807 Lagoons, HE Process area, LLNL Site 300* (Crow et al., 1986).
1986	Building 815 steam boiler taken out of service and removed.
1987	Well 6 sealed and abandoned.
1988	Nine unlined HE rinsewater lagoons were decommissioned under the supervision of the RWQCB. Rinse water was diverted to two lined surface water impoundments. Of these nine lagoons, four are located in or are directly upgradient of the Building 815 OU. An HE rinsewater lagoon closure plan titled *Closure Plan for the Decommissioned High Explosives Rinsewater Lagoons at LLNL Site 300* (Carpenter et al., 1988) was submitted to the regulatory agencies.
1988–1989	Closure of the lagoons in the HE Process area. The closure included filling and capping the four lagoons located in the Building 815 OU. The capping of the HE lagoons effectively prevented ground water recharge and further migration of contaminants to ground water.
1989	Eighteen drywells were investigated, including two in the current Building 815 OU. The Building 815 dry well may have caused flushing of contaminants into the aquifers beneath Building 815. The results of the soil and rock analyses were reported in *Remedial Investigation of Dry Wells, LLNL Site 300* (Lamarre et al., 1989).
1987–1990	A site investigation was performed at the Building 823 Drum Disposal area. LLNL collected water samples from springs, performed geologic mapping of the area, and conducted a metal detection survey. Three wells were placed downgradient of the disposal area. Initial samples indicated low concentrations of TCE as reported in *Site Inspection of the Disposal Site Near Building 823, LLNL Site 300* (Crow et al., 1990b). However, contaminants have not been detected in these wells since 1993.

Table 1. (Continued)

Year	Activity
1990	Site 300 placed on the National Priorities List (NPL) (Superfund). DTSC and EPA join the RWQCB in providing regulatory oversight.
1990	Environmental investigations conducted in the HE Process area were presented in the *Draft Remedial Investigation of the High Explosives Process Area* (Crow et al., 1990a). This document presented an overview of previous investigations of the wastewater lagoons and the dry wells in the HE Process area, including information obtained from 42 exploratory boreholes and 17 monitor wells. This document identified potential release sites for TCE, other VOCs, and HE compounds.
1993	The Building 815 TCE plume designated as a CERCLA OU. At the Building 815 OU, TCE contamination has been identified in ground water in the $Tnbs_2$ aquifer resulting from releases at Building 815.
1994	Building 815 dry well closed.
1984–1994	Environmental investigations in the HE Process area were performed to further investigate contaminant source areas. These investigations included installing monitor wells, collecting soil and ground water samples, conducting soil vapor surveys, and conducting a risk assessment. The results of the investigation were reported in the SWRI report (Webster-Scholten, 1994).
1995	Two remedial alternatives were presented to the regulators in *the Draft Evaluation of Remedial Alternatives for the Building 815 Operable Unit* (Madrid and Green-Horner, 1995).
1995–1996	Additional investigations were performed at the Building 823 Drum Disposal area including a soil vapor survey, metal detection survey, slant borings beneath the disposal area, soil borings into the fill above the disposal area, and installation of a monitor well in the first water-bearing zone beneath the disposal area. Ground water samples at this location have been non-detect for all analytes. Motor oil was detected in trace quantities in two of the soil samples. A removal action for excavating the buried drums was started at the request of DOE. Excavation was halted when a lid from a high explosives drum was uncovered.
1996–1997	Additional characterization work in the 815 OU included installing six additional wells. Well W-6BR, a well that was screened over multiple water-bearing zones, was sealed and abandoned. A study of the trends of the TCE data in each of the wells in the plume was performed. These data and a proposed removal action is presented in this *Draft Engineering Evaluation/Cost Analysis for the Building 815 Operable Unit Lawrence Livermore National Laboratory Site 300* (Madrid and Jakub, 1997).
	Proposed Future Activities
1997	Final engineering evaluation/cost analysis report for the Building 815 OU
1998	Public workshop
1998	Building 815 Action Memorandum
1999	Aquifer tests and modeling to be performed before the final removal design is completed. The final design will be reported in the Building 815 OU Removal Action Design Workplan.
1999	Implementation of removal action.
2000	Site-Wide Record of Decision

Table 2. Summary of health-based standards, current analytical laboratory detection limits, and background concentrations for the primary ground water contaminants in the Building 815 OU.

Chemical of concern	MCL	Detection limit	Background concentration
TCE	5.0 μg/L[a]	0.5 μg/L	<0.5 μg/L
RDX	0.61 μg/L[b]	5.0 μg/L[c]	<5.0 μg/L
Nitrate	45 mg/L[d]	0.5 mg/L	12 mg/L[e]

[a] USEPA and Cal-EPA MCL for TCE in drinking water.

[b] Because no MCL exists for RDX, we are using USEPA Region IX PRG for drinking water (1/95).

[c] Current analytical laboratory detection limit for RDX.

[d] USEPA and Cal-EPA MCL for nitrate as (NO_3) in drinking water.

[e] Based on the average nitrate concentration in ground water from four water-supply wells located northwest of Site 300.

Table 3. Potential Federal, State, and local ARARs for removal action in the Building 815 OU.

Action	Source	Description	Application to this removal action
Ground water extraction and treatment	*Federal:*		
	Safe Drinking Water Act [42 USCA 300 and 40 CFR 141.11-141.16, 141.50-141.51] (Applicable: Chemical-specific)	Establishes treatment standards for current potential drinking water sources by setting MCLs and non-zero Maximum Contaminant Level Goals (MCLGs), which are used as cleanup standards.	As part of this removal action, TCE concentrations will be reduced to levels that will be specified in the Site-Wide ROD.
	State:		
	Cal. Safe Drinking Water [California Health and Safety Code Section 116365] (Applicable: Chemical-specific)	Establishes treatment standards for potential drinking water sources by setting MCL goals.	As part of this removal action, TCE concentrations will be reduced to levels that will be specified in the Site-Wide ROD.
	SWRCB Resolution 92-49 (Applicable: Chemical-specific)	Requires oversight of investigations and cleanup and abatement activities resulting from discharges of waste that affect or threaten water quality.	All cleanup activities associated with this removal action will be conducted with oversight by the CVRWQCB.
	Chapter 15, Code of California Regulations (CCR), Title 23, Sections 2550.7, 2550.10 (Applicable: Chemical-specific)	Requires monitoring of the effectiveness of the remedial actions.	During and after completion of this removal action, concentrations of TCE, RDX, and nitrate in *in situ* ground water will be monitored.

Table 3. (Continued)

Action	Source	Description	Application to this removal action
Ground water extraction and treatment (cont.)	*State: (cont.)*		
	Water Quality Control Plan (Basin Plan) for CVRWQCB (Applicable: Chemical-specific)	Establishes beneficial uses and water quality objectives for ground water and surface waters in the Central Valley Region as well as implementation plans to meet water quality objectives and protect beneficial uses.	As part of this removal action, TCE concentrations in ground water will be remediated to levels that will be specified in the Site-Wide ROD.
	SWRCB Resolution 88-63 (Applicable: Chemical-specific)	Designates all ground and surface waters in the State as drinking water sources with specific exceptions. Ground water in the $Tnbs_2$ aquifer qualifies as drinking water under this policy.	As part of this removal action, TCE concentrations will be remediated to levels that will be specified in the Site-Wide ROD.
Treated ground water discharge	*State:*		
	State Water Resources Control Board (SWRCB) Resolution 68-16 (Anti-degradation policy) (Applicable: Chemical-specific)	Requires that high quality surface and ground water be maintained to the maximum extent possible.	All discharges of treated water will comply with Substantive Requirements.
Disposition of hazardous waste	*State:*		
	Health and Safety Code, Sections 25100-25395, CCR, Title 22, Ch. 30: Minimum Standards for Management of Hazardous and Extremely Hazardous Wastes (Applicable: Action-specific)	Controls hazardous wastes from point of generation through accumulation, transportation, treatment, storage, and ultimate disposal.	This ARAR applies primarily to the handling, transportation, and ultimate disposal of spent GAC vessels.

Table 3. (Continued)

Action	Source	Description	Application to this removal action
Protection of endangered species	*Federal:*		
	Endangered Species Act of 1973, 16 USC Section 1531 et seq. 50 CFR Part 200, 50 CFR Part 402 [40 CFR 257.3-2] (Applicable: Location-specific)	Requires that facilities or practices not cause or contribute to the taking of any endangered or threatened species of plants, fish, or wildlife. NEPA implementation requirements may apply.	Prior to any well installation, facility construction, or similar potentially disruptive activities, wildlife surveys will be conducted and mitigation measures implemented, if required.
	State:		
	California Endangered Species Act, California Department of Fish and Game Sections 2050-2068		
	(Applicable: Location-specific)		

Table 4. Removal action ground water monitoring program for the wells at the leading edge of the TCE plume in the Building 815 OU.

Well	Analyte[a]	Sample frequency
TCE leading edge wells		
W-35C-04	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-6ER	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-4A	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-4B	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-6H	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-6J	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-6K	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-6L	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-880-01	VOCs, nitrates	Quarterly
	HE compounds	Annually
W-880-02[b]	VOCs, nitrates	Quarterly
	HE compounds	Annually
New offsite wells		
W-35B-01[b]	VOCs, nitrates	Quarterly
W-35B-02	VOCs, nitrates	Quarterly
W-35B-03	VOCs, nitrates	Quarterly
W-35B-04	VOCs, nitrates	Quarterly
W-35B-05	VOCs, nitrates	Quarterly

[a] U.S. EPA analytical methods:
VOCs: 601.
Nitrates: 353.2.
HE: 8330.

[b] Alluvial aquifer wells.

Table 5. Removal action ground water monitoring program for TCE mass tracking wells in the Building 815 OU.

Well	Analyte[a]	Sample frequency
TCE mass tracking wells		
W-6CD	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-809-02	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-809-03	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-814-02	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-815-02	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-815-04	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-815-06	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-815-07	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-817-01[b]	VOCs, HE compounds, nitrates	Quarterly
W-817-02[b]	VOCs, HE compounds, nitrates	Quarterly
W-817-03[b]	VOCs, HE compounds, nitrates	Quarterly
W-817-04[b]	VOCs, HE compounds, nitrates	Quarterly
W-817-06A	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-818-01	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-818-03	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-818-06	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-818-07	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-818-11	VOCs	Semi-annually
	HE compounds, nitrates	Annually
W-823-02	VOCs, HE compounds	Semi-Annually
	Nitrates	Annually

[a] U.S. EPA analytical methods:
VOCs: 601.
HE: 8330.
Nitrates: 353.2.

[b] Wells are sampled under a waste discharge requirement (WDR) for the surface impoundments by Water Guidance and Monitoring Group (WGMG).

Table 6. Removal action ground water monitoring program for RDX compliance wells in the Building 815 OU.

Well	Analyte[a]	Sample frequency
RDX compliance wells		
W-818-08	VOCs, HE compounds, nitrates	Semi-annually
W-818-09	VOCs, HE compounds, nitrates	Semi-annually
W-823-03	VOCs, HE compounds	Semi-Annually
	Nitrates	Annually
W-6G	VOCs, HE compounds	Semi-annually
	Nitrates	Annually

[a] U.S. EPA analytical methods:
VOCs: 601.
HE: 8330.
Nitrates: 353.2.

Table 7. Removal action ground water monitoring program for the Tps wells.

Well	Analyte[a]	Sample frequency
Tps wells		
W-35C-05	VOCs, HE compounds	Quarterly
W-4AS	VOCs, HE compounds	Semi-Annually
W-6BD	VOCs, HE compounds	Semi-Annually
W-6BS	VOCs, HE compounds	Annually
W-6CS	VOCs, HE compounds	Annually
W-6I	VOCs, HE compounds	Annually
W-808-01	VOCs, HE compounds	Annually
W-809-01	VOCs, HE compounds	Annually
W-814-01	VOCs, HE compounds	Annually
W-814-03	VOCs, HE compounds	Annually
W-815-01	VOCs, HE compounds	Annually
W-815-03	VOCs, HE compounds	Annually
W-815-05	VOCs, HE compounds	Annually
W-817-03A	VOCs, Nitrates, HE compounds	Quarterly
W-823-01	VOCs, HE compounds	Annually

* Alluvial aquifer wells.

[a] U.S. EPA analytical methods:
HE: 8330.
VOCs: 601.
Nitrates: 353.2.

Table 8. Removal action reporting requirements for the Building 815 OU.

Report	Elements	Deadline
RPM Meeting Summary	• Compliance issues and corrective actions, if any • Facility status update • Work performed • Work anticipated • As needed, may include the following: – Performance data – Proposed remediation plan changes – Progress report – Identification of actual or potential problems	Variable
Quarterly	• Compliance issues and corrective actions, if any • Ground water monitoring: – Water-level elevation data – Potentiometric surface elevation maps – Sampling results – Contaminant isoconcentration maps • Ground water extraction and treatment systems: – Operations summary – Modifications or upgrades – Flow rate and volume summary – Influent/effluent sampling results – Contaminant mass removal estimate – Receiving water monitoring results • The final report for each year contains tabular summaries of data obtained during the previous year	60 days following the end of each quarter
CERCLA 5-Year Review	• Status of remedial objectives • Areas of non-compliance • Recommendations • Statement of protectiveness	5 years after mitigating ground water extraction and treatment

Table 9. Preliminary removal action schedule for the Building 815 OU.

Task	Completion date
Submit Draft Building 815 OU EE/CA to regulators[a]	July 1, 1997
Begin additional characterization work	October 1, 1997
Proposed Draft Final Building 815 OU EE/CA[a]	November 18, 1997
Building 815 Final EE/CA[a]	December 18, 1997
Public Workshop[a]	March 4, 1998
Building 815 OU Draft Action Memorandum[a]	May 1, 1998
Building 815 Draft Final Action Memorandum[a]	July 9, 1998
Building 815 Final Action Memorandum[a]	August 17, 1998
Removal Action Design Workplan[a]	November 17, 1998
Begin installation of TF815A and TF815B	January 1999
Site 300 Record of Decision with cleanup goals for the Building 815 OU[a]	December 20, 2000
Site-Wide Contingency Plan with contingency plan for the Building 815 OU	To be determined

[a] Federal Facility Agreement deliverable (1997).

Appendix A

Building 815 TCE Plume Conceptual Contaminant Hydrogeologic Model

Appendix A

Building 815 TCE Plume Conceptual Contaminant Hydrogeologic Model

This Appendix presents a conceptual contaminant hydrogeologic model of the Building 815 TCE plume. This conceptual model is based on an evaluation of all characterization data, including TCE plume concentration trends and natural attenuation mechanisms. Characterization data collected after the SWRI data cut-off date that are relevant to this conceptual model are summarized in Tables A-1 through A-16. This conceptual model will be used as the basis for a numerical flow and transport model that will be developed as part of this removal action.

A.1. Building 815 TCE Plume Trend Analysis

We analyzed Building 815 TCE plume trends using time-series TCE plume maps and single-well TCE concentration data. Figure A-1 presents TCE plume maps from 1992 to 1996. Visual inspection of the time-series TCE plume maps indicate:

- Maximum TCE concentrations have decreased since 1992.
- Interior and outer edge of the plume, as defined by the 5 and 10 ppb contours, have remained essentially unchanged.
- Leading edge of the plume appears to be migrating in a southeast direction.

As part of this evaluation, we statistically analyzed TCE concentration data from all monitor wells within the plume to determine if they exhibited statistically significant increasing or decreasing trends. The results of this analysis are presented in Table A-15 and Figure A-2. The statistical analysis consisted of fitting a linear regression line to data on TCE vs. time from each monitor well to determine whether this line could be distinguished from a zero slope at the 95% confidence level. If the linear regression line exhibited a statistically significant positive slope at the 95% confidence level, the trend was interpreted to be increasing. Similarly, if the regression line had a statistically significant negative slope, the trend was interpreted to be decreasing.

TCE concentration data for 9 of the 20 wells analyzed, could not be distinguished from a zero slope. The six wells that exhibited statistically significant decreasing trends are generally located within the plume interior. Based on this statistical analysis, five wells exhibit increasing trends. Two of the increasing-trend wells (W-814-02 and W-815-04) are located upgradient of the Building 815 source area. The increasing trends in these wells probably result from diffusion, which tends to spread dissolved contaminants in all directions. Wells W-6BR, W-6ER, and W-4A, located at or near the leading edge of the plume, also exhibit increasing trends. The increasing trends in these wells suggest that the leading edge of the plume is migrating.

A.2. Natural Attenuation

Natural attenuation, the reduction of contaminant concentration, mass, or mobility through natural processes, is believed to be one of the dominant factors influencing the Building 815 TCE plume. These natural processes include:

- Dilution (through ground water recharge).
- Evapotranspiration (volatilization through soil and plants).
- Hydrodynamic dispersion (through advection and diffusion).
- Biodegradation (biological processes that break down chemicals into other constituents).
- Sorption to the aquifer's solid matrix (primarily organic carbon and clay).

Dilution and hydrodynamic dispersion result in lower concentrations by distributing contaminant mass into a larger volume of water. Sorption and evapotranspiration transfer mass from ground water to other media (onto solids and into the air, respectively). Biodegradation and chemical degradation reduce contaminant concentrations and mass by breaking down certain chemicals into other chemicals.

Hydrodynamic dispersion is an irreversible process that encompasses both molecular diffusion and mechanical dispersion. Molecular diffusion is the process by which dissolved contaminants spread out in three dimensions from areas of higher concentration to areas of lower concentration. Mechanical dispersion is the spreading of dissolved contaminants around the aquifer's solid matrix, as contaminants move in response to diffusion and/or advection. Both molecular diffusion and mechanical dispersion result in contaminant dilution, but not mass removal.

VOCs, including TCE, can be chemically degraded by biologically mediated processes, referred to as biodegradation or intrinsic biotransformation. Biodegradation generally involves the chemical transformation of compounds by micro-organisms to satisfy nutritional or energy requirements. Chlorinated solvents that are biodegraded by anaerobic micro-organisms through co-metabolic reductive dehalogenation reactions include: carbon tetrachloride, tetrachloroethylene (PCE), TCE, and 1,1,1-trichloroethane (1,1,1-TCA) (McCarty, 1994). In general, these reactions occur under E_h conditions sufficiently low to exclude dissolved oxygen and in some cases NO_3^- (McNab and Narasimhan, 1994).

Sorption is one of the most significant processes controlling the mobility of contaminants in the subsurface (Piwoni and Keeley, 1990). Sorption can be defined as the interaction of a contaminant with the aquifer's solid matrix. Several physical and chemical characteristics of the contaminant and the aquifer material influence the tendency of a particular contaminant to adhere (or partition) to the solid phase, including aqueous solubility, polar/ionic character, octanol/water partition coefficient, acid/base chemistry, and oxidation/reduction chemistry. TCE is an uncharged, non-polar compound that has a low aqueous solubility and a high octanol/water partition coefficient. The main characteristics of the aquifer's solid matrix that influence TCE sorption are mineralogy (especially clay type and content), organic carbon, surface charge, and surface area. The aquifer's solid matrix generally consists of varying amounts of sand, silt, clay, and natural organic carbon. Fine-grained sediments exhibit higher sorption capacity than coarse sediments because they generally contain higher organic carbon and clay.

A.2.1. Natural Attenuation Data

As part of our evaluation of natural attenuation mechanisms, we considered data on ground water chemistry and aquifer physical property. The ground water chemistry data that we considered included:

- Dissolved oxygen concentrations.
- Oxidation state of dissolved nitrogenous compounds.
- Presence of TCE degradation products, such as 1,2-DCE or vinyl chloride.

These data were evaluated to determine whether subsurface conditions are favorable for TCE biodegradation. We also collected 12 core samples from the W-6J borehole for physical property measurements, including:

- Porosity.
- Bulk density.
- Particle size distribution.
- Total organic carbon (TOC) content.
- Clay type and content.
- Laboratory-measured K_d.

The main objective of these physical property measurements was to evaluate the sorption characteristics of the $Tnbs_2$ aquifer's solid matrix. Samples were submitted to contract analytical laboratories for particle size distribution by sieve analysis, TOC analysis, dry bulk density, and porosity. Samples were also submitted to a physical property laboratory at LLNL for clay analysis and K_d measurements. These data are summarized in Tables A-4 through A-6.

A.2.2. Evaluation of Natural Attenuation Data

As presented in Table A-16, we concluded that dispersion, diffusion, and sorption are the dominant natural attenuation mechanisms that could influence transport of the TCE plume. The implications of these natural attenuation mechanisms to our conceptual contaminant hydrogeologic model are discussed in Section A.3.

Contaminant dilution due to ground water recharge events and hydrodynamic dispersion are important attenuation mechanisms that are common to all dissolved contaminant plumes (Vance, 1997). The importance of these mechanisms during different stages in the life cycle of the Building 815 TCE plume is discussed in Section A.3.

Reduction in TCE mobility due to sorption to the $Tnbs_2$ aquifer's solid matrix was evaluated using physical property data, including laboratory-measured K_d, bulk density, porosity, TOC content, and clay analysis. As presented in Appendix D, we estimated a TCE retardation factor of 4 for the $Tnbs_2$ aquifer, based on these physical property data. This factor is relatively high for a sandstone aquifer with a low organic carbon content (0.06 – 0.17%). We interpret this high retardation factor to be related to the presence of smectite clay at an average of 2% by weight.

Biologically mediated processes were essentially ruled out because data on $Tnbs_2$ ground water chemistry indicate unfavorable subsurface conditions for TCE biodegradation. This interpretation is based on the presence of relatively high dissolved oxygen levels (1.0 – 7.6 mg/L) and the absence of detectable concentrations of TCE degradation products, such as 1,2-DCE or vinyl chloride. The absence of detectable concentrations of nitrite (NO_2^-, the reduced form of NO_3^-) also supports this interpretation, indicating that nitrate is not being used as an electron donor in any biologically mediated process of TCE degradation (McNab and Narasimhan, 1994; McCarty, 1994).

A.3. Conceptual Contaminant Hydrogeologic Model

The conceptual contaminant hydrogeologic model for the Building 815 TCE plume is based on the integration of all available characterization data. This conceptual model provides the basis for numerical flow and transport modeling of this plume.

TCE releases at Building 815, in conjunction with steam plant waste water discharges to a nearby dry well, provided a TCE mobilization mechanism and created a saturated pathway in the vadose zone for TCE to migrate downward into the $Tnbs_2$ aquifer. Former water-supply well 6, located near the southern Site 300 boundary, was in use from 1960 – 1980 and is believed to have influenced ground water flow and TCE transport in the $Tnbs_2$ aquifer due to:

- Increased magnitude of the hydraulic gradient and corresponding increase in ground water velocity.
- Preferential ground water flow in the high conductivity portions of the $Tnbs_2$ aquifer.
- Changes in local hydraulic gradient direction in the vicinity of well 6.

As a result of these hydraulic changes in subsurface conditions, TCE plume migration was:

- Dominated by advection and longitudinal dispersion.
- TCE sorption was limited as a result of high ground water velocity and TCE transport in the high conductivity, less sorptive, portions of the $Tnbs_2$ aquifer.

After well 6 pumping and Building 815 activities ceased in 1980, the subsurface began returning to natural hydraulic conditions as:

- TCE releases were discontinued.
- Volume of wastewater discharges was reduced.
- Hydraulic gradient and the ground water velocity in the $Tnbs_2$ aquifer decreased.

As the subsurface returned to natural hydraulic conditions, the plume began to stabilize as:

- TCE plume migration rate decreased due to lower ground water velocity.
- Sorption became an important attenuation mechanism.
- Gradient direction changes created a larger plume interface for dispersion.
- Vertical hydraulic gradients were re-established.

Single-well TCE concentration trends and time-series TCE isoconcentration contour maps indicate that the leading edge of the plume appears to be migrating, while concentrations in other parts of the plume are generally decreasing or unchanged. These trends suggest that advective flow of ground water dominates over natural attenuation mechanisms at the plume's leading edge. As shown in Figure A-2, the ground water gradient direction near the plume's leading edge, is east to southeast. Additionally, an evaluation of hydraulic heads suggests that ground water flow is influenced by an upward hydraulic gradient in this area. In response to this upward gradient, TCE could potentially migrate from the $Tnbs_2$ aquifer into the overlying Quaternary alluvial aquifer. As part of this removal action, we will further evaluate the influence of upward gradients on TCE plume migration using a ground water flow and transport model.

References

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Table A-1. Soil analyses (mg/kg) for volatile organic compounds (VOCs) at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

VOCs in Soil/Rock from Boreholes,
HE Process Area, Building 815,
Site 300
March 7, 1997
gemini2

s3vocSOL.07mar97
s3vocSOR.07mar97

Table A-1. Soil analyses (mg/kg) for volatile organic compounds (VOCs) at the HE Process

Location Date	Lab	Note	Val.	Depth (ft)	1,1-DCE	cis-1,2-DCE	trans-1,2-DCE	Total 1,2-DCE	TCE	PCE	1,1-DCA
HE Process Area Study Area											
W-6H											
03-jun-94	CS	a	V	0.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	14.2	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	16.3	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	27.3	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	27.7	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	28.9	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	34.1	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	38.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	45.8	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	49.4	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
08-jun-94	CS	a	V	60.4	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
08-jun-94	GT	a	V	60.4	<0.005 U	-	-	<0.005 U	<0.005 U	<0.005 U	<0.005 U
14-jun-94	CS	ah	V	71.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
14-jun-94	CS	ah	V	71.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
14-jun-94	CS	a	V	78.9	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
14-jun-94	CS	a	V	82.8	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
15-jun-94	CS	a	V	98.2	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
15-jun-94	CS	a	V	110.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
W-818-11											
05-sep-96	CS	a	V	150.7	<0.0005 U	<0.0005 U	<0.0005 U	-	<0.0005 U	<0.0005 U	<0.0005 U
05-sep-96	CS	a	V	160.7	<0.0005 U	<0.0005 U	<0.0005 U	-	<0.0005 U	<0.0005 U	<0.0005 U
05-sep-96	CS	a	V	170.5	<0.0005 U	<0.0005 U	<0.0005 U	-	<0.0005 U	<0.0005 U	<0.0005 U

Area, Building 815, Site 300. Results recorded by March 6, 1997.

1,2-DCA	1,1,1-TCA	Chloro-form	Freon 11	Freon 113	Methylene chloride	Location Date
					HE Process Area Study Area	
						W-6H
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	03-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	08-jun-94
<0.005 U	<0.005 U	<0.005 U	<0.005 U	-	<0.005 U	08-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	15-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	15-jun-94
						W-818-11
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	0.0012 B	05-sep-96
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	0.00082 B	05-sep-96
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	0.00089 B	05-sep-96

See following page for notes

Table A-1. Soil analyses (mg/kg) for volatile organic compounds (VOCs) at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Notes:

-	Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample collected during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
m	Confirmation sample
n	Sample analyzed after standard holding time
o	Sample comprised of partial composite
p	Alpha spectroscopy analysis of uranium isotopes
q	Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA
GT	Groundwater Technology Environmental Labs, Concord, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Table A-2. Soil analyses for HE compounds (HMX, RDX, and TNT) at the HE Process Area, Building 815, Site 300. Units are in mg/kg. Results recorded by March 4, 1997.

HMX Compounds in Soil/Rock from Boreholes
HE Process Area, Building 815,
Site 300
March 6, 1997
gemini1

s3hmxso.06mar97

Table A-2. Soil analyses for HE compounds (HMX, RDX, and TNT) at the HE Process Area, Building 815, Site 300. Units are in mg/kg. Results recorded by March 4, 1997.

Location Date	Lab	Val. Note	Depth (ft)	HMX	RDX	TNT
HE Process Area Study Area						
W-6H						
03-jun-94	CS a	V	0.0	<0.2 U	<0.15 U	<0.1 U
08-jun-94	MS a	N	0.0	0.05	<0.02 U	<0.02 U
06-jun-94	CS a	V	14.7	0.85	<0.15 U	<0.1 U
06-jun-94	CS a	V	15.4	<0.2 U	<0.1 U	<0.1 U
06-jun-94	CS a	V	28.0	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS ah	V	33.3	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS ah	V	33.3	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS a	V	38.4	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS a	V	50.7	<0.2 U	<0.15 U	<0.1 U
08-jun-94	CS a	V	61.0	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS ah	V	74.7	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS ah	V	74.7	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS a	V	77.0	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS a	V	82.3	<0.2 U	<0.15 U	<0.1 U
15-jun-94	CS a	V	98.5	<0.2 U	<0.15 U	<0.1 U
15-jun-94	CS a	V	110.4	<0.2 U	<0.15 U	<0.1 U
W-818-11						
05-sep-96	CS a	V	150.7	<0.2 U	<0.15 U	-
05-sep-96	CS a	V	160.7	<0.2 U	<0.15 U	-
05-sep-96	CS a	V	170.5	<0.2 U	<0.15 U	-

See following page for notes

Table A-2. Soil analyses for HE compounds (HMX, RDX, and TNT) at the HE Process Area, Building 815, Site 300. Units are in mg/kg. Results recorded by March 4, 1997.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample collected during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
m	Confirmation sample
n	Sample analyzed after standard holding time
o	Sample comprised of partial composite
p	Alpha spectroscopy analysis of uranium isotopes
q	Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA
MS	C & MS-Gas Chromatography, LLNL, Livermore, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Table A-3. TTLC analyses (mg/kg) for metals in soil at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Metals in Soil from Boreholes,
HE Process Area, Building 815,
Site 300
March 7, 1997
gemini2

s3metttlc.soL.07mar97
s3metttlc.soR.07mar97

Table A-3. TTLC analyses (mg/kg) for metals in soil at the HE Process Area, Building 815,

Location Date	Lab	Note	Val.	Depth (ft)	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt
HE Process Area Study Area											
W-6H											
03-jun-94	CS	a	V	0.0	<1 U	<0.5 U	160	0.51	<1 U	17	10
03-jun-94	CS	ah	V	0.0	–	–	–	–	<0.1 U	–	–
06-jun-94	CS	ah	V	5.0	<1 U	1.3	64	0.64	<1 U	18	9.1
06-jun-94	CS	ah	V	5.0	<1 U	<0.5 U	100	<0.5 U	<1 U	10	7.6
06-jun-94	CS	ah	V	5.0	–	–	–	–	<0.1 U	–	–
06-jun-94	CS	ah	V	5.0	–	–	–	–	<0.1 U	–	–

Site 300. Results recorded by March 6, 1997.

Copper	Iron	Lead	Mercury	Nickel	Selenium	Silver	Zinc	Location Date
							HE Process Area Study Area	
								W-6H
17	-	<10 U	<0.05 U	20	<0.5 U	<2.5 U	36	03-jun-94
-	-	-	-	-	-	-	-	03-jun-94
26	-	<10 U	<0.05 U	19	<0.5 U	<2.5 U	47	06-jun-94
14	-	<10 U	<0.05 U	13	<0.5 U	<2.5 U	27	06-jun-94
-	-	-	-	-	-	-	-	06-jun-94
-	-	-	-	-	-	-	-	06-jun-94

See following page for notes

Table A-3. TTLC analyses (mg/kg) for metals in soil at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Notes:

\- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample collected during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
m	Confirmation sample
n	Sample analyzed after standard holding time
o	Sample comprised of partial composite
p	Alpha spectroscopy analysis of uranium isotopes
q	Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Table A-4. Physical properties data in rock at the HE Process Area, Building 815, Site 300. Results recorded by April 1, 1997.

Physical Properties Data
from Boreholes
HE Process Area, Building 815,
Site 300
April 7, 1997
gemini1

PhyspropsL.07apr97.props
PhyspropsR.07apr97.props

Table A-4. Physical properties data in rock at the HE Process Area, Building 815, Site 300.

Location Date	Lab	Val. Note	Depth (ft)	Bulk Density (g/cm3)	Wet Bulk Density (g/cm3)	Total Organic Carbon(TOC)	Hydraulic Conductivity (cm/sec)
HE Process Area Study Area							
W-6J							
01-may-96	FG a	N	140.0	-	-	-	-
01-may-96	FG a	N	140.3	-	-	<0.1	-
01-may-96	FG ah	N	141.5	-	-	-	-
01-may-96	FG ah	N	141.8	-	-	0.12	-
01-may-96	FG a	N	143.5	-	-	-	-
01-may-96	FG a	N	143.8	-	-	0.12	-
01-may-96	FG a	N	149.6	-	-	-	-
01-may-96	FG a	N	149.9	-	-	0.17	-
01-may-96	FG a	N	157.8	-	-	-	-
01-may-96	FG a	N	158.5	-	-	<0.1	-
01-may-96	FG a	N	165.8	-	-	-	-
01-may-96	FG a	N	166.3	-	-	0.11	-
11-jun-96	DS a	N	167.5	1.61	1.72	-	5.7e-07
01-may-96	FG a	N	170.4	-	-	-	-
01-may-96	FG a	N	170.7	-	-	<0.1	-
01-may-96	FG a	N	175.1	-	-	-	-
01-may-96	FG a	N	175.4	-	-	0.1	-
11-jun-96	DS a	N	176.0	1.66	1.78	-	6e-08
01-may-96	FG a	N	181.0	-	-	-	-
01-may-96	FG a	N	181.2	-	-	0.1	-
11-jun-96	DS a	N	182.1	2.21	2.34	-	1e-08
01-may-96	FG a	N	185.4	-	-	-	-
01-may-96	FG a	N	185.7	-	-	<0.1	-
11-jun-96	DS a	N	188.4	1.67	1.97	-	8.7e-09
01-may-96	FG a	N	190.3	-	-	-	-
01-may-96	FG a	N	190.6	-	-	0.12	-
01-may-96	FG a	N	195.7	-	-	-	-
01-may-96	FG a	N	196.0	-	-	0.25	-

Results recorded by April 1, 1997.

Porosity (Percent)	Kd with TCE	Clay (Percent)	Sand (Percent)	Silt (Percent)	Location Date
					HE Process Area Study Area
					W-6J
–	–	2.4	92.4	5.2	01-may-96
–	–	–	–	–	01-may-96
–	–	2.4	80.4	17.2	01-may-96
–	–	–	–	–	01-may-96
–	–	2.4	74.4	23.2	01-may-96
–	–	–	–	–	01-may-96
–	–	4.4	61.4	34.2	01-may-96
–	0.81	–	–	–	01-may-96
–	–	2.4	86.4	11.2	01-may-96
–	–	–	–	–	01-may-96
–	–	2.4	78.8	18.8	01-may-96
–	–	–	–	–	01-may-96
39.1	–	–	–	–	11-jun-96
–	–	2.4	90.6	7	01-may-96
–	–	–	–	–	01-may-96
–	–	2.4	92.4	5.2	01-may-96
–	0.54	–	–	–	01-may-96
37.4	–	–	–	–	11-jun-96
–	–	2.4	96	1.6	01-may-96
–	–	–	–	–	01-may-96
16.6	–	–	–	–	11-jun-96
–	–	2.4	92.4	5.2	01-may-96
–	–	–	–	–	01-may-96
36.9	–	–	–	–	11-jun-96
–	–	3.2	82	14.8	01-may-96
–	–	–	–	–	01-may-96
–	–	14.8	54.6	30.6	01-may-96
–	–	–	–	–	01-may-96

See following page for notes

Table A-4. Physical properties data in rock at the HE Process Area, Building 815, Site 300. Results recorded by April 1, 1997.

Notes:

\- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample collected during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
m Confirmation sample
n Sample analyzed after standard holding time
o Sample comprised of partial composite
p Alpha spectroscopy analysis of uranium isotopes
q Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

DS Daniel B. Stevens & Associates
FG Fruit Growers Laboratory, Inc., Santa Paula, CA

Validation Codes:

V Validated
N Not validated (default value)
U Undeclared
H Historical comparison only

Table A-5. Sieve analyses in rock from boreholes at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Sieve Analyses from Boreholes
HE Process Area, Building 815,
Site 300
March 10, 1997
gemini2

PhyspropsL.10mar97.sieve
PhyspropsR.10mar97.sieve

Table A-5. Sieve analyses in rock from boreholes at the HE Process area, Building 815, Site 300.

Location Date	Lab	Val. Note	Depth (ft)	US #4 (Percent Finer)	US #10 (Percent Finer)	US #14 (Percent Finer)	US #35 (Percent Finer)
HE Process Area Study Area							
W-6J							
01-may-96	FG a	N	175.1	100	100	100	100
01-may-96	FG a	N	185.4	100	100	100	99.96

Results recorded by March 6, 1997.

US #60 (Percent Finer)	US #140 (Percent Finer)	US #200 (Percent Finer)	US #325 (Percent Finer)	Location Date
				HE Process Area Study Area
				W-6J
85	6.1	3	1	01-may-96
64.25	6.56	2.66	0.66	01-may-96

See following page for notes

Table A-5. Sieve analyses in rock from boreholes at the HE Process area, Building 815, Site 300. Results recorded by March 6, 1997.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample collected during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
m	Confirmation sample
n	Sample analyzed after standard holding time
o	Sample comprised of partial composite
p	Alpha spectroscopy analysis of uranium isotopes
q	Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

FG	Fruit Growers Laboratory, Inc., Santa Paula, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

Table A-6. Clay minerology in rock at the HE Process Area, Building 815, Site 300.

Clay Minerology in Rock
from Boreholes
HE Process Area, Building 815,
Site 300

Interdepartmental letterhead

Mail Code: L-219
Extension: 3-2001
FAX: 2-0208
Electronic Mail: viani@llnl.gov

June 7, 1996

To: Vic Madrid

From: Brian Viani

Subject: Clay mineral analysis of HEPA samples from Neroly Formation

See attached report.

University of California
Lawrence Livermore National Laboratory

Xray Diffraction Analysis of Clay Fractions from Neroly Formation

GET Clay Mineralogy Lab

Six samples were received for clay mineral analysis.

Methods

Subsamples were lightly ground, air dried, and used for XRD analysis of the bulk material and for extracting the clay (< 2 μm) fraction. The clay was separated from the bulk sample as follows:

1. 1 or 2 g of air dried ground sample were placed in 50 mL centrifuge tubes with 40 mL of DI H_2O.
2. The mixture was agitated ultrasonnically for 30 s to 1 min using a probe type sonnifier.
3. The samples were centrifuged at 500 rpm for 9 minutes to sediment the > 2 μm fraction.
4. The supernatant containing the < 2 μm fraction was collected.
5. Steps 2-4 were repeated a total of 4 times to extract all the clay in each sample.

The clay fraction was prepared for XRD analysis as follows:

1. The supernatants containing the clay fraction were made approximately 1N in $MgCl_2$ to saturate exchange sites with Mg and to flocculate the suspension.
2. The mixture was centrifuged and the clear supernatant discarded.
3. The clay sediment was washed once with 20 mL of DI H_2O by centrifugation and decantation of the supernatant to remove excess $MgCl_2$.
4. The clay sediment was suspended in a small amount of DI H_2O (< 1 mL) and placed on a glass slide sample holder and air dried.
5. After xraying the air dried sample, the samples were placed in a chamber over ethylene glycol (EG) and equilibrated under vacuum for 2-12 hrs and xrayed again.

Bulk samples were prepared for XRD analysis by grinding in an agate mortar and pestle, and placing in a side loading well-type sample holder.

Xray Diffraction Analysis

The samples were xrayed using Cu radiation. The diffracted beam was detected using a SiLi solid stated detector. Clay samples were scanned from 2 to 32 degrees 2-Θ; ground bulk samples were scanned from 2 to 72 degrees 2-Θ. The as collected xray scans were smoothed to reduce noise, and peak positions picked using the data analysis software or visually.

Results and Discussion

Sample	Identification	Clay XRD	Bulk XRD	Clay (< 2 μm) Mineralogy	Bulk Mineralogy
1	W-6J-141.3f	√	√	Smectite with minor feldspar	Feldspar and smectite with minor mafic minerals
2	W-6J-142.3f	√		Smectite with minor feldspar	
3	W-6J-150.4f	√	√	Smectite with minor feldspar	Feldspar and smectite with minor mafic minerals
4	W-6J-167.0f	√		Smectite with minor feldspar	
5	W-6J-171.3f	√		Smectite with minor feldspar	
6	W-6J-186.4f	√	√	Smectite with minor feldspar	Feldspar and smectite with minor mafic minerals

With the exception of sample 3 (W-6J-150.4), the samples were very similar in appearance, being relatively friable sandstone. Sample 3 appeared to be finer grained, possibly a silt stone or clay. However, the mineralogical differences between the samples were minor. Based on the mass of clay extracted for XRD analysis, I calculated the percent clay in each sample. Note that no chemical dispersants (e.g., Na hexametaphosphate), or energetic grinding was used (only the sonnification) to disperse the samples. Hence these numbers might be lower than clay contents measured using a more vigorous dispersing technique.

Clay Mineralogy

The XRD analysis of the clay fractions indicated that all 6 samples contained essentially only smectite and feldspar (plagioclase). The feldspar component is minor (probably less than 10%) and varies somewhat from sample to sample. No quartz was detected in any of the clay samples. (diffraction patterns attached).

Bulk Mineralogy

XRD analysis of three of the bulk samples indicated that feldspar (Na, Ca) is the major component. Minor amounts of an amphibole is also present. The deepest sample, W-6J-186.4f, also had a trace quantity of quartz. (Diffraction patterns attached).

Sample	Identification	Clay Content, %
1	W-6J-141.3f	1.6
2	W-6J-142.3f	2.3
3	W-6J-150.4f	6.0
4	W-6J-167.0f	2.1
5	W-6J-171.3f	2.2
6	W-6J-186.4f	2.1

Table A-7. Ground water analyses for volatile organic compounds (VOCs) at the HE Process Area, Building 815, Site 300. Units are ug/L. Results recorded by March 6, 1997.

VOCs in Ground Water
HE Process Area, Building 815,
Site 300
March 7, 1997
gemini2

s300vocL.07mar97
s300vocR.07mar97

Table A-7. Ground water analyses for volatile organic compounds (VOCs) at the HE Process Area, Building

Location Date	Lab	Note	Val.	1,1-DCE	cis-1,2-DCE	trans-1,2-DCE	Total 1,2-DCE	TCE	PCE	1,1-DCA
HE Process Area Study Area										
W-6H										
07-mar-95	CS	a	V	<1 ULO	-	-	<1 U	<0.5 ULO	<1 U	<1 U
01-jun-95	CS	a	V	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
20-jul-95	CS	a	V	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
22-nov-95	CS	a	V	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
29-jan-96	CS	a	V	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
14-jun-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	<0.5 U	<0.5 U	<0.5 U
13-aug-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	<0.5 U	<0.5 U	<0.5 U
W-6I										
07-mar-95	CS	a	V	<1 U	-	-	<1 ULO	<0.5 ULO	<1 U	<1 U
14-jun-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	<0.5 U	<0.5 U	<0.5 U
W-6J										
28-jun-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	<0.5 U	<0.5 U	<0.5 U
13-aug-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	<0.5 U	<0.5 U	<0.5 U
W-6K										
26-jun-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	14	<0.5 U	<0.5 U
04-sep-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	15	<0.5 U	<0.5 U
12-dec-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	13	<0.5 U	<0.5 U
W-6L										
18-jun-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	14	<0.5 U	<0.5 U
30-aug-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	15	<0.5 U	<0.5 U
12-dec-96	CS	a	V	<0.5 U	<0.5 U	<0.5 U	-	18	<0.5 U	<0.5 U
W-818-11										
27-dec-96	CS	a	V	<1 U	-	-	<1 U	55 DO	<1 U	<1 U

815, Site 300. Units are ug/L. Results recorded by March 6, 1997.

1,2-DCA	1,1,1-TCA	Chloroform	Freon 11	Freon 113	Methylene chloride	Location Date
						HE Process Area Study Area
						W-6H
<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	07-mar-95
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	01-jun-95
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	20-jul-95
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	22-nov-95
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	29-jan-96
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	14-jun-96
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	13-aug-96
						W-6I
<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	07-mar-95
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	14-jun-96
						W-6J
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	28-jun-96
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	13-aug-96
						W-6K
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	26-jun-96
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	04-sep-96
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	12-dec-96
						W-6L
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	18-jun-96
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	30-aug-96
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	12-dec-96
						W-818-11
<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	27-dec-96

See following page for notes

Table A-7. Ground water analyses for volatile organic compounds (VOCs) at the HE Process Area, Building 815, Site 300. Units are ug/L. Results recorded by March 6, 1997.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample collected during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
m Confirmation sample
n Sample analyzed after standard holding time
o Sample comprised of partial composite
p Alpha spectroscopy analysis of uranium isotopes
q Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V Validated
N Not validated (default value)
U Undeclared
H Historical comparison only

CLP flags: (follow result)

B Analyte detected in method blank
C Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D Analysis performed at a secondary dilution or concentration (i.e., vapor)
E Concentration exceeds calibration range
F Analyte detected in field blank
H Sample analyzed outside of the holding time; sample results should be rejected
J Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L Spike accuracy not within control limits
O Duplicate spike precision not within control limits
P Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Table A-8. Ground water analyses for HE compounds (HMX, RDX, and TNT) at the HE Process Area, Building 815, Site 300. Units are in ug/L. Results recorded by March 6, 1997.

HE Compounds in Water
HE Process Area, Building 815,
Site 300
March 7, 1997
gemini2

s3hmx.07mar97

Table A-8. Ground water analyses for HE compounds (HMX, RDX, and TNT) at the HE Process Area, Building 815, Site 300. Units are in ug/L. Results recorded by March 6, 1997.

Location Date	Lab	Note	Val.	HMX	RDX	TNT
HE Process Area Study Area						
W-6H						
07-mar-95	CS	a	V	<5 U	<5 U	<5 U
01-jun-95	CS	a	V	<5 U	<5 U	-
20-jul-95	CS	a	V	<5 U	<5 U	-
22-nov-95	CS	a	V	<5 U	<5 U	<5 U
29-jan-96	CS	a	V	<5 U	<5 U	-
14-jun-96	CS	a	V	<5 U	<5 U	-
13-aug-96	CS	a	V	<5 U	<5 U	-
W-6I						
07-mar-95	CS	a	V	<5 U	<5 U	<5 U
14-jun-96	CS	a	V	<5 U	<5 U	-
W-6J						
28-jun-96	CS	a	V	<5 U	<5 U	-
13-aug-96	CS	a	V	<5 U	<5 U	-
W-6K						
26-jun-96	CS	a	V	<5 U	<5 U	-
04-sep-96	CS	a	V	<5 U	<5 U	-
12-dec-96	CS	a	V	<5 U	<5 U	-
W-6L						
18-jun-96	CS	a	V	<5 U	<5 U	-
30-aug-96	CS	a	V	<5 U	<5 U	-
12-dec-96	CS	a	V	<5 U	<5 U	-
W-818-11						
27-dec-96	CS	a	V	<5 U	<5 U	-

See following page for notes

Table A-8. Ground water analyses for HE compounds (HMX, RDX, and TNT) at the HE Process Area, Building 815, Site 300. Units are in ug/L. Results recorded by March 6, 1997.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample collected during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
m Confirmation sample
n Sample analyzed after standard holding time
o Sample comprised of partial composite
p Alpha spectroscopy analysis of uranium isotopes
q Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V Validated
N Not validated (default value)
U Undeclared
H Historical comparison only

CLP flags: (follow result)

B Analyte detected in method blank
C Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D Analysis performed at a secondary dilution or concentration (i.e., vapor)
E Concentration exceeds calibration range
F Analyte detected in field blank
H Sample analyzed outside of the holding time; sample results should be rejected
J Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L Spike accuracy not within control limits
O Duplicate spike precision not within control limits
P Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Table A-9. Ground water analyses (mg/L) for metals at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Ground Water Metals Report
HE Process Area, Building 815,
Site 300
March 7, 1997
gemini2

s3metsL.07mar97
s3metsR.07mar97

Table A-9. Ground water analyses (mg/L) for metals at the HE Process Area, Building 815, Site 300.

Location Date	Lab	Note	Val.	Antimony	Arsenic	Barium	Beryllium	Cadmium	Total chromium	Copper	Iron
HE Process Area Study Area											
W-6H											
07-mar-95	CS	a	V	-	0.014	<0.025 U	-	<0.0005 U	<0.01 U	-	-
07-mar-95	CS	a	V	-	-	-	-	-	-	<0.05 U	<0.1 U
W-6I											
07-mar-95	CS	a	V	-	0.0057	0.084	-	<0.0005 U	<0.01 U	-	-
07-mar-95	CS	a	V	-	-	-	-	-	-	<0.05 U	<0.1 U
W-6J											
28-jun-96	CS	a	V	-	0.02	<0.025 U	-	<0.0005 U	0.002	-	-
28-jun-96	CS	a	V	-	-	-	-	-	-	<0.05 U	<0.1 U
W-6K											
26-jun-96	CS	a	V	-	0.033	<0.025 U	-	<0.0005 U	<0.001 U	-	-
26-jun-96	CS	a	V	-	-	-	-	-	-	<0.05 U	<0.1 U
04-sep-96	CS	a	V	-	-	-	-	-	-	<0.05 U	0.17
12-dec-96	CS	a	V	-	-	-	-	-	-	<0.05 U	<0.1 U
W-6L											
18-jun-96	CS	a	V	-	0.043 L	<0.025 U	-	<0.0005 U	<0.001 U	-	-
18-jun-96	CS	a	V	-	-	-	-	-	-	<0.05 U	<0.1 U
W-818-11											
27-dec-96	CS	a	V	-	0.013 L	<0.025 U	-	<0.0005 UL	0.0032	-	-
27-dec-96	CS	a	V	-	-	-	-	-	-	<0.05 U	<0.1 U

Results recorded by March 6, 1997.

Lead	Manganese	Mercury	Nickel	Selenium	Silver	Vanadium	Zinc	Location Date
								HE Process Area Study Area
								W-6H
<0.002 U	-	<0.0002 U	-	<0.002 LOU	<0.001 LOU	-	-	07-mar-95
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	07-mar-95
								W-6I
<0.002 U	-	<0.0002 U	-	0.003 LO	<0.001 LOU	-	-	07-mar-95
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	07-mar-95
								W-6J
<0.002 U	-	<0.0002 U	-	<0.002 ULO	<0.001 U	-	-	28-jun-96
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	28-jun-96
								W-6K
<0.002 ULO	-	<0.0002 U	-	0.015 LO	<0.001 ULO	-	-	26-jun-96
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	26-jun-96
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	04-sep-96
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	12-dec-96
								W-6L
<0.002 U	-	<0.0002 U	-	0.028	<0.001 UL	-	-	18-jun-96
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	18-jun-96
								W-818-11
<0.002 U	-	<0.0002 U	-	0.028 L	<0.001 U	-	-	27-dec-96
-	<0.03 U	-	<0.1 U	-	-	-	<0.05 U	27-dec-96

See following page for notes

Table A-9. Ground water analyses (mg/L) for metals at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Notes:

\- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample collected during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
m	Confirmation sample
n	Sample analyzed after standard holding time
o	Sample comprised of partial composite
p	Alpha spectroscopy analysis of uranium isotopes
q	Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Table A-10. Field ground water measurement (mg/L) of dissolved oxygen at the HE Process Area, Building 815, Site 300.

Field Ground Water Measurement of Dissolved Oxygen
HE Process Area, Building 815,
Site 300

Table A-10. Field measurements (mg/L) of dissolved oxygen in ground water from the Tnbs2 aquifer in the Building 815 OU, Site 300.

Location	Sample Date	Type	Requested Analysis	Description	Concentration	Units
GALLO1	20-May-91	RTN	FIELDMEAS	Dissolved Oxygen	3.3	mg/L
W-4A	20-May-91	RTN	FIELDMEAS	Dissolved Oxygen	2.5	mg/L
W-6BR	17-May-91	RTN	FIELDMEAS	Dissolved Oxygen	1.6	mg/L
W-6CD	14-May-91	RTN	FIELDMEAS	Dissolved Oxygen	1.2	mg/L
W-6ER	13-May-91	RTN	FIELDMEAS	Dissolved Oxygen	1.	mg/L
W-809-02	8-May-91	RTN	FIELDMEAS	Dissolved Oxygen	4.6	mg/L
W-809-03	8-May-91	RTN	FIELDMEAS	Dissolved Oxygen	4.1	mg/L
W-814-02	2-May-91	RTN	FIELDMEAS	Dissolved Oxygen	5.7	mg/L
W-815-04	3-May-91	RTN	FIELDMEAS	Dissolved Oxygen	7.6	mg/L
W-815-06	2-May-91	RTN	FIELDMEAS	Dissolved Oxygen	7.6	mg/L
W-815-07	2-May-91	RTN	FIELDMEAS	Dissolved Oxygen	7.6	mg/L
W-823-02	10-May-91	RTN	FIELDMEAS	Dissolved Oxygen	1.8	mg/L
W-823-03	9-May-91	RTN	FIELDMEAS	Dissolved Oxygen	4.	mg/L
W-827-02	10-May-91	RTN	FIELDMEAS	Dissolved Oxygen	6.	mg/L

*RTN = Routine

** FIELDMEAS= Field Measurement

Table A-11. Ground water analyses for nutrients at the HE Process Area, Building 815, Site 300. Units are mg/L. Results recorded by April 1, 1997.

Nutrients in Ground Water
HE Process Area, Building 815,
Site 300
April 7, 1997
gemini1

s3nutrientsL.07apr97
s3nutrientsR.07apr97

Table A-11. Ground water analyses for nutrients at the HE Process Area, Building 815, Site 300.

Location Date	Lab	Note	Val.	Ammonia Nitrogen (as N)	Nitrate (as N)	Nitrate (as NO3)	Nitrite (as N)
HE Process Area Study Area							
W-6H							
07-mar-95	CS	a	V	-	-	<0.5 U	-
07-mar-95	CS	a	V	0.2	-	-	-
01-jun-95	CS	a	V	0.23	-	0.66	-
20-jul-95	CS	a	V	0.35 LO	-	<0.5 U	-
22-nov-95	CS	a	V	0.22	-	<0.5 LOU	-
29-jan-96	CS	a	V	<0.1 U	-	<0.5 U	-
14-jun-96	CS	a	V	<0.1 LOU	<0.5 U	<0.5 LOU	<2.5 DU
13-aug-96	CS	a	V	0.1	<0.5 U	<0.5 ULO	<5 DU
W-6I							
07-mar-95	CS	a	V	-	-	<0.5 U	-
07-mar-95	CS	a	V	0.2	-	-	-
W-6J							
28-jun-96	CS	a	V	-	<0.5 U	<0.5 U	<5 DU
28-jun-96	CS	a	V	0.71 LO	<0.5 U	<0.5 U	<5 DU
13-aug-96	CS	a	V	0.63	<0.5 U	<0.5 ULO	<5 DU
W-6K							
26-jun-96	CS	a	V	-	<0.5 U	2	<2.5 DULO
26-jun-96	CS	a	V	0.54 LO	<0.5 U	2	<2.5 DU
04-sep-96	CS	a	V	-	<0.5 U	<0.5 U	<5 DU
04-sep-96	CS	a	V	<0.1 U	<0.5 U	<0.5 U	<0.5 U
12-dec-96	CS	a	V	-	<0.5 U	<0.5 U	<0.5 HU
12-dec-96	CS	a	V	0.34	-	-	-
10-feb-97	CS	a	V	-	<0.5 U	<0.5 LOU	<0.5 LOU
10-feb-97	CS	a	V	0.3	<0.5 LOU	<0.5 U	<0.5 U
W-6L							
18-jun-96	CS	a	V	-	0.83	3.7 LO	<2.5 DULO
18-jun-96	CS	a	V	0.22 LO	0.83	3.7 LO	<2.5 DU
30-aug-96	CS	a	V	<0.1 U	1.2	5.5 LO	<2.5 DU
12-dec-96	CS	a	V	<0.1 U	-	-	-
10-feb-97	CS	a	V	<0.5 U	1.1 LO	4.9	<0.5 U
W-818-11							
27-dec-96	CS	a	V	-	13 D	59 D	<0.5 U
27-dec-96	CS	a	V	0.13	13 D	58 D	<0.5 U
14-feb-97	CS	a	V	0.11	15 D	66 D	<0.5 U

Units are mg/L. Results recorded by April 1, 1997.

Nitrite (as NO2)	Total Kjeldahl Nitrogen	Total Phosphorus (as P)	Location Date
			HE Process Area Study Area
			W-6H
<0.5 U	-	-	07-mar-95
-	0.22	-	07-mar-95
<5 U	<0.5 U	-	01-jun-95
<0.5 U	<0.5 U	-	20-jul-95
<0.5 LOU	<0.5 U	-	22-nov-95
<5 DULO	<0.5 U	-	29-jan-96
<2.5 DHUL	<0.5 UO	-	14-jun-96
<5 DULO	0.73 LO	-	13-aug-96
			W-6I
<0.5 U	-	-	07-mar-95
-	0.65	-	07-mar-95
			W-6J
-	-	-	28-jun-96
<5 DHULO	1.1	-	28-jun-96
<5 DULO	0.84 LO	-	13-aug-96
			W-6K
-	-	-	26-jun-96
<2.5 DHUL	<0.5 U	-	26-jun-96
-	-	-	04-sep-96
<0.5 U	1	-	04-sep-96
-	-	-	12-dec-96
-	0.4	-	12-dec-96
-	-	-	10-feb-97
<0.5 U	0.32	-	10-feb-97
			W-6L
-	-	-	18-jun-96
<2.5 DHULO	<0.5 U	-	18-jun-96
<2.5 DHULO	0.86	-	30-aug-96
-	<0.2 U	-	12-dec-96
<0.5 U	<0.2 U	-	10-feb-97
			W-818-11
-	-	-	27-dec-96
<0.5 U	<0.2 LU	-	27-dec-96
<0.5 HU	<0.2 U	-	14-feb-97

See following page for notes

Table A-11. Ground water analyses for nutrients at the HE Process Area, Building 815, Site 300. Units are mg/L. Results recorded by April 7, 1997.

Notes:

\- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample collected during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
m Confirmation sample
n Sample analyzed after standard holding time
o Sample comprised of partial composite
p Alpha spectroscopy analysis of uranium isotopes
q Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V Validated
N Not validated (default value)
U Undeclared
H Historical comparison only

CLP flags: (follow result)

B Analyte detected in method blank
C Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D Analysis performed at a secondary dilution or concentration (i.e., vapor)
E Concentration exceeds calibration range
F Analyte detected in field blank
H Sample analyzed outside of the holding time; sample results should be rejected
J Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L Spike accuracy not within control limits
O Duplicate spike precision not within control limits
P Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Table A-12. Ground water analyses for anions and water quality at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Anions in Ground Water
HE Process Area, Building 815,
Site 300
March 7, 1997
gemini2

s3anionsL.07mar97
s3anionsR.07mar97

Table A-12. Ground water analyses for anions and water quality at the HE Process Area, Building 815,

Location Date	Lab	Note	Val.	Floride (mg/L)	Silica (mg/L)	Nitrate as (NO3) (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
HE Process Area Study Area								
W-6H								
07-mar-95	CS	a	V	0.9	-	<0.5 U	120	150
01-jun-95	CS	a	V	-	-	0.66	-	-
20-jul-95	CS	a	V	-	-	<0.5 U	-	-
22-nov-95	CS	a	V	-	-	<0.5 LOU	-	-
29-jan-96	CS	a	V	-	-	<0.5 U	-	-
14-jun-96	CS	a	V	-	-	<0.5 LOU	-	-
13-aug-96	CS	a	V	-	-	<0.5 ULO	-	-
W-6I								
07-mar-95	CS	a	V	0.56	-	<0.5 U	200 D	140 D
W-6J								
28-jun-96	CS	a	V	-	-	-	-	-
28-jun-96	CS	a	V	-	-	-	-	-
28-jun-96	CS	a	V	0.74 LO	-	<0.5 U	130 R	170 D
28-jun-96	CS	a	V	-	-	<0.5 U	-	-
13-aug-96	CS	a	V	-	-	<0.5 ULO	-	-
W-6K								
26-jun-96	CS	a	V	0.89 LO	-	2	270	210
26-jun-96	CS	a	V	-	-	2	-	-
04-sep-96	CS	a	V	0.81 L	-	<0.5 U	250 DLO	170 D
04-sep-96	CS	a	V	-	-	<0.5 U	-	-
12-dec-96	CS	a	V	0.83 L	-	<0.5 U	180 D	160 D
W-6L								
18-jun-96	CS	a	V	1.2 DLO	-	3.7 LO	210	180
18-jun-96	CS	a	V	-	-	3.7 LO	-	-
30-aug-96	CS	a	V	-	-	5.5 LO	-	-
W-818-11								
27-dec-96	CS	a	V	0.45	-	59 D	230 D	210 D
27-dec-96	CS	a	V	-	-	58 D	-	-

Site 300. Results recorded by March 6, 1997.

Carbonate (mg/L)	Bicar- bonate** (mg/L)	TDS (mg/L)	Spec Cond (umhos/cm)	pH	Location Date
					HE Process Area Study Area
					W-6H
56	200	800	1100	8.9	07-mar-95
-	-	-	-	-	01-jun-95
-	-	-	-	-	20-jul-95
-	-	-	-	-	22-nov-95
-	-	-	-	-	29-jan-96
-	-	-	-	-	14-jun-96
-	-	-	-	-	13-aug-96
					W-6I
<1 U	300	930	1400	8.3	07-mar-95
					W-6J
-	-	-	-	9.6	28-jun-96
-	-	750	-	-	28-jun-96
<1 U	220	750	1100	9.6	28-jun-96
-	-	-	-	-	28-jun-96
-	-	-	-	-	13-aug-96
					W-6K
<1 U	230	860	1200	8.1	26-jun-96
-	-	-	-	-	26-jun-96
<1 U	230	830	1100	8.1	04-sep-96
-	-	-	-	-	04-sep-96
<1 U	230	820	1400	8.1	12-dec-96
					W-6L
<1 U	220	840	1300	8.2	18-jun-96
-	-	-	-	-	18-jun-96
-	-	-	-	-	30-aug-96
					W-818-11
160	<1 U	1000	1700	10	27-dec-96
-	-	-	-	-	27-dec-96

See following page for notes

Table A-12. Ground water analyses for anions and water quality at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Notes:

\- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample collected during hydraulic testing
e Blind sample, sent to lab without well identity
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k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
m Confirmation sample
n Sample analyzed after standard holding time
o Sample comprised of partial composite
p Alpha spectroscopy analysis of uranium isotopes
q Gamma spectroscopy analysis of uranium isotopes

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CLP flags: (follow result)

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E Concentration exceeds calibration range
F Analyte detected in field blank
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O Duplicate spike precision not within control limits
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S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Table A-13. Ground water analyses for cations at the HE Process Area, Building 815, Site 300. Units are mg/L. Results recorded by March 6, 1997.

Cations Report
HE Process Area, Building 815,
Site 300
March 6, 1997
gemini2

s3cationL.07mar97
s3cationR.07mar97

Table A-13. Ground water analyses for cations at the HE Process Area, Building 815, Site 300.

Location Date	Lab	Note	Val.	Sodium	Potassium	Calcium	Magnesium	Iron
HE Process Area Study Area								
W-6H								
07-mar-95	CS	a	V	270	14	2.9	0.7	<0.1 U
W-6I								
07-mar-95	CS	a	V	330	8.3	12	4	<0.1 U
W-6J								
28-jun-96	CS	a	V	270	7.7	5.3	<0.5 U	<0.1 U
W-6K								
26-jun-96	CS	a	V	280	4.5	6.5	1.7	<0.1 U
04-sep-96	CS	a	V	290	4.7	7.6	2	0.17
12-dec-96	CS	a	V	310 RL	5.6	7.3	1.8	<0.1 U
W-6L								
18-jun-96	CS	a	V	270	4.7	7.8	1.4	<0.1 U
W-818-11								
27-dec-96	CS	a	V	320	15	17	3.8	<0.1 U

Units are mg/L. Results recorded by March 6, 1997.

Manganese	Copper	Zinc	Boron	Strontium	Aluminum	Location Date
					HE Process Area Study Area	
						W-6H
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	07-mar-95
						W-6I
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	07-mar-95
						W-6J
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	28-jun-96
						W-6K
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	26-jun-96
<0.03 U	<0.05 U	<0.05 U	-	-	0.37	04-sep-96
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	12-dec-96
						W-6L
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	18-jun-96
						W-818-11
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	27-dec-96

See following page for notes

Table A-13. Ground water analyses for cations at the HE Process Area, Building 815, Site 300. Units are mg/L. Results recorded by March 6, 1997.

Notes:

\- Indicates no analysis performed for this compound

Val. = Validation

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample collected during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
m Confirmation sample
n Sample analyzed after standard holding time
o Sample comprised of partial composite
p Alpha spectroscopy analysis of uranium isotopes
q Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V Validated
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U Undeclared
H Historical comparison only

CLP flags: (follow result)

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C Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D Analysis performed at a secondary dilution or concentration (i.e., vapor)
E Concentration exceeds calibration range
F Analyte detected in field blank
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S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Table A-14. Bailed ground and drilling water analyses (ug/L) for volatile organic compounds at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

VOCs in Bailed Ground Water
HE Process Area, Building 815,
Site 300
March 10, 1997
gemini2

s3vocSOL.10mar97
s3vocSOR.10mar97

Table A-14. Bailed ground and drilling water analyses (ug/L) for volatile organic compounds at the

Location Date	Lab	Val. Note	Depth (ft)	1,1- DCE	cis- 1,2- DCE	trans- 1,2- DCE	Total 1,2- DCE	TCE	PCE	1,1- DCA
HE Process Area Study Area										
W-6H										
07-jun-94	CS a	V	38.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
16-jun-94	CS a	V	122.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
16-jun-94	CS a	V	157.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
27-jun-94	CS a	V	190.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
W-6I										
05-jul-94	CS a	V	38.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
W-6J										
29-may-96	CS a	V	0.0	<0.5 U	<0.5 U	<0.5 U	-	<0.5 U	<0.5 U	<0.5 U
W-6L										
02-apr-96	CS a	V	0.0	<0.5 U	-	-	<0.5 U	15	<0.5 U	<0.5 U
W-818-11										
23-oct-96	CS a	V	0.0	<0.5 U	<0.5 U	<0.5 U	-	4.4	<0.5 U	<0.5 U

HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

1,2-DCA	1,1,1-TCA	Chloroform	Freon 11	Freon 113	Methylene chloride	Location Date
					HE Process Area Study Area	
						W-6H
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	07-jun-94
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	16-jun-94
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	16-jun-94
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	27-jun-94
						W-6I
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	05-jul-94
						W-6J
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	29-may-96
						W-6L
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	02-apr-96
						W-818-11
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	23-oct-96

See following page for notes

Table A-14. Bailed ground and drilling water analyses (ug/L) for volatile organic compounds at the HE Process Area, Building 815, Site 300. Results recorded by March 6, 1997.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample collected during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
m	Confirmation sample
n	Sample analyzed after standard holding time
o	Sample comprised of partial composite
p	Alpha spectroscopy analysis of uranium isotopes
q	Gamma spectroscopy analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

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V	Validated
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CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
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R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

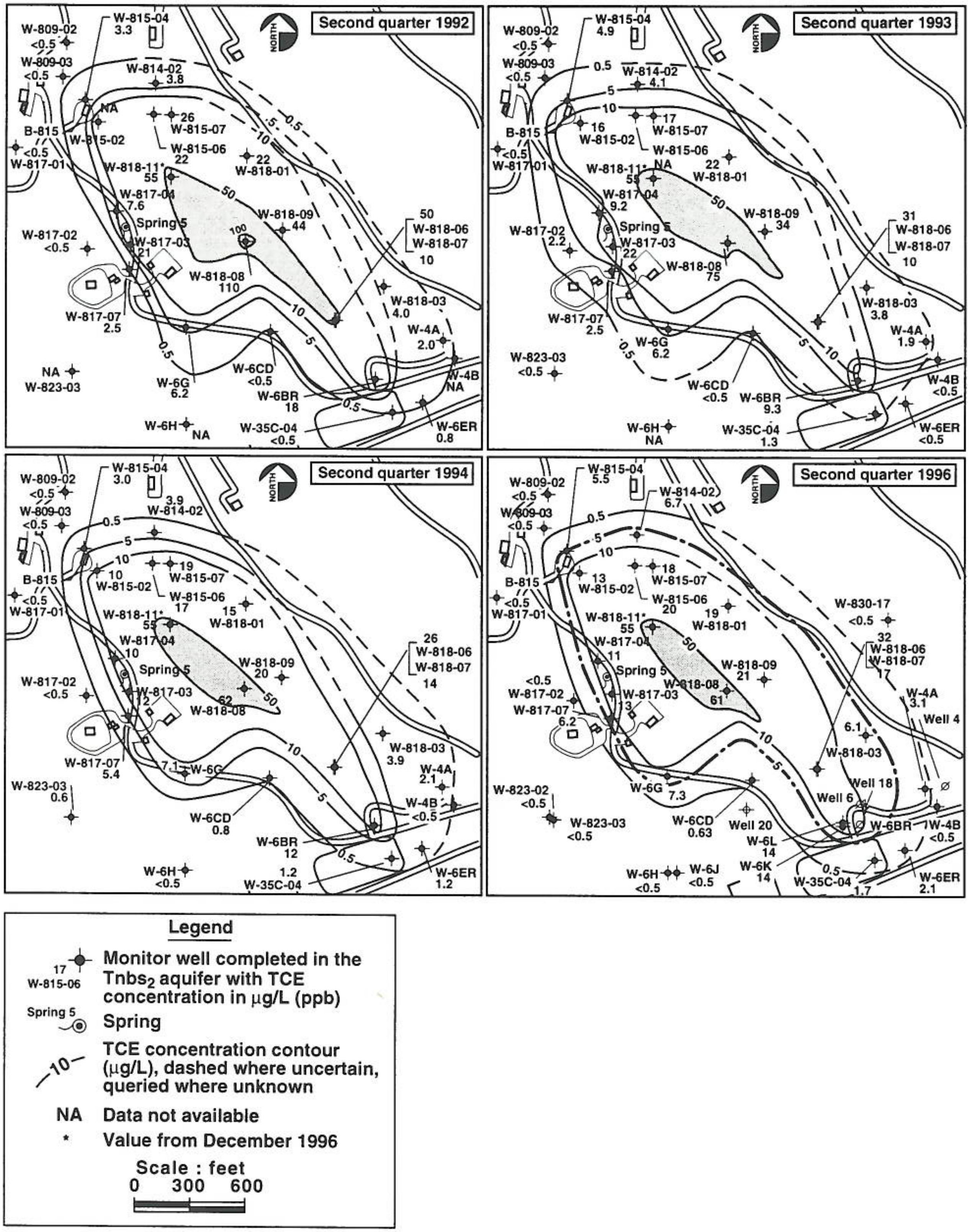
Table A-15. Statistical analysis of concentration trends in the Building 815 TCE plume.

Well number	Number of analyses	Regression slope	t-value (data)	$t_{.975}$-value (table)	Trend
W-814-02	12	+ 0.002272	+6.230	2.228	Increasing
W-815-02	30	- 0.003217	-2.490	2.048	Decreasing
W-815-04	25	+ 0.000930	+4.144	2.069	Increasing
W-815-06	18	+ 0.000216	+0.144	2.120	Flat
W-815-07	14	- 0.0033204	-1.136	2.179	Flat
W-817-03	48	- 0.004157	-6.830	2.021	Decreasing
W-817-04	48	- 0.000969	-2.490	2.021	Decreasing
W-817-07	9	+ 0.0021458	+1.346	2.365	Flat
W-818-01	13	- 0.009948	-2.149	2.201	Flat
W-818-03	16	+ 0.001001	+1.620	2.145	Flat
W-818-06	14	- 0.011505	-2.084	2.179	Flat
W-818-07	10	- 0.001794	-0.683	2.306	Flat
W-818-08	11	- 0.02213258	-2.823	2.262	Decreasing
W-818-09	9	- 0.01393058	-2.516	2.365	Decreasing
W-4A	24	+ 0.0087453	+7.748	2.074	Increasing
W-6BR	34	+ 0.0029264	+3.762	2.042	Increasing
W-6CD	33	- 0.0000678	-0.982	2.042	Flat
W-6ER	27	+ 0.000433	+5.502	2.060	Increasing
W-6G	12	- 0.003757921	-2.713	2.228	Decreasing
W-35C-04	23	+ 0.000602	+1.684	2.080	Flat

Table A-16. Summary of natural attenuation mechanisms that could influence migration of the Building 815 OU TCE.

Mechanism	$Tnbs_2$ aquifer conditions	Impact
Biological:		
Bioattenuation	Aerobic. Biodegradation products not detected.	None.
Physical:		
Volatilization	Possible mechanism where $Tnbs_2$ aquifer is under water table conditions.	Minor to none.
Longitudinal dispersion	Significant in high-K sediments during Well 6 pumping.	Decrease concentration with time and distance from source.
Transverse dispersion	Significant due to reduced ground water velocity after Well 6 stopped pumping.	Decrease concentration and rate of TCE transport downgradient.
Diffusion	Increased due to reduced ground water velocity after Well 6 stopped pumping.	Migration of TCE from high K to low-K sediments in response to concentration gradients.
Chemical:		
Sorption	Laboratory measured TCE partitioning coefficient (K_d) = 0.54.	Decrease rate of TCE transport downgradient.
	TCE retardation factor (R) = 4.	Significant after Well 6 stopped pumping.

K = Hydraulic conductivity.



ERD-S3R-97-0129

Figure A-1. Time-series TCE plume maps for the $Tnbs_2$ aquifer between second quarter 1992 and second quarter 1996.

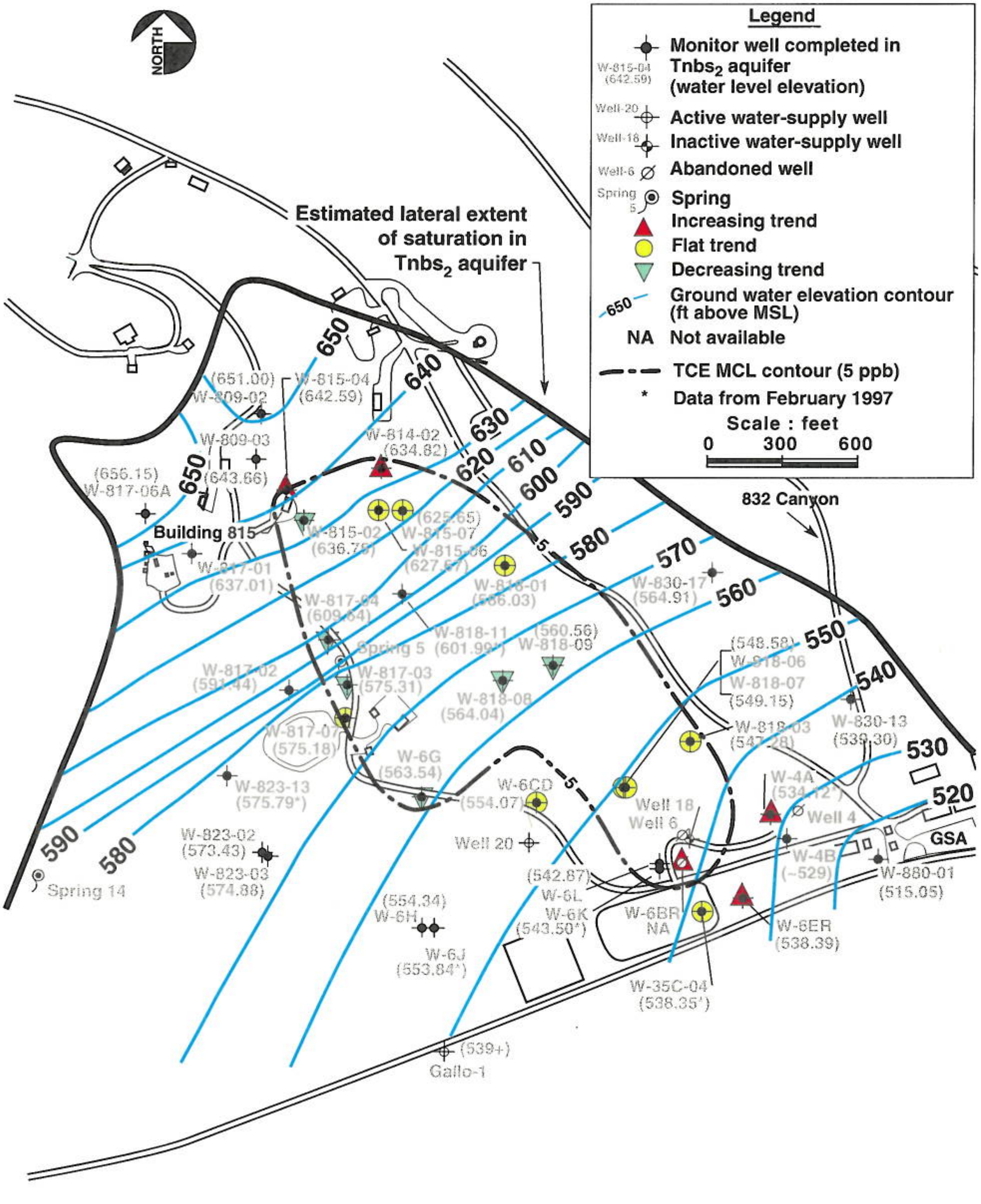


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Figure A-2. Potentiometric surface map showing single-well TCE concentration trends, 5 ppb TCE MCL contour, and second quarter 1996 water levels.

Appendix B

Evaluation and Screening of Remedial Technologies

Appendix B

Evaluation and Screening of Remedial Technologies

This Appendix evaluates and screens remedial technologies that are relevant to this removal action and consistent with the RAOs described in Chapter 2.

B.1. Overview of Screening Process

Remedial technologies were evaluated and screened on the basis of applicability, effectiveness, implementability, cost, site-specific requirements, and best professional judgment. The retained technologies were combined to form the removal action presented in Chapter 3.

B.2. Evaluation and Screening of Remedial Technologies

The RAOs for this removal action include controlling TCE plume migration, mitigating human health risk, and removing TCE mass. Therefore, the technologies that were considered for this removal action include: ground water containment and hydraulic control, ground water extraction and treatment, and disposal of treated ground water. The following sections briefly describe each of these technology categories. Table B-1 documents our reasons for retaining a remedial technology or eliminating it from further consideration. Table B-2 summarizes the retained technologies.

B.2.1. Ground Water Containment/ Hydraulic Control

Ground water containment/hydraulic control methods protect human health by restricting and controlling the migration of ground water contaminants. Ground water containment methods include physical barriers such as slurry walls or grout curtains. Hydraulic control methods include hydraulic barriers formed by ground water extraction and/or reinjection.

B.2.2. Ground Water Extraction and Treatment

Ground water extraction and treatment involves pumping contaminated ground water from extraction wells and treating the contaminants *in situ* or *ex situ*. A successful extraction and treatment system requires designing (1) an extraction wellfield to ensure that ground water contaminants are adequately captured, and (2) a treatment technology that is appropriate for the anticipated flow rates and contaminant concentrations.

In situ ground water treatment methods destroy or convert contaminants to less toxic compounds, without removing the contaminated ground water from the subsurface. *In-situ* methods that are potentially applicable to this removal action include air sparging, biological enhancement, and dehalogenation using zero-valent metals.

Ex situ ground water treatment methods remove contaminated ground water from the subsurface and separate, destroy, or convert the contaminants and vapor byproducts at the surface. *Ex situ* methods that are potentially applicable to this removal action include sorption to aqueous-phase or vapor-phase GAC, air stripping/air sparging, ultraviolet (UV)/oxidation, ozone/hydrogen peroxide (H_2O_2) peroxidation, biological treatment, constructed wetlands, photolysis in evaporation ponds, ion-exchange, and reverse osmosis.

B.2.3. Discharge of Treated Ground Water

Methods considered for discharge of treated ground water include onsite surface discharge, reinjection, and air misting. We also considered an innovative technology (constructed wetland), that could be used, if necessary, to treat nitrate-bearing effluent from the treatment systems. Constructed wetlands are discussed in Appendix C.

B.3. Summary of Retained Technologies

As presented in Table B-2, the primary treatment technologies that were retained through the screening process and selected for this removal action, include ground water extraction and treatment using aqueous-phase GAC. Treated ground water discharge method(s) retained for this removal action include surface discharge, misting towers, reinjection, and constructed wetlands. The final selection of a discharge method will depend primarily on nitrate concentrations in the treatment system effluent considerations for restoring the $Tnbs_2$ water resource by reinjecting treated ground water. The retained technologies are included in the conceptual removal action design presented in Chapter 3. The final design of this removal action will be based on results from additional aquifer testing and ground water modeling, and will be presented in a RADW.

Table B-1. Preliminary remediation technology screening and evaluation.

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
Ground water containment/ control	Slurry walls	Applicable	Due to construction constraints, effective only for horizontal source migration control in unconsolidated material.	Difficult to implement. Would require excavation of bedrock up to 100-ft depth, and steep terrain would restrict access.	High	No
	Grout curtain	Applicable	Effective for horizontal source migration control.	Difficult to implement because steep terrain restricts access.	Very high	No
	Hydraulic barrier (via injection)	Applicable. Regulatory permits required. Possible use for treated ground water. Additional modeling may be required.	Effective for onsite plume control of RDX.	Implementable	Medium	Yes
Ground water extraction	Hydraulic control (via extraction)	Applicable for $Tnbs_2$ aquifer.	Effective	Implementable	Medium	Yes
	Extraction from wells (vertical)	Applicable	Effective when combined with treatment. Provides hydraulic control of contaminant plume.	Implementable. Steep terrain may limit access to installation locations.	Medium	Yes
	Extraction from wells (horizontal)	Applicable for Tps perched water-bearing zone.	Not effective if all water-bearing zones are not intercepted.	Difficult to implement. Water-bearing zones are laterally heterogeneous and possibly discontinuous. Therefore, interception is not guaranteed. Steep terrain may limit access to installation locations.	High	No

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Extraction from trenches	Applicable	Lateral heterogeneity may limit effectiveness.	Difficult to implement. Steep terrain may limit access to installation locations.[a]	Very high	No
In-situ ground water treatment	Air sparging	Applicable for VOCs only. Innovative technology.	Effectiveness uncertain due to localized subsurface permeability, heterogeneities, and low concentrations.	Difficult to control movement and capture of sparged VOCs.	NCF	No
	Biologically enhanced degradation.	Applicable. Innovative technology.	Compound-specific. Not proven effective at low concentrations.	Compound-specific	NCF	No
	Dehalogenation with zero-valent metal(s)	Applicable. Innovative technology.	Effective, if shown not to generate toxic by-products such as vinyl chloride.	Implementability dependent on ability to install interceptor trench/caisson.	High	No
Ex situ ground water treatment	GAC sorption—aqueous phase	Applicable for VOCs.	Effective for most VOCs, but not nitrates. Most appropriate for low flow rates and low concentrations.	Implementable. Potentially high operation and maintenance (O&M) due to chemical precipitation and vessel clogging. Offsite GAC regeneration for sorbed VOCs.	Medium	Yes
	Coupled chemical/biological treatment of RDX	Applicable for treating RDX-laden GAC. Innovative technology.	Effective for re-generating RDX-laden GAC.	Implementable. Will require onsite pilot testing and regulatory acceptance.	Medium	Yes
	Air stripping/air sparging	Applicable for VOCs. Air permit required. Vapor-phase GAC required.	Effective when combined with vapor-phase GAC. Possible reduced efficiency due to chemical precipitation.	Implementable. Potentially high O&M due to chemical precipitation and reduced efficiency. Need to design to prevent scaling.	Medium	Yes

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	UV/oxidation—aqueous phase	Applicable for VOCs.	Effective, destroys VOCs. Possible reduced efficiency due to chemical precipitation, turbidity.	Implementable. High energy consumption due to high concentration of nitrates and sulfates. May require GAC polishing unit to achieve discharge requirements. High O&M costs.	High	Yes
	Ozone/H_2O_2 peroxidation	Applicable for VOCs.	Effective	Implementable	Medium	Yes
	Ion exchange	Applicable for nitrates.	Effective when designed for Site 300 high sulfate water. Commercially available resins will preferentially select sulfate over nitrate.	May be implementable with nitrate-selective resins. Resin regeneration required. Disposal costs for brine are high.	High	No
	Reverse osmosis	Applicable	Effective. 97.7% nitrate-removal rate.	Implementable. Brine disposal costs are high.	High	No
Disposal of treated ground water	Onsite surface discharge	Applicable	Effective	Additional investigation required to identify discharge areas.	Low	Yes
	Constructed wetlands/natural degradation ponds	Applicable. Innovative technology.	Effective	Implementable. May need subsurface flow to avoid mosquitoes. High sulfate concentrations may cause odors, algae growth, or hydrogen sulfide.	Medium	Yes

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Reinjection	Applicable. May also act to mitigate plume migration when combined with ground water extraction.	Effective. May also be used to hydraulically displace contaminants toward extraction wells/trenches.	Must ensure that recharge does not adversely affect subsurface (e.g., migration of contaminants). Permitting required. Scaling may clog system, requiring regular maintenance.	Medium–high	Yes
	Air misting	Applicable	Only effective for low flows.	Implementable	Low	Yes

Note:

NCF = Not considered further.

[a] Discussed in Appendix E with regard to Tps remediation.

Table B-2. Retained remedial technologies.

Remediation technology type	Effectiveness	Cost
Ground water containment/control		
Hydraulic control (via extraction)	Effective for RDX plume control.	Medium
Hydraulic barrier (via injection)	Effective.	Medium
Ground water extraction		
Extraction from wells (vertical)	Effective when combined with treatment. Provides hydraulic control of contaminant plume.	Medium
Ex situ ground water treatment		
GAC sorption—aqueous phase	Effective for most VOCs, but not nitrates. Most appropriate for low flow rates and low concentrations.	Medium
Coupled chemical/biological treatment of RDX	Effective for re-generating RDX-laden GAC.	Medium
Disposal of treated ground water		
Onsite surface discharge	Effective.	Low
Air misting	Only effective for low flows.	Low
Constructed wetlands/natural degradation ponds	Effective.	Medium
Reinjection	Effective. May also be used to hydraulically displace contaminants toward extraction wells.	Medium–high

Appendix C

Innovative Technologies

Appendix C

Innovative Technologies

This Appendix presents two innovative remedial technologies that could be incorporated into this removal action, if nitrate or RDX treatment is necessary. In Section C-1, we discuss a constructed wetland to meet discharge requirements for treating nitrate-bearing effluent. In Section C-2, we discuss a coupled chemical/biological treatment technology for treating RDX.

C-1. Constructed Wetland

We are considering the use of a constructed wetland for nitrate treatment because conventional methods, such as ion exchange and reverse osmosis, are expensive and may not effectively achieve the low nitrate concentrations required for surface discharge. Conventional nitrate treatment technologies also require lengthy retention times and are susceptible to interference from other inorganics (such as sulfates) in the ground water. Constructed wetlands provide a means for destroying contaminants rather than transferring them from one medium to another. Although constructed wetlands are an established technology for treating municipal waste water, this technology has not been widely implemented for ground water remediation.

Constructed wetlands use the interaction of rhyzomous vegetation and anaerobic bacteria to denitrify nitrate-bearing water. Although a variety of designs may be employed, we have chosen a subsurface flow wetland system for our conceptual removal action design and cost analysis. Limited data on denitrification rates indicate that subsurface flow systems are significantly more effective than surface flow systems (Hammer, 1989). Additionally, a subsurface flow system would virtually eliminate any need for mosquito abatement or odor control.

As shown in Figure C-1, three primary components are required in a subsurface flow constructed wetland: an impermeable layer (generally clay), a gravel layer that provides a substrate for the vegetation root zone, and an above-surface vegetation zone. The impermeable layer prevents infiltration of the waste water. The waste water flows and the denitrification process occurs in the gravel layer and associated root zone. The above-surface vegetative zone contains the green, photosynthetic portion of the plants that provide the initial carbon fixation and ultimate carbon supply to the denitrification process. In addition, this top zone lends an aesthetic nature to the system. Nitrate-bearing water is pumped or gravity drained through a piping manifold into one end of the constructed wetland to evenly distribute the water and prevent channeling. Water then gradually flows about 1 ft below the surface through the gravel layer and the root zone, and discharges from the distal end of the constructed wetland.

Constructed wetland dimensions (width, depth, and length) are specified based on the retention time necessary for sufficient denitrification to occur. Frequently, constructed wetlands are designed with multiple cells to provide flexible flow rates to achieve adequate retention time and ensure sufficient water to sustain the vegetation. The capacity of a constructed wetland can be affected by precipitation and evapotranspiration rates, the root depth of the chosen vegetation, and areal extent. Areal extent can be limited by local topography or cultural features.

Although many reactions occur in the root and gravel zone, the primary process of interest is anaerobic denitrification. This process is a form of cellular respiration that occurs in the anoxic portions of the root zone. The rhyzomatous roots provide a substrate for bacterial attachment. They also help create adjacent aerobic and anoxic zones, which are important for the cycling of nitrogen and carbon in the system. Such cycling includes the initial breakdown of root matter or root exudate. Once the carbon is released in the aerobic zone directly adjacent to the root, it can be used in the more distal anoxic areas where denitrification occurs. The following formula describes the denitrification process:

$$5\ CH_2O + 4H^+ + 4\ NO_3^- \text{ ------> } 2\ N_2 + 5\ CO_2 + 7\ H_2O.$$

Nitrification also takes place, which conflicts with denitrification. This process is controlled by the supply of organic carbon produced by decaying plants. The choice of plants with a favorable carbon-nitrogen ratio can minimize nitrification.

C-2. RDX Remediation

There are no readily available, cost-effective technologies for remediating low concentrations (< 1 ppm) of RDX in ground water. However, researchers at LLNL have developed an innovative technology for regenerating RDX-laden GAC (Knezovich et al., 1996). Knezovich and others have developed a coupled chemical-biological treatment process that uses GAC to remove HE compounds from aqueous waste streams. The HE is desorbed from the GAC using a heated solvent or an alkaline solution that hydrolyzes the HE. The HE- or hydrolysate-laden effluent is treated using a denitrifying culture of microorganisms in a fixed-bed bioreactor. This technology has been successfully pilot-tested at Pantex Plant in Amarillo, Texas. Testing at Pantex verified the long-term efficiency and reliability of this technology to treat HE-laden aqueous waste streams in a continuous flow mode. This treatment technology removes the hazardous constituents from the GAC and allows the GAC to be regenerated for future use, thereby minimizing waste and reducing costs.

Although RDX cleanup is outside the scope of this removal action, RDX extraction and treatment may be necessary to achieve TCE mass removal (RAO 3). Aquifer testing and ground water modeling will be used to determine how TCE mass removal could influence the RDX plume. This information will be used to manage and optimize the extraction wellfields to minimize influence on the RDX plume and avoid extracting RDX with the TCE. Additionally, certain monitor wells have been designated as RDX compliance wells. If RDX is detected and confirmed in any of these compliance wells, a contingency action will be considered to hydraulically control and/or remediate the RDX. This contingency action, which will be specified in the Site-Wide CP, will include the treatment technology discussed above as a possible RDX treatment option. This technology will also be considered if RDX cleanup is required as part of the Site-Wide ROD.

C-3. References

Hammer, D. A., Ed. (1989), *Constructed Wetlands for Waste Water Treatment: Municipal, Industrial, and Agricultural* (Lewis Publishers, Chelsea, Mich.).

Knezovich, J. P., J. Daniels., M. K. Stenstrom, and H. M. Heilmann (1996), *Coupled Chemical and Biological Systems for Regenerating Activated Carbon Contaminated with High Explosives* (UCRL-ID-103483-95).

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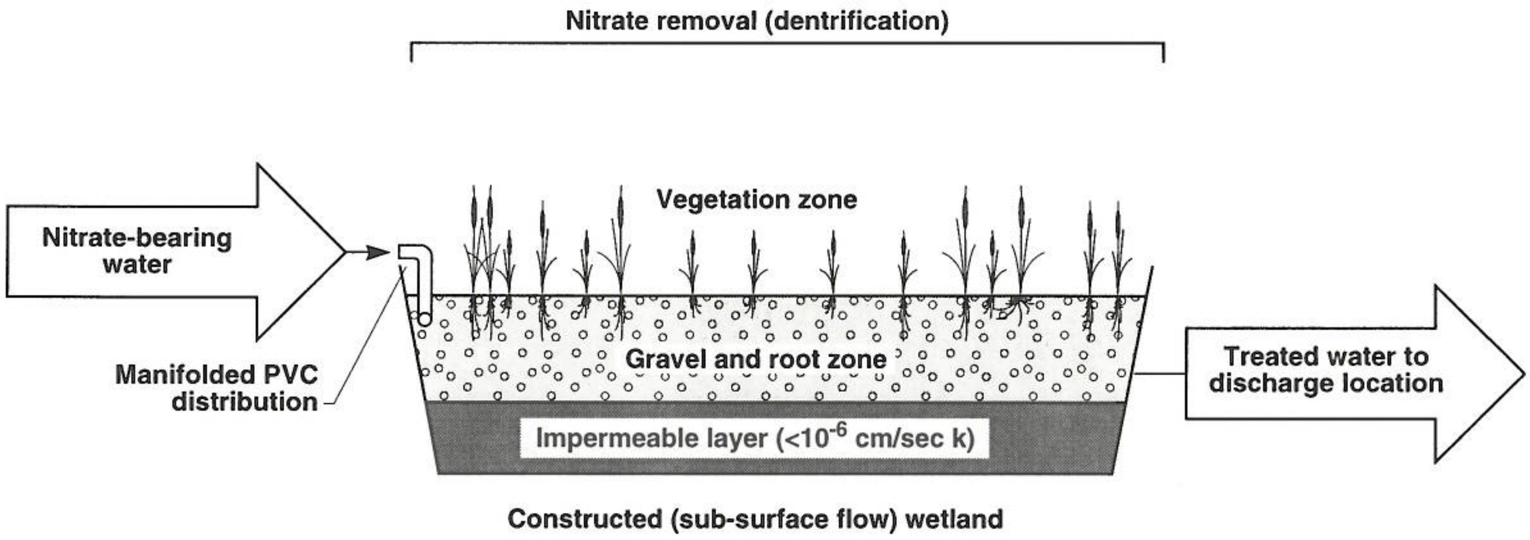

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Figure C-1. Schematic for a constructed wetland nitrate treatment system.

Appendix D

Capture Zone Analysis: Estimates of TCE Area, Volume, and Mass and Determination of Retardation Factor

Appendix D

Capture Zone Analysis: Estimates of TCE Area, Volume, and Mass and Determination of Retardation Factor

D-1. Estimates of Capture Zones for Ground Water Extraction

D-1.1. Objective

The objective of the procedure described below is to estimate hydraulic capture zones resulting from ground water extraction.

D-1.2. Calculation

We made our calculations using a 2-D analytical element computer code Winflow, version 1.02 (Rumbaugh and Rumbaugh, 1995). This software assumes a uniform, horizontal flow field in a homogeneous isotropic aquifer. It accounts for the interference between extraction wells by applying superposition. The model was calibrated with two conditions: 1) non-stressed, using water elevation data from second quarter 1996, and 2) stressed, using Well 6 draw down and extraction rate data from pump tests.

D-1.3. Parameter Discussion

This 2-D approach assumes a homogeneous, isotropic, confined aquifer of constant thickness, uniform gradient, horizontal flow, and constant rate of extraction. This approach also includes the conservative assumption that the $Tnbs_2$ aquifer is of infinite extent. We obtain Q and K from well tests; and b from water level data and well logs. Table D-1 shows parameter values for these calculations.

D-1.4. Results

Figures D-1 through D-3 show the plotted capture zones for the three extraction scenarios discussed in Section 3.2. These capture zones are based on the conservative assumption that the aquifer is of infinite extent. Because the $Tnbs_2$ aquifer is of limited extent, the actual capture zones are expected to be larger. Flow lines upgradient of the Spring 5 fault are shown parallel to the natural ground water flow direction.

D-2. Estimates of Area, Volume, and Mass

This section presents estimates of area, volume, and mass of ground water TCE contamination in the Building 815 OU, and describes how these estimates were derived.

As discussed in Chapter 1, TCE is the primary indicator chemical for VOCs; therefore, we used TCE to delineate the extent, volume, and mass of VOCs in the Building 815 OU. Although we do not address other VOCs of potential concern in this appendix, we considered them in the design of the Removal Action.

D-2.1 Estimates of Area, Volume, and Mass in the Tps Water-Bearing Zone and Tnbs$_2$ Aquifer

In calculating estimates of area, volume, and mass of TCE in the Tps and Tnbs$_2$ aquifers, we used a porosity value of 0.25 and 0.30 (dimensionless), for the aquifers, respectively. These values are from physical property tests on Tnbs$_2$ aquifer material, and best professional judgment for the Tps. We use a density of 1.46 grams per cubic centimeter (g/cc) for TCE (Windholz, 1983). For the estimates, we derived the concentration data from second quarter 1996 and/or our most complete sampling data set. To define the affected areas, we used isoconcentration contours for contaminants in ground water in the Tps and Tnbs$_2$ aquifers (Appendix E, Fig. E-6; main text, Fig. 7, respectively) in the Building 815 OU. We assumed complete vertical mixing of contaminants in ground water, and we used water level measurements and well logs to determine the saturated thickness of the aquifer. To calculate the total volume of a contaminant in ground water, we used the geometric mean concentration to represent the bulk concentration of the contaminated volume between adjacent contours. For example, the volume of contaminated ground water between the 10 µg/L and 1.0 µg/L TCE isoconcentration contours was assigned a geometric mean TCE concentration value of 3.16 µg/L. We calculated the volume of contaminated ground water, the mass of contaminant, and the volume of contaminant for each of the contour intervals. The corresponding masses/volumes calculated for each interval were summed to estimate the total quantity of contaminated ground water and the corresponding volume/mass of contaminant contained within the ground water plumes.

We used the following equation to calculate the total volume (in gallons) of ground water contaminated with TCE ($V_{C\text{-}GW}$):

$$V_{C\text{-}GW} = A \times b \times n \times 7.48 \qquad \text{(D-1)}$$

where

$V_{C\text{-}GW}$ = volume of ground water containing TCE.

We used the following equation to calculate mass of TCE (M_{TCE}) dissolved in ground water:

$$M_{TCE} = V_{C\text{-}GW} \times (C_{TCE}/10^6) \times 3.785 \qquad \text{(D-2)}$$

where

A = area between contour intervals (ft^2),

b = contaminated saturated thickness (ft),

n = porosity (dimensionless),

C_{TCE} = geometric-mean TCE ground water concentrations (µg/L), and

10^6 and 3.785 = conversion factors (micrograms per gram [µg/g] and liters per gallon [L/gal], respectively).

We used the following equations to convert the mass of TCE into an equivalent liquid volume of TCE (V_{TCE}):

$$V_{TCE} = M_{TCE} / (\rho_{TCE} \times 1{,}000 \times 3.785) \qquad \text{(D-3)}$$

where

M_{TCE} = mass of TCE (g) from equation D-2,

ρ_{TCE} = density of TCE (g), 1.46 grams per milliliter (g/ml), and

$(1.46 \times 1{,}000 \times 3.785)$ = conversion factors (milliliters per liter [ml/L] and L/gal, respectively).

Table D-2 shows the results of our calculations.

To verify our $Tnbs_2$ calculations, we employed a similar method using computer software (EarthVision 3.1, 1997) that interpolates a minimum-tension grid from a set of data points. We used three data sets to create grids: 1) $Tnbs_2$ aquifer bottom elevations derived from well logs, 2) average ground water elevations from 1996 for unconfined areas of the aquifer, combined with the top of the aquifer for areas with confined conditions, and 3) contaminant concentrations in ground water from second quarter 1996. These three grids were then merged to create an aquifer volume with mapped isoconcentration contours. The results showed a difference of less than 5% between the two methods that we used to estimate TCE mass in the $Tnbs_2$ aquifer.

D-2.2. Sensitivity Analysis for Estimates of TCE in the $Tnbs_2$ Aquifer and the Tps Water-bearing Zone

Four variables were used for each of our mass and volume estimates of contaminants in ground water: area, saturated thickness, porosity, and contaminant concentration. By inspecting equations D-1 and D-2, we see a linear relationship between all four parameters and the resulting mass or volume estimates. Therefore, if one of these parameters is adjusted, the result will be adjusted by the same factor. For example, if the saturated thicknesses were decreased by 50%, the resulting mass and volume would also decrease by 50%.

D-3. Retardation Factor

A TCE retardation factor for the $Tnbs_2$ aquifer of 4.0 was determined based on a labortory-measure TCE partioning coefficient (K_d) of 0.54 ml/g. The following equation was used to calculate the retardation factor (Freeze and Cherry, 1979):

$$R = 1 + \rho_b (K_d/n) \qquad \text{(D-4)}$$

where

R = retardation factor [dimensionless],

ρ_b= dry bulk density [$M \bullet L^{-3}$]

= 1.65 (g/cc)

K_d= mass of solute on solid phase per unit mass of solid/concentration of solute in solution [$L^3 \bullet M$]

= 0.54 (ml/g)

n= porosity [dimensionless]

= 0.30

The above values were obtained from analysis of core samples from the $Tnbs_2$ aquifer in the Building 815 OU.

D-4. References

Earth Vision 3.1 (1997).

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

Rumbaugh, J., and D. Rumbaugh (1995), *Winflow version 1.02 Two-Dimensional Ground Water Flow Model* (Environmental Simulations, Inc., Herndon, VA)

Windholz, M., Ed. (1983), *The Merck Index*, 10th Edition (Merck & Co., Rahway, NJ).

Table D-1. Capture zone calculation parameters.

Proposed extraction well	Extraction rate (gpm)	Hydraulic conductivity (cm/sec)	Hydraulic gradient (ft/ft)	Saturated thickness (ft)
W-6ER	20	4×10^{-4}	0.042	60
W-35C-04	20	4×10^{-4}	0.042	60
W-818-06	20	4×10^{-4}	0.042	60

Table D-2. Estimated TCE in ground water in the Building 815 OU $Tnbs_2$ aquifer.

Aquifer	Volume of contaminated water (gal)	TCE volume (gal)	TCE mass (kg)
Tps	6,200,000	6.7×10^{-2}	0.37
$Tnbs_2$	250,000,000	3.2	17.4

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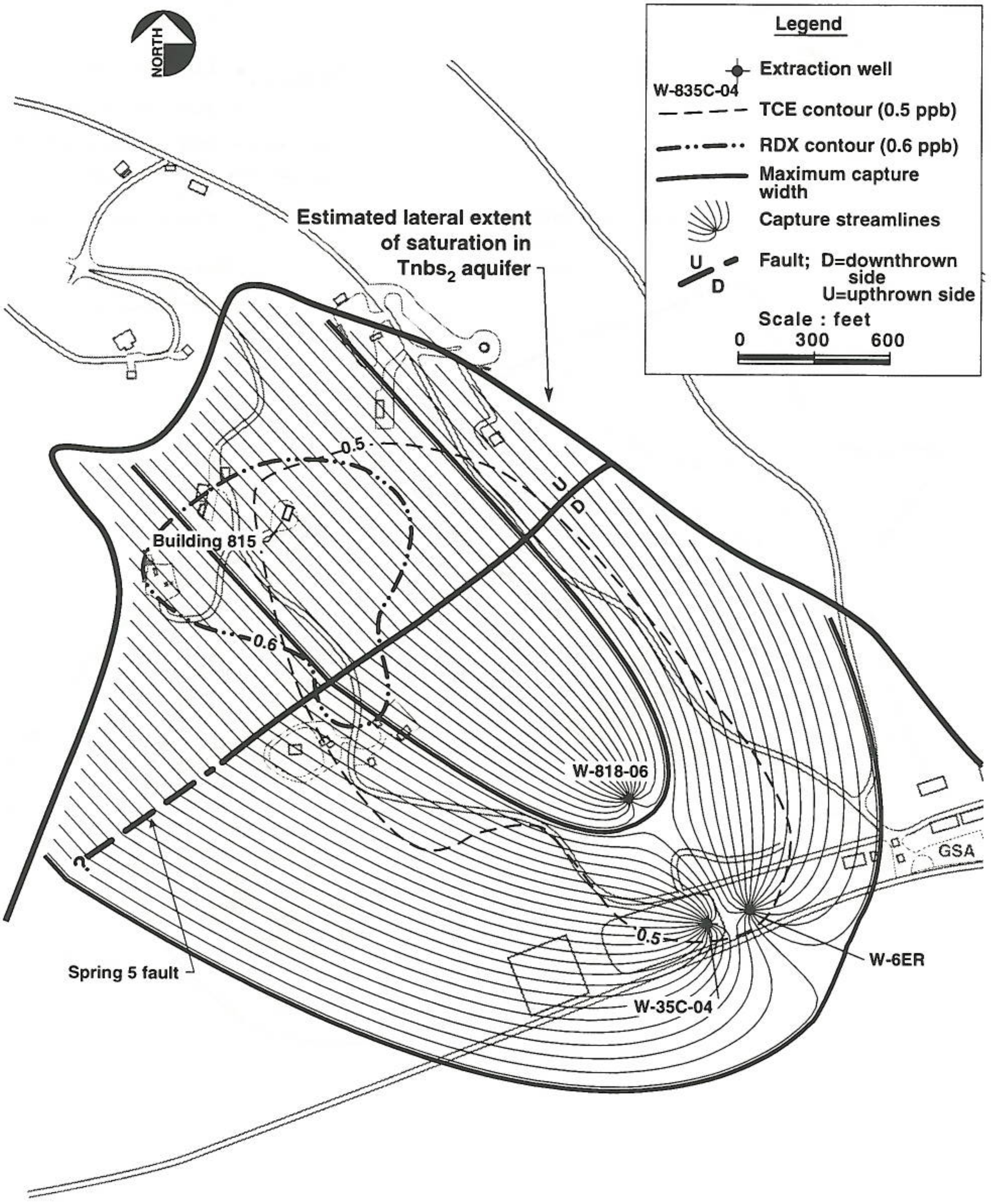

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Figure D-1. Estimated capture zones based on ground water extraction from wells W-35C-04, W-6ER, and W-818-06.

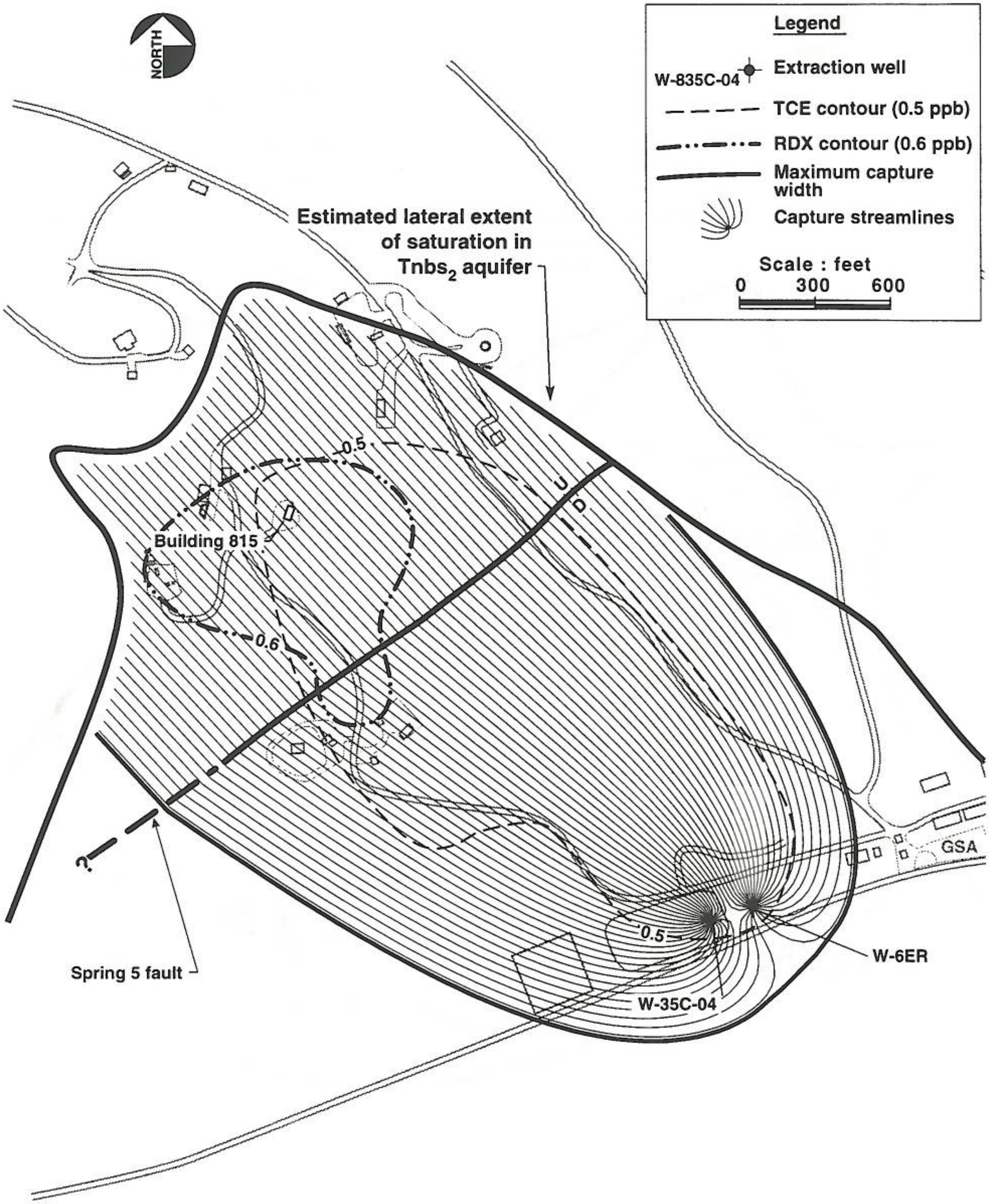

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Figure D-2. Estimated capture zones based on ground water extraction from wells W-35C-04 and W-6ER.

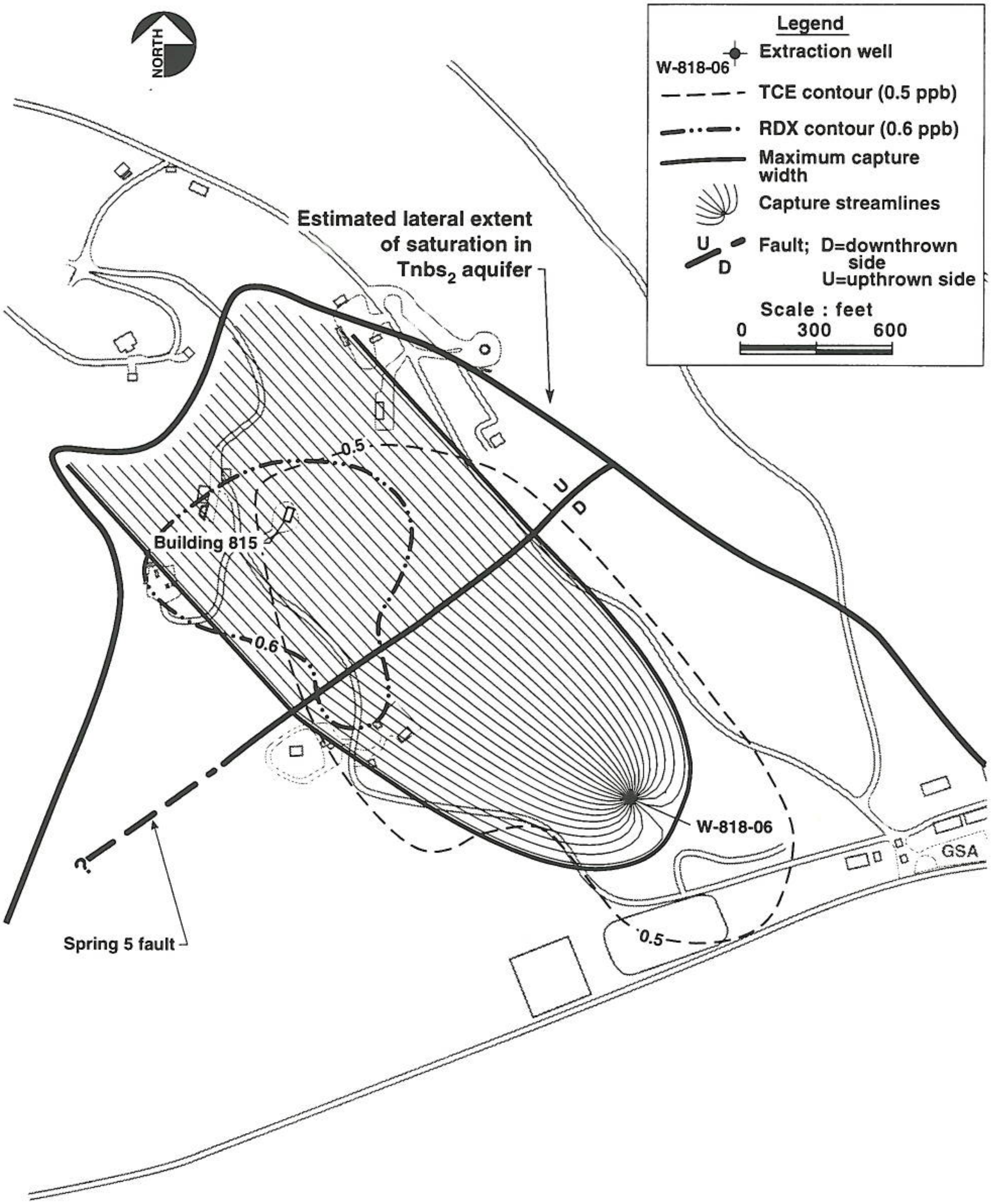

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Figure D-3. Estimated capture zones based on ground water extraction from well W-818-06.

Appendix E

Evaluation of Tps
Perched Water-Bearing Zone

Appendix E

Evaluation of Tps Perched Water-Bearing Zone

This Appendix evaluates the Tps perched water-bearing zone to address the following concerns:

- The potential for dissolved contaminants in the Tps perched water-bearing zone to degrade the beneficial uses of the $Tnbs_2$ aquifer.
- The potential for the Tps perched water-bearing zone to be a source of public drinking water under SWRCB Resolution No. 88-63.
- The potential for human exposure to contaminants in the Tps perched water-bearing zone.
- The capital costs associated with extracting ground water from the Tps perched water-bearing zone.

Table E-1 summarizes relevant physical and geochemical properties of the Tps perched water-bearing zone, including saturated thickness, TDS, and estimated yield.

E-1. Evaluation of Potential for Dissolved Contaminants in the Perched Tps Water-Bearing Zone to Degrade Beneficial Uses of the $Tnbs_2$ Aquifer

This section presents an evaluation of unsaturated flow modeling for the Tps perched water-bearing zone, using VLEACH (U.S. EPA, 1990). The VLEACH model simulates potential downward migration of contaminants in the Tps perched water-bearing zone to the underlying $Tnbs_2$ aquifer.

Based on the Building 815 OU conceptual hydrogeologic model, dissolved contaminants in the Tps are contained within a low-yielding, laterally heterogeneous, and discontinuous perched water-bearing zone that is hydraulically isolated from the underlying $Tnbs_2$ aquifer. Information to support this model is presented in hydrogeologic cross-section C-C' (Fig. E-1) and geophysical log correlation section D-D' (Fig. E-2). As shown by the geophysical log responses, a contrast exists between the variable but generally fine-grained Tps material and the laterally continuous underlying $Tnbs_2$ aquifer.

E-1.1. Objective

The modeling objective is to estimate any potential future additional impact of TCE, presently in the Tps water-bearing zone, on the underlying $Tnbs_2$ aquifer. We used the numerical code VLEACH to model this potential impact by simulating TCE transport through the unsaturated portion of the $Tnbs_2$ aquifer.

E-1.2. Conceptual Model

The Tps water-bearing zone is perched on silts and clays of the Tps/Tnsc$_2$ units about 30 ft above the Tnbs$_2$ water table. Although data indicate that the predominant mode for ground water flow in the Tps is horizontal and south toward Spring 5, we conservatively assume transport to occur vertically downward through 2–3 ft of Tps/Tnsc$_2$ confining material and 30 ft of unsaturated Tnbs$_2$ aquifer. Furthermore, we conservatively assume that the entire TCE mass from the Tps is dissolved in water at the top of the Tnbs$_2$ unsaturated zone, with additional TCE in other phases that are in equilibrium with the dissolved phase. At time $t = 0$, we assume that the TCE is instantaneously released and begins to migrate downward.

E-1.3. Code Description

VLEACH is a simplified, one-dimensional (1D) numerical model that simulates the vertical migration of contaminants in the vadose zone. VLEACH calculates the following processes:

- Aqueous-phase advection.
- Vapor-phase diffusion.
- Solid-phase sorption.

The VLEACH model is based on the following assumptions:

- Solid-liquid partitioning coefficient (K_d) and the liquid-vapor partitioning coefficient (H) are constants, i.e., the partitioning relationships are linear between phases.
- Aqueous, vapor, and sorbed phases are in a state of equilibrium in each cell.
- Moisture content profile is constant, i.e., the volumetric water content is constant with depth.
- Contaminant dispersion in the aqueous phase is negligible.
- No free product is present in the simulation column.
- Soil within a simulated column is completely homogeneous and isotropic, i.e., uniform porous medium with no preferential flow pathways.
- Volatilization from the top of the soil column is completely restricted.

Contaminant transport is assumed to occur in the aqueous and gas phases. Equations E-1 and E-2 define 1D contaminant transport in the aqueous and gas phases, respectively. The processes include aqueous-phase advection resulting from downward seepage, vapor-phase diffusion, partitioning (sorption) described by a linear equilibrium isotherm, and contaminant degradation in the aqueous phase with first-order kinetics. Sorption slows the rate of solute transport relative to ground water flow, and is represented by the retardation factor (R) in the transport equation:

$$\mathrm{R}\frac{\partial C_1}{\partial t} = \mathrm{v}\frac{\partial C_1}{\partial z} - \lambda R C_1, \text{ and} \qquad \text{(E-1)}$$

$$R \frac{\partial C_g}{\partial t} = D_{eff} \frac{\partial^2 C_g}{\partial z^2} \tag{E-2}$$

where

Cl = Contaminant concentration in the aqueous phase [M • L–3],

Cg = Contaminant concentration in the gas phase [M • L–3],

Deff = Effective diffusion coefficient [L2 • T–1],

R = Retardation factor [dimensionless],

v = Vertical seepage velocity [L • T–1],

z = Vertical depth variable [L], and

l = Degradation rate constant [T–1].

Equation E-3 describes the vapor diffusion coefficient as a function of the total and water-filled porosity, and the free-air diffusion coefficient. Equation E-4 describes the effective diffusion coefficient in terms of the vapor-diffusion coefficient; it incorporates retardation due to linear, equilibrium partitioning.

Dv = , and (E-3)

$$D_{eff} = \frac{HD_v}{\left[\rho_b K_d + \theta + (n - \theta)H\right]} \tag{E-4}$$

where

Dair = Vapor diffusion coefficient for air [L2 • T–1],

Dv = Vapor diffusion coefficient for porous media [L2 • T–1],

Deff = Effective diffusion coefficient [L2 • T–1],

Kd = Liquid/solid partitioning coefficient [L3 • M–1],

H = Henry's law constant [dimensionless],

n = Total porosity [dimensionless],

q = Water-filled porosity [dimensionless], and

rb = Bulk density [M • L–3].

In each column, the soil is assumed to be completely homogeneous, with no preferential flow pathways. Each column is divided into cells of uniform thickness. An initial depth-concentration profile can be assumed by specifying the initial aqueous-phase concentration for each cell along a simulated column. The boundaries at the upper and lower ends of the simulated column may be specified as either being impermeable to contaminant flux out of the system (zero-flux boundary), or as each having a constant contaminant concentration (constant-concentration boundary). A contaminant present in infiltrating water at a specified initial concentration may enter the soil column at a constant recharge or infiltration rate.

The model source code was modified to include aqueous-phase contaminant degradation. The model assumes equilibrium between the solid, aqueous, and gas phases, and redistributes the contaminant mass in each phase after every time step. At the end of the simulation, the model predicts a flux of contaminant to ground water, and generates a profile of contaminant concentration versus depth for each of the three phases. VLEACH is conservative to the extent that it considers the shortest possible transport path. Details of the model, the initial and boundary conditions, and the input parameters are included in the VLEACH manual (U.S. EPA, 1990).

We modified the original version of VLEACH to account for possible aqueous-phase degradation. To do this, we assumed that the rate of contaminant mass loss due to chemical transformation was proportional to the contaminant mass present. Accordingly,

$$\frac{\partial C}{\partial t} = kC \tag{E-5}$$

where

$C =$ Contaminant concentrations at time t $[M \bullet L^{-3}]$ and

By integrating equation E-5, we obtain an exponential loss rate,

$$C = C_0 \exp(-\pi t) \tag{E-6}$$

where

$C_0 =$ Contaminant concentrations at time $t = 0$ $[M \bullet L{-}3]$, and

$\pi =$ First-order rate constant $[T{-}1]$.

The constant k is related to the contaminant degradation half-life $T_{1/2}$ by

$$\pi = \frac{\ln 2}{T_{1/2}}. \tag{E-7}$$

The modification requires the addition of an assumed contaminant degradation half-life $T_{1/2}$ to the VLEACH input file.

E-1.4. Input Parameter Values

Tables E-2 through E-4 present the soil properties, chemical properties, and input parameter values we used, respectively. These soil and chemical property values are consistent with values used during modeling for the Final Site Wide Remedial Investigation (SWRI) report (Webster-Scholten, 1994); the HE Burn Pit Closure report (Lamarre et al., 1993); and the mass, area, and volume estimations presented in Appendix D of this report. Other input parameters, such as temporal and spatial discretization, were chosen to optimize the accuracy of the numerical code. We applied the present total mass of TCE in the Tps ground water, 370 g (Appendix D), to an area defined by the Tps extent of saturation. Allowing for equilibration in all three phases, a total mass (aqueous, vapor, and sorbed phases) of 880 g of TCE was placed in the top cell of the $Tnbs_2$ unsaturated zone to obtain 370 g of TCE in the aqueous phase at time $t = 0$. The 30-ft thickness of the $Tnbs_2$ unsaturated zone was estimated using hydrogeologic cross-section C-C' (Fig. E-1). The recharge contaminant concentration was set to zero (0.0).

E-1.5. Results

The results indicate the estimated maximum TCE concentration in percolate reaching the $Tnbs_2$ saturated zone is 0.78 µg/L. The estimated peak concentration arrives at the $Tnbs_2$ saturated zone after 90 years. After 300 years, the total TCE mass in the model domain ($Tnbs_2$ unsaturated zone) is about 0.1% of the initial TCE mass. During this time, the average concentration is predicted to be 0.34 µg/L. Figure E-3 displays our results.

E-1.6. Sensitivity Analysis

We examined the sensitivity of estimated peak concentrations of TCE reaching the $Tnbs_2$ saturated zone to the following parameters: original aqueous phase TCE mass, degradation rate, infiltration rate, and volumetric water content. The alternate parameter values we used to determine sensitivities represent realistic ranges based on site-specific experience and best professional judgment.

E-1.6.1. Original Aqueous Phase TCE Mass

Model results indicate that a linear relationship exists between the initial aqueous phase TCE mass and the calculated peak concentration reaching the $Tnbs_2$ saturated zone. The peak TCE concentrations of 0.39, 0.78, and 1.6 µg/L were obtained when the initial aqueous phase mass was 190, 370, and 740 g, respectively. The estimated peak concentration arrival time (90 years) is not affected by varying the initial TCE aqueous phase mass.

E-1.6.2. Degradation Rate

This model is not highly sensitive to the degradation rate for the time period required for the peak concentration to reach the saturated zone. The maximum concentrations predicted to reach the $Tnbs_2$ saturated zone are 0.78, 1.0, and 1.4 µg/L for degradation half-lives of 50 years, 100 years, and ∞ (infinity, which is equal to zero degradation), respectively.

E-1.6.3. Infiltration Rate

This model is very sensitive to the infiltration rate. The maximum concentrations predicted to reach the $Tnbs_2$ saturated zone are 0.047, 0.78, and 9.6 µg/L, for infiltration rates of 0.0091, 0.091, and 0.91 ft/year, respectively. The time required for the predicted maximum concentrations to reach the $Tnbs_2$ saturated zone are 170, 90, and 13 years, respectively.

E-1.6.4. Volumetric Water Content

This model is highly sensitive to the volumetric water content. The predicted maximum concentrations to reach the $Tnbs_2$ saturated zone are 0.24, 0.78, and 5.7 µg/L for volumetric water contents of 0.13, 0.17, and 0.21, respectively. The time required for the predicted maximum concentrations to reach the $Tnbs_2$ saturated zone are 40, 90, and 130 years, respectively.

E-1.7. Conclusions

Our model includes the following assumptions:

- Tps TCE mass would instantaneously appear in the top of the $Tnbs_2$ unsaturated zone, by-passing $Tnsc_2$ confining materials.
- TCE must be added in other phases to allow for equilibrium.
- No lateral dispersion or diffusion of TCE occurs; TCE takes only the shortest path vertically downward,
- No volatilization occurs on the top of the $Tnbs_2$.
- Vertical recharge penetrates the $Tnsc_2$ confining materials and enters the top of the $Tnbs_2$ unsaturated zone.
- $Tnbs_2$ aquifer material is homogeneous.
- $Tnbs_2$ aquifer material is isotropic.
- Dilution that will occurs when TCE mixes with the $Tnbs_2$ saturated zone is not included.

Simulation results using mid-range values indicate that TCE concentrations reaching the $Tnbs_2$ saturated zone (resulting from Tps percolate) would be near or below the limit of detection, 0.5 µg/L.

E-2. Evaluation of Tps Perched Water-Bearing Zone as Suitable Public Water Supply

This section evaluates the suitability of the Tps perched water-bearing zone as a potential source of public water supply based on criteria listed in SWRCB Resolution No. 88-63. According to this resolution, all surface and ground waters of the State are considered to be suitable for municipal or domestic water supply except:

a. Water containing TDS exceeding 3,000 mg/L that is not reasonably expected by Regional Boards to supply a public water system.

b. Water contaminated by natural processes or human activity (unrelated to a specific pollution incident) that cannot be treated reasonably for domestic use applying best management practices or best economically achievable treatment practices.

c. Water sources that cannot provide sufficient water to supply a single well capable of producing an average, sustained yield of 200 gpd.

Although the Tps perched water-bearing zone meets the TDS requirement specified in criterion "a" (above), field hydraulic data indicate that it does not meet the minimum sustained yield requirement specified in criterion "c." Criterion "b" is evaluated in Section E-3. The estimation of a low yield is based primarily on drawdown in Tps monitor wells during well development and sampling. Tps wells are routinely pumped "dry" at relatively low flow rates (0.2–0.8 gpm) prior to extracting three casing volumes during ground water sampling events. This low sustained yield precludes conducting long-term aquifer tests. Low-yield water-bearing zones are commonly tested using the slug/bail test method. Such a test was performed on well W-809-01, resulting in a transmissivity (T) of 2.5 gpd/ft (Fig. E-4). Assuming order of magnitude accuracy (i.e., T ranges from 0.25–25 gpd/ft) and a saturated thickness of 5 ft, the maximum yield from this well would be 125 gpd. This result is below the 200 gpd minimum sustained yield criteria specified in SWRCB Resolution No. 88-63.

E-3. Evaluation of Potential for Human Exposure to Tps Ground Water at Concentrations Exceeding Health Based Levels

The Tps ground water plume is contained in a perched water bearing zone that is approximately 500 ft wide by 1,000 ft long and is located entirely onsite. As shown in Figure E-5, the areal extent of saturation in this perched water-bearing zone is limited based on observations made during the drilling of nearby monitor well boreholes. It is unlikely that the areal extent of perched Tps ground water will increase significantly in the future, because all artificial recharge mechanisms have been eliminated or rerouted. Additionally, there are no existing or planned water-supply wells to extract ground water from the Tps perched water-bearing zone.

E-4. Evaluation of Tps Ground Water Extraction Methods

In this section, we evaluate ground water extraction methods for the Tps TCE plume. Ground water extraction and treatment are the only technologies potentially applicable to remediate Tps ground water, although we screen out this approach based on concerns for effectiveness, implementability, and cost. Effectiveness of *in situ* methods such as bioremediation are limited because the Tps water-bearing zone is heterogeneous and of low permeability; therefore, delivery of a bio-reagent to this zone would be ineffective. Soil vapor extraction (SVE) was excluded because TCE soil concentrations are too low to be effectively remediated using SVE.

For this evaluation, we assume that extracted Tps ground water could be treated with the same treatment system discussed in Chapter 2. Three methods of ground water extraction are possible:

1. Vertical ground water extraction wells.
2. Horizontal ground water extraction wells.
3. Ground water interceptor trench.

Pumping from vertical extraction wells is the conventional method for extracting ground water. To be effective, an array of vertical ground water extraction wells must have sufficient sustained yield to adequately capture the ground water contaminant plume. The Tps perched water-bearing zone consists of a series of small, partially saturated lenses of unknown connectivity. Because typical yields from existing monitor wells are so low, we consider ground water extraction from vertical wells to be impractical; therefore, we evaluate two possible alternatives, horizontal wells and trenching.

E-4.1. Horizontal Wells for Ground Water Extraction

An alternative method for extracting ground water from the Tps perched water-bearing zone is to install a horizontal well perpendicular to the direction of ground water flow. To estimate costs, we assume that one horizontal well is installed approximately half way between Tps ground water monitor wells W-815-01 and W-815-03, and five exploratory boreholes are drilled to confirm the presence and depth of ground water at this location. We also assume the length of the borehole to be about 600 ft, and the length of the screen to be about 320 ft.

Because the horizontal drilling method generates a large volume of cuttings, disposal of drilling spoils may present a problem. For waste characterization purposes, we assume that one sample is collected per 100 yards^3 of drilling spoils, and all drilling spoils are disposed of on site.

E-4.2. Interceptor Trench for Ground Water Extraction

An alternative method to installing horizontal wells is to install a screen with standpipes or caissons in an interceptor trench for ground water extraction. To estimate costs, we assume the trench is in the same location as the horizontal well, and five exploratory boreholes are drilled to confirm the presence and depth of ground water. We assume that the trench is installed in 275 ft of unconsolidated soil, a 6-in. screen is installed along the base of the trench and backfilled with gravel to 3 ft below surface, and 3 ft of excavated material is used to backfill to the surface.

We also assume that sufficient ground water is encountered and no excavation or installation-related delays occur. Because trenching generates excess soil, disposal of materials may present a problem. For waste characterization purposes, we assume that one sample is collected per 100 yards^3 of soil, and all excess soil is disposed of on site.

E-4.3. Cost Evaluation

We evaluated the capital costs for two alternatives to extract ground water from the Tps perched water-bearing zone, a horizontal well and an interceptor trench. These capital cost estimates (Tables E-5 and E-6) do not include a contingency factor, operation and maintenance (O&M), long-term monitoring, analytical and data analyses, and administration. We estimate the capital cost to install one horizontal well and one interceptor trench is $475K and $870K, respectively. The effectiveness of either approach is uncertain because of the lateral heterogeneity and lack of interconnectivity within the Tps perched water-bearing zone. To successfully implement either approach, multiple horizontal wells or interceptor trenches may be required.

E-5. References

Lamarre, A. L., H. K. Otsuki, T. D. Epley, D. W. Carpenter, K. G. Fischer, S. Mathews, 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).

Papadopulos, I. S., J. D. Bredehoeft, and H. H. Cooper, Jr. (1973), "On the Analysis of 'Slug Test' data," *Water Resources Research 9*, pp. 1087–89.

U.S. Environmental Protection Agency (1990), *VLEACH—A One Dimensional Finite Difference Vadose Zone Leaching Model, U.S. EPA*, Washington, D.C.

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-21010).

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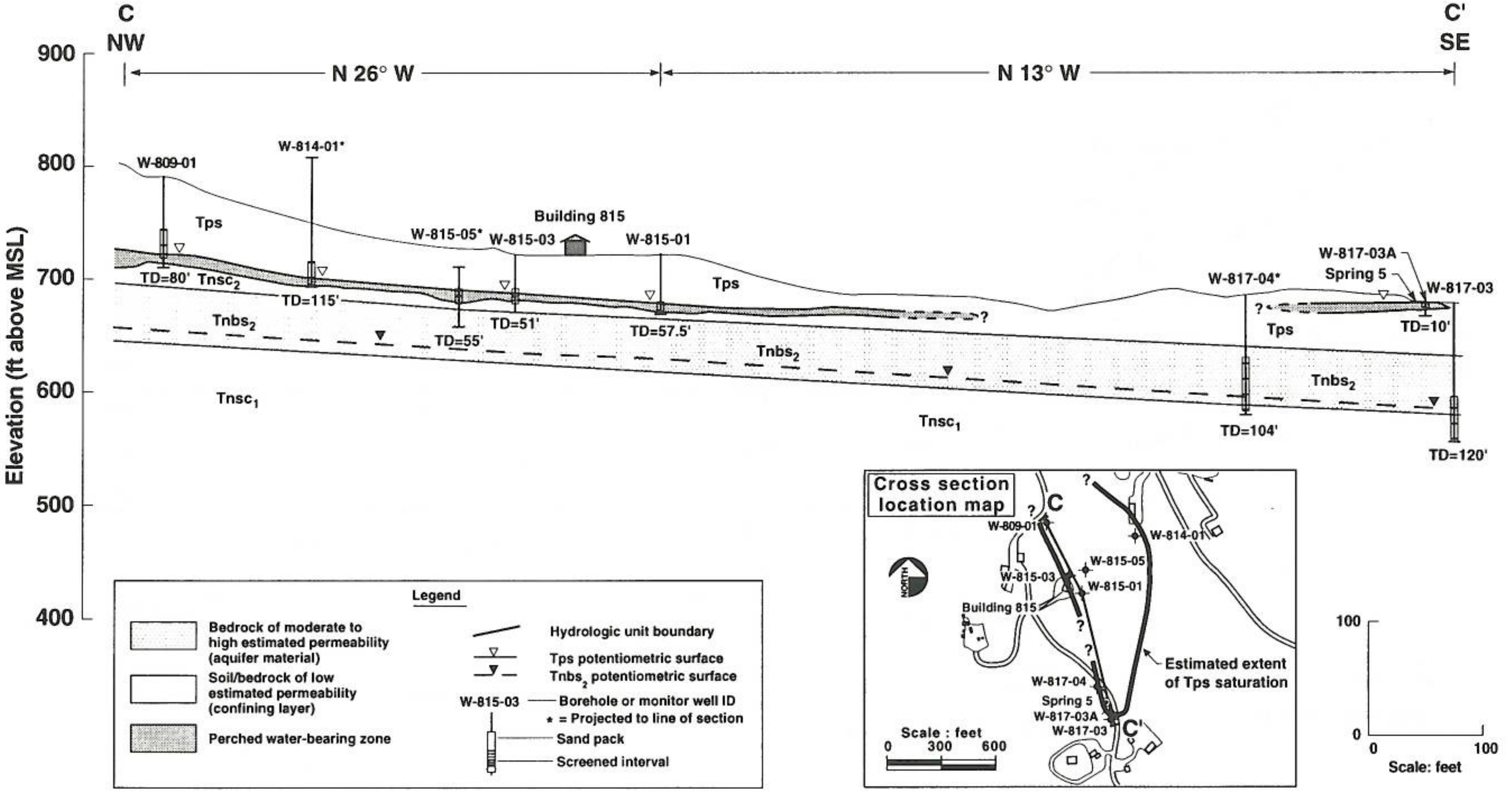
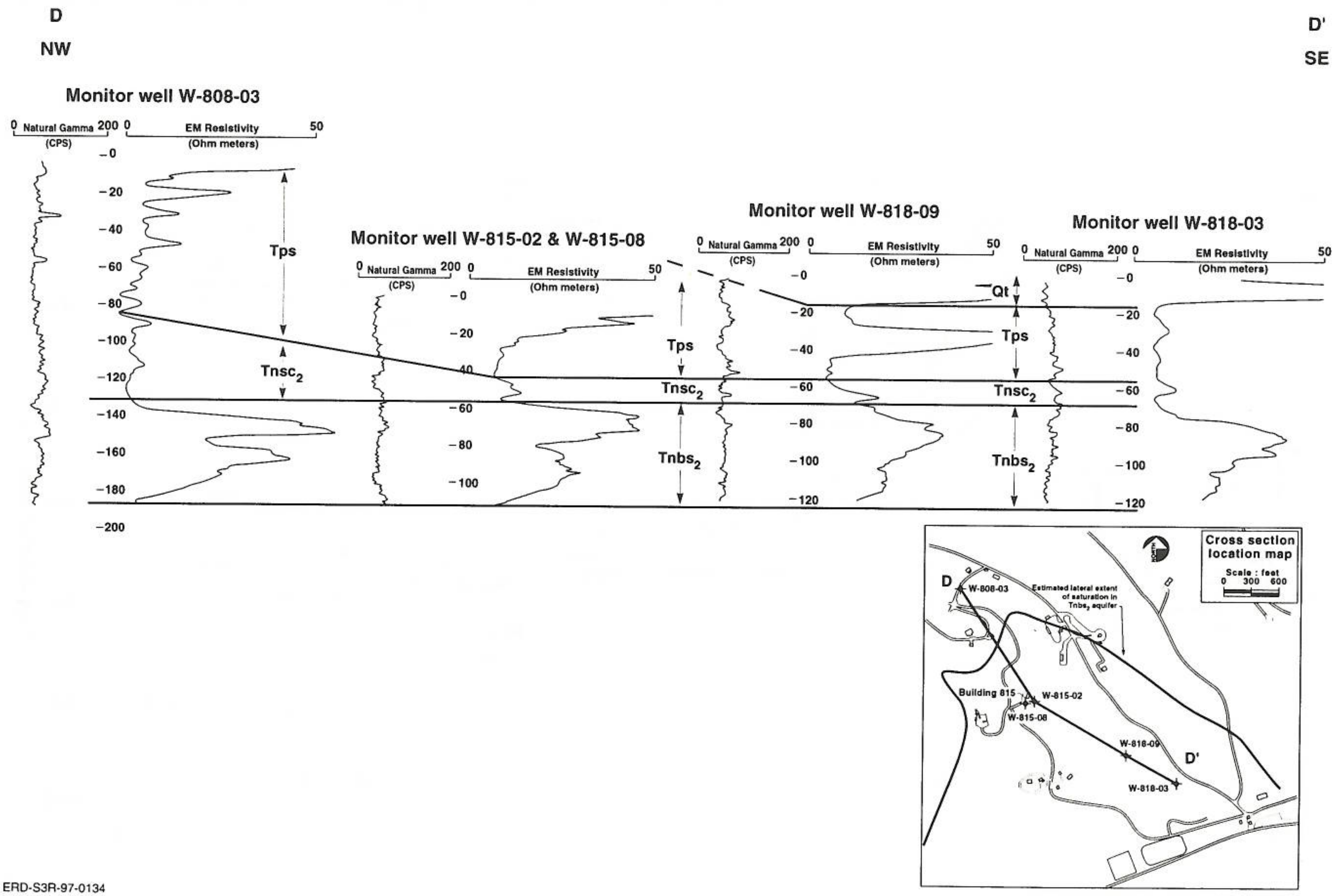


ERD-S3R-97-0133

Figure E-1. Cross section C-C' showing Tps perched water-bearing zone.



ERD-S3R-97-0134

Figure E-2. Geophysical log correlation section D-D' showing Tps hydrologic unit and $Tnbs_2$ aquifer.

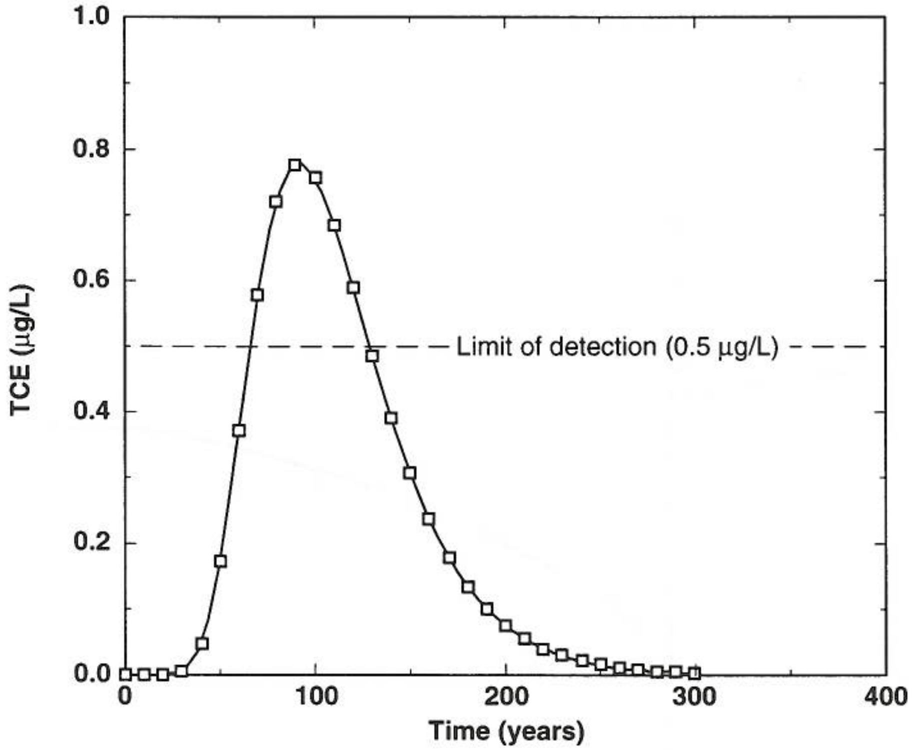


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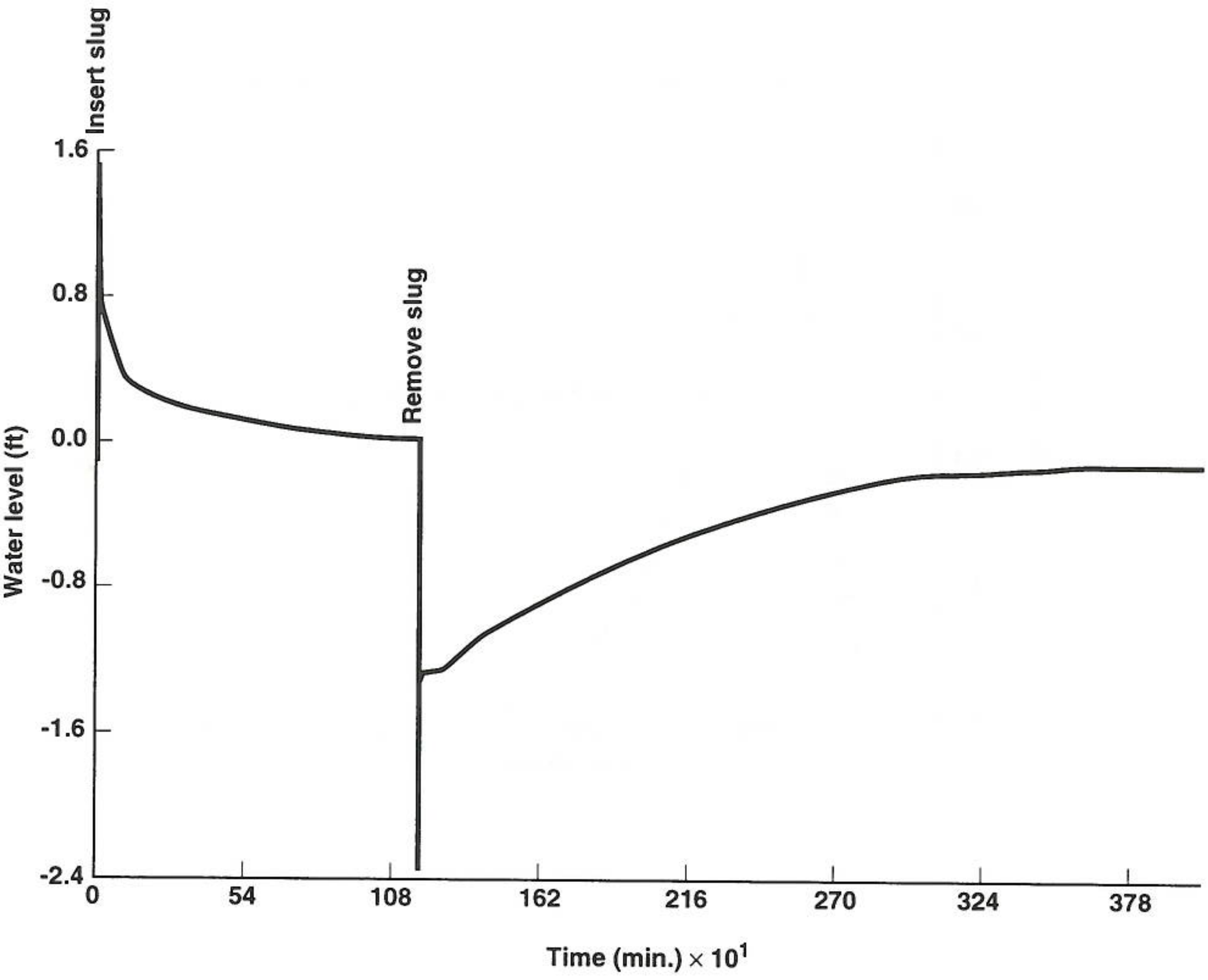
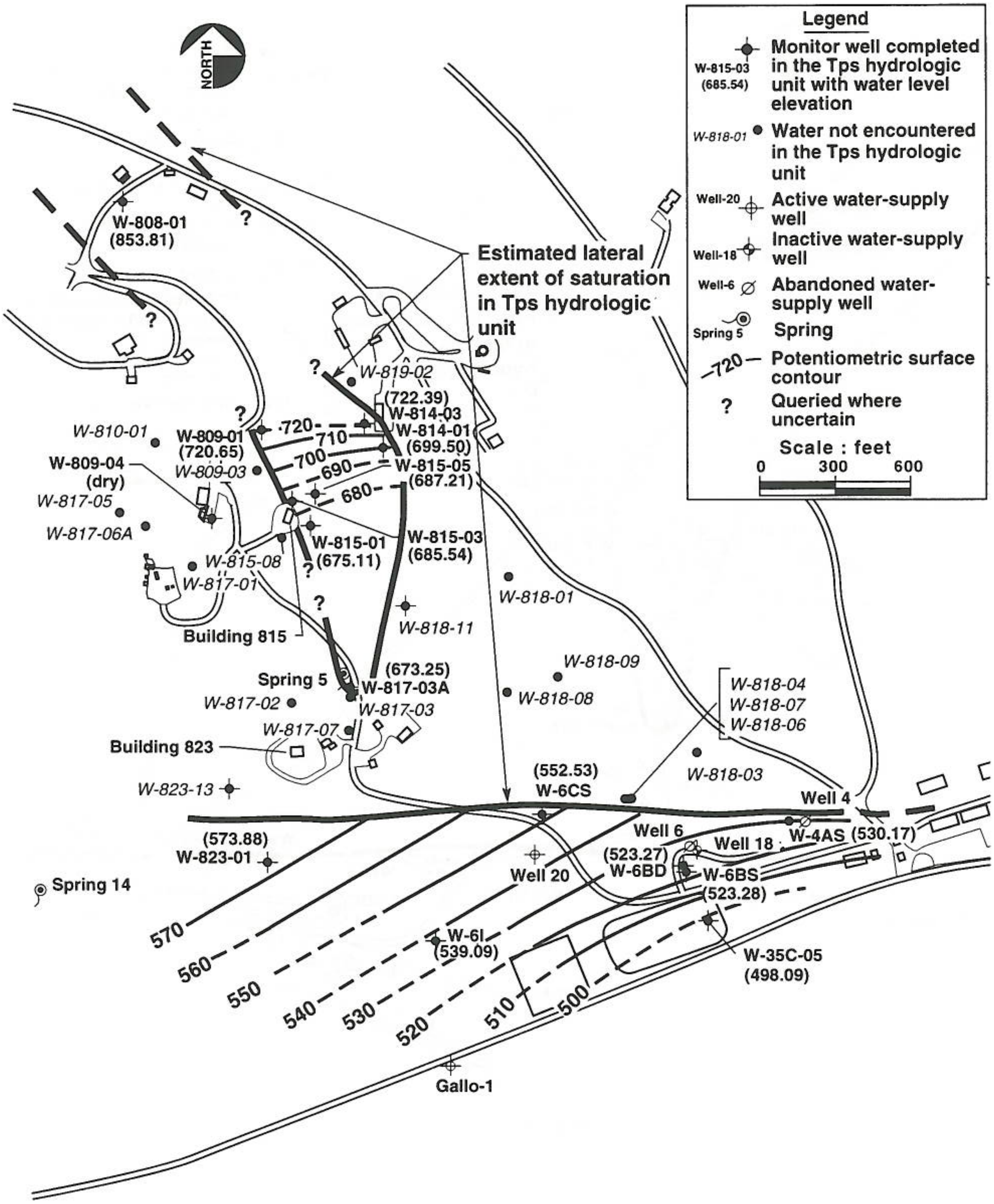
Figure E-3. Aqueous phase TCE concentrations in Tps percolate reaching the saturated portion of the Tnbs$_2$ aquifer.



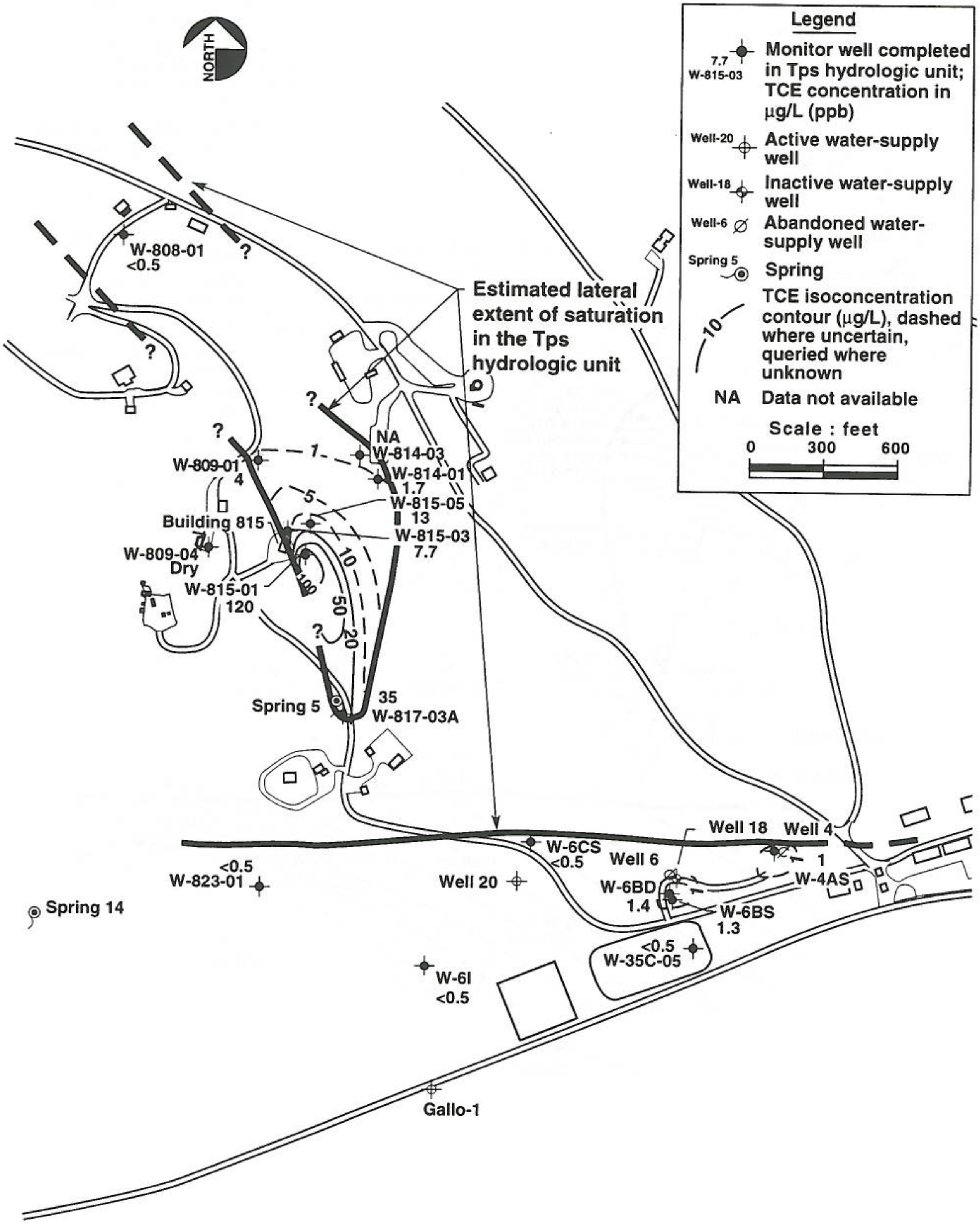
ERD-S3R-97-0136

Figure E-4. Slug/bail test results for Tps well W-809-01.



ERD-S3R-97-0137

Figure E-5. Potentiometric surface map and extent of saturation in the Tps hydrologic unit (first quarter 1995).



ERD-S3R-97-0143

Figure E-6. TCE isoconcentration contour map and extent of saturation in the Tps hydrologic unit (second quarter 1994).

Table E-1. Summary of Tps perched water-bearing zone saturated thickness, total dissolved solids, and yield.

Well	Saturated thickness (ft)	Total dissolved solids (mg/L)	Well test	Analysis	T (gpd/ft)	Pump type	Yield during sampling
W-809-01	5.0	980	slug bail	M. Pap. M. Pap.	1.5 2.5	ww –	<0.2 gpm (dry)
W-814-01	1.5	570	NA	NA	NA	ww	<0.8 gpm (dry)
W-814-03	(dry)	NA	NA	NA	NA	(dry)	(dry)
W-815-01	1.5	780–920	NA	NA	NA	bailer	NA
W-815-03	1.0	740–860	NA	NA	NA	ww	<0.3 gpm (dry)
W-815-05	3.7	800	slug	Pap.	NA	ww	<0.6 gpm (dry)
W-817-03A Spring 5	7.5	1,000–1,100	NA	NA	NA	bailer	NA

Notes:

M. Pap. = Modified Papadopulos method (Papadopulos, 1973).

Pap. = Papadopulos method (Papadopulos, 1973).

ww = Well wizard.

NA = Not available.

T = Transmissivity.

– = Not applicable.

Table E-2. Soil properties for VLEACH modeling.

Property	Value
Porosity (dimensionless)	0.25
Bulk density (g/cc)	2.0
Volumetric water content (dimensionless)	0.17
Organic carbon content (dimensionless)	0.001

Table E-3. Chemical properties for VLEACH modeling.

Property	Value
Organic partitioning coefficient (ml/g)	98
Henry's law constant	0.44
Aqueous solubility (dimensionless)	1,100
Free-air diffusion coefficient (mg/L)	0.43
Degradation half-life (years)	50

Table E-4. Input parameters for VLEACH modeling.

Parameter	Value
Number of polygons	1
Polygon area (ft^2)	150,000
Polygon thickness (ft)	30
Number of cells	120
Cell thickness (ft)	0.25
Calculation time step (year)	0.1
Infiltration rate (ft/year)	0.091
Infiltrating concentration (mg/L)	0.0
Atmospheric concentration (mg/L)	0.0
Ground water concentration—first cell only (g/ft^3)	0.057 (equivalent to 370 g of TCE in the ground water of the first cell)
Ground water concentration—all other cells (g/ft^3)	0.0
Partition coefficient (ml/g)	0.098
Retardation factor (dimensionless)	1.8
Degradation coefficient (1/year)	0.014 (equivalent to a 50-year half-life)

Table E-5. Cost estimate to install a horizontal well for Tps source removal.

Capital cost items	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
Site Preparation				
Grade access roads				60,000
Total site preparation cost				**60,000**
Surface and overburden characterization				
Exploratory boreholes (equipment and labor)	5	Boreholes	5,200	26,000
Analyze samples (121 soil samples, 6 liquid samples including 10% QA/QC samples)	127	Samples	155	19,685
Total characterization costs				**45,685**
Installation of horizontal well				
Well installation	605	Feet	100	60,500
Dedicated pump	2	Each	2,000	4,000
Analysis of cuttings for disposal	2	Sample suite	1,000	2,000
Total horizontal well installation costs				**62,500**
Site Restoration				
Regrade site/restore road				100,000
Total site restoration costs				**100,000**
Subtotal horizonal well costs				**268,185**
Contractor overhead and profit (15% of subtotal field costs)				40,228
Subtotal contractor field costs				**308,413**
LLNL material procurement charge (MPC) (9.7% of contractor field costs)				29,916
Total field costs				**338,329**
Professional environmental services				
Work Plan, Site Safety Plan	40	Hours	75	3,000
Assist with project management	40	Hours	75	3,000
Assist with contractor negotiation	40	Hours	75	3,000
Subtotal professional environmental services				**9,000**

Table E-5. Cost estimate to install a horizontal well for Tps source removal.

Capital cost items	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
LLNL MPC (9.7% of professional environmental services)				873
Total professional environmental services				**9,873**
Total capital costs				**348,202**
LLNL G&A tax (7.5%)				26,115
Subtotal				**374,317**
LLNL LDRD tax (6.0%)				22,459
Subtotal				**396,776**
Contingency (20%)				79,355
Total cost for excavation				**476,131**

Table E-6. Cost estimate to install an interceptor trench for Tps source removal.

Capital cost items	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
Site Preparation				
Grade access roads				60,000
Total site preparation cost				**60,000**
Surface and overburden characterization				
Exploratory boreholes (equipment and labor)	5	Boreholes	5,200	26,000
Analyze samples (121 soil samples, 6 liquid samples including 10% QA/QC samples)	127	Samples	155	19,685
Total characterization costs				**45,685**
Installation of horizontal drains				
Excavation of soil and installation of 6-inch screen with several risers	275	Feet	1,000	275,000
Dedicated pump	2	Each	2,000	4,000
Total horizontal drain installation costs				**279,000**
Waste disposal				
Analytical (one sample/100 yd3)	9	Sample suite	1,000	9,000
Set up of aeration pile	40	Hours	30	1,200
Aeration of soil	72	Hours	30	2,160
Total waste disposal costs				**12,360**
Site Restoration				
Regrade site/restore road				100,000
Total site restoration costs				**100,000**
Subtotal trenching scenario costs				**497,045**
Contractor overhead and profit (15% of subtotal field costs)				74,557

Table E-6. Cost estimate to install an interceptor trench for Tps source removal.

Capital cost items	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
Subtotal contractor field costs				**571,602**
LLNL material procurement charge (MPC) (9.7% of contractor field costs)				55,445
Total field costs				**627,047**
Professional environmental services				
Work Plan, Site Safety Plan	40	Hours	75	3,000
Assist with project management	40	Hours	75	3,000
Assist with contractor negotiation	40	Hours	75	3,000
Subtotal professional environmental services				**9,000**
LLNL MPC (9.7% of professional environmental services)				873
Total professional environmental services				**9,873**
Total capital costs				**636,920**
LLNL G&A tax (7.5%)				47,769
Subtotal				**684,689**
LLNL LDRD tax (6.0%)				41,081
Subtotal				**725,770**
Contingency (20%)				145,154
Total cost for excavation scenario				**870,925**

Appendix F

Cost Estimates and Design Assumptions for the Removal Action at the Building 815 OU

Appendix F

Cost Estimates and Design Assumptions for the Removal Action at the Building 815 OU

This Appendix presents cost estimates and design assumptions for the removal action at the Building 815 OU. These cost estimates were developed in accordance with U.S. EPA guidelines (U.S. EPA, 1987). 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.

These costs may be subject to:

- Changes in ARARs.
- Variations in specific assumptions such as implementation, construction, effectiveness, and system life.
- Changes in dollar value during construction.
- Changes in available equipment and technology at the time of construction.
- Changes in assumed discount rate used in total present-worth costs.
- Changes in applicable LLNL overhead charges such as General and Administrative (G&A), Lab-Directed Research and Development (LDRD), and other applicable LLNL charges such as Material Procurement Charge (MPC), etc.
- 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%.

As presented in Table F-1, we estimated removal action costs based on three cost categories: 1) direct capital, 2) indirect capital, and 3) post-removal site control (PRSC). Whenever possible, we used similar costs based on other Site 300 treatment system installations or used cost quotes from LLNL Plant Engineering.

F-1. General Assumptions Used for Development of Removal Action Cost Estimates

The following general assumptions apply to all three cost categories:

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 LLNL employees (FTEs) are included as required at a rate of $62.45/hr for technicians and administrative support, and $89.47/hr for scientists and engineers. The FTE rate is based on resource estimates for LLNL fiscal year 1997, and includes all applicable LLNL overhead charges (G&A, LDRD, etc.).
3. Subcontractor services are included as required at a rate of $89.85/hr for scientists and engineers. This rate is based on resource estimates for LLNL fiscal year 1997, and includes all applicable LLNL overhead charges (G&A, LDRD, etc.).
4. The LLNL overhead charges on material and professional contract services is estimated to be 13% for purchase orders < $25,000 and 9% for orders > $25,000. This cost includes the MPC on material/equipment costs and professional contract services, and G&A overhead charges applied to the MPC.
5. LLNL Protective Service escorts are not required in the HE Process area at the proposed location of the treatment facilities and aquifer tests during normal operating hours; and therefore, they are not included in these cost estimates. All employees working after normal operating hours will have the required DOE Q-clearance.
6. A 20% contingency will be applied to the capital costs, indirect capital costs, and PRSC costs (Table F-1).

F-1.1. Direct Capital Cost Assumptions

The following activities and assumptions apply to the estimate of direct capital costs for this removal action.

F-1.1.1. Offsite Monitor Well Clusters

1. We assume that Offsite Well Cluster #1 and Offsite Well Cluster #2 will be installed on the Gallo Ranch property.
2. Offsite Well Cluster #1 will consist of two wells in the $Tnbs_2$ aquifer. Offsite Well Cluster #2 will consist of three wells; one completed in the alluvial aquifer and two in the $Tnbs_2$ aquifer.
3. The depth of the wells in each cluster is assumed to be 35 ft for the alluvial aquifer and 210 and 250 ft, respectively, for each of the wells in the $Tnbs_2$ aquifer.
4. The costs for these offsite wells include:
    - Work plan preparation.
    - Materials for installing a 5-in.-diameter Schedule 40 PVC screen and riser.
    - Ground water analytical results.
    - Geophysical logging for the deepest well in each cluster.
    - Well development.
    - Materials and labor for installing dedicated sampling pumps.
5. No analytical samples will be collected from soil.

6. Drill cuttings produced from ground water well installation at these locations are assumed to be clean. Soil cuttings will be disposed onsite.
7. Each well will be fitted with a dedicated pump for sample collection, a concrete pad, a protective steel stove pipe, and a lock.

Operations and maintenance (O&M), activation, project management, and monitoring costs for the treatment facilities are not included in the direct capital costs, but are included with the indirect capital costs and the PRSC costs.

F-1.1.2. Treatment Facility Construction

Construction costs for B815-TF1 and B815-TF2 include: 1) equipment/materials, and 2) labor. These costs are presented separately, except where price quotes have been given as a total estimate.

F-1.1.2.1. Equipment/Materials

1. We assume that existing wells will be used as extraction wells for the treatment facilities. The locations of the extraction wells and treatment systems are shown on Figure 10 of the main text. The proposed extraction wells are outfitted with electric submersible pumps. We assume we can use these pumps for extraction.
2. We assume that B815-TF1 will be located near wells W-6ER and W-35C-04, the extraction wells for this treatment facility.
3. We assume that B815-TF2 will be located near W-818-06, the extraction well for this treatment facility.
4. We assume that treated ground water from B815-TF1 will be gravity discharged to the drainage culvert near the treatment facility.
5. Treated ground water from B815-TF2 will be directed to a temporary storage tank and then be pumped through misting towers at this location.
6. Ground water treatment facilities consist of a particulate filter assembly and 1,000-lb aqueous-phase GAC canisters, connected in series, with associated piping and instrumentation. Two aqueous-phase GAC canisters will be used at B815-TF1 and three GAC canisters will be used at B815-TF2. Two particulate filters will be connected in parallel at each facility so flow can be switched when a buildup of pressure occurs in one of the filters.
7. Plumbing materials to convey extracted ground water include: 1.5-in.-diameter steel piping and 3-in. PVC piping treated for UV-protection. The steel piping will be run from the extraction wells to the treatment system, and supported by unistrut to convey extracted ground water to the treatment facility. The 3-in. PVC will be used to convey treated water to the storm sewer for B815-TF1 and to the misting towers for B815-TF2. We assume that Site 300 Site Planning Department will allow us to install discharge piping aboveground. Landscaping at B815-TF1 will be required by Site 300 Site Planning Department.

8. Electrical controls and instrumentation (i.e., valves, totalizing flow meters, solenoid switches, interlocks, pressure gauges, a multi-channel autodialer, and associated hardware) will be installed to control and monitor the treatment systems.
9. We assume a flow rate of 20 gpm for B815-TF1 and 15 gpm for B815-TF2. Under expected flow and contaminant concentrations, the treatment will reduce VOCs to concentrations at or below 0.5 μg/L.
10. Each treatment facility will be placed on a 15 × 20-ft concrete slab and will be installed by LLNL Plant Engineering Department. The labor and material cost for the concrete is a direct price quote.
11. Landscaping will be performed at B815-TF1 and will meet Site 300 Site Planning requirements. Landscaping costs include installing a chain-link fence around B815-TF1 and extraction well W-35C-04, and planting shrubbery in front of the fence and pipe lines.
12. Materials for the misting system include: a 1.5-in. steel pipe, miscellaneous fittings, and spray nozzles. These costs are based on costs to install a similar discharge system at a Site 300 treatment facility.

F-1.1.2.2. Labor

1. Electrical supply connection costs are estimated to be $20,000. This cost includes: labor and materials used to convey electricity approximately 280 ft from the Well 18 pump house to each treatment facility, and 2) installing a new power pole.
2. We estimate the costs for electrical wiring for each facility to be $15,000. This cost includes the labor and materials used to connect electrical supply lines in the facility and to each of the extraction wells.
3. Treatment facility installation will be performed by ERD technicians. Labor costs are based on estimates from work performed at a similar Site 300 facility.
4. Costs for installing piping and unistrut at the treatment facilities include:

Installation of unistrut by Plant Engineering at a rate of $75.55/hr for 60 hours at B815-TF1 and 10 hours at B815-TF2).

Installation of piping from the extraction wells to the treatment system and from the treatment facility to the discharge point at 300 hours for B815-TF1 and 50 hours for B815-TF2.

Costs to install the piping and unistrut are significantly different because of the short distance between the extraction well and treatment facility at B815-TF2. The cost for installing the unistrut is a direct quote from Plant Engineering personnel.

5. We estimate 150 hours for riggers and plumbers at $75.55/hr and 40 hours for ERD technicians at $62.45/hr to install the misting towers at B815-TF2.

6. B815-TF2 will be automated to ensure that the misting towers operate only in the appropriate ambient air conditions. This estimated cost includes a computer system and an ERD engineer to install it.

F-1.2. Indirect Capital Costs

The following assumptions apply to the indirect capital cost estimations for this removal action.

F-1.2.1. Aquifer Tests

1. Setup costs for aquifer tests include work plan preparation, construction of a treatment unit using materials on hand, and instrumentation of wells with transducers. The treatment unit will be required to treat contaminated ground water from the pumping well during each test. We assume that we will be able to access all of the wells with this treatment unit.
2. We will be performing aquifer tests at four wells for 48 hours each. These wells could include any of the following: W-35C-04, W-6ER, W-6L, W-818-06, W-818-08, W-4A, and W-4B. We will monitor nearby wells and sample the extracted ground water for TCE and nitrates every 8 hours. Additional samples will be collected to monitor potential influence on the RDX plume.
3. Costs include monitoring the tests, as required, to allow for generator refueling and sampling.
4. Extracted ground water will be treated for VOCs using aqueous-phase GAC. Treated water will be pumped from the treatment facility into a storage tank until analytical results confirm that VOCs are beneath detection limits; then the treated water will be discharged to the surface. Costs for storage tanks and analytical samples are included in this estimate.

F-1.2.2. Ground Water Flow and Transport Model

1. Model preparation and calibration includes using available data to develop and calibrate a ground water flow and transport model for the Building 815 OU. Costs for developing and calibrating this model have been included in the budget for this fiscal year and are not included in this estimate.
2. Extraction wellfield management costs include using the model as a decision-making tool for extraction wellfield management during implementation of this removal action.

F-1.2.3. Removal Action Design Document Preparation

1. A RADW document will be prepared to direct construction of the two treatment facilities. This document will be prepared instead of Title I and II documents and will be a scaled-down report.
2. Because a treatment facility similar to the ones proposed in this removal action is presently operating at Site 300, the engineering design of the treatment facilities will

require a minimum amount of effort. Engineering design will be performed by an LLNL FTE.

3. The RADW report will include a description of the treatment facility, with diagrams of extraction well locations and treatment facility schematics. Existing graphics will be used where possible.

F-1.2.4. Treatment Facility Activation

1. Two tests will be required during the activation of B815-TF1 and B815-TF2: 1) Treatment Performance Evaluation, and 2) Proof-of-System. These two tests may be combined into one 48-hour test for each treatment facility. These tests will require setup time for ERD scientists, and ERD technicians will be required to be present during the tests. We assume we can start each of these tests on the same day with a slight lapse in time to allow for adequate sampling time.
2. Analytical costs for these tests include sampling for VOCs at each wellhead, at the mid-point between the GAC canisters, and at the discharge point of the GAC canisters. Treated water will be discharged as specified for each treatment system.
3. Activation costs for the two treatment systems are assumed to be $10,000, which includes the cost for extra materials/equipment that may be required and time for the technicians to make any necessary adjustments.

F-1.2.5. Permits

1. Permit costs to install offsite wells include $89/parcel for two parcels, and a $78/hr fee for the County Health official's inspection of the grout seal. We assume we will grout each well separately, which will require five separate visits at 4 hours for each well inspection.
2. Permit costs for treated water are estimated to be $20,000. This cost includes obtaining a Substantive Requirement discharge agreement for discharge of treated ground water. We assume no other permits are required for construction and operation of the treatment facility.

F-1.2.6 Interim Project Management and Document Preparation

1. Interim project management and document preparation costs include a project manager at 75% for 18 months to prepare the Action Memorandum, analyze data and model results, attend meetings, prepare for and attend the public workshop, track project progress and budget, and coordinate logistics.

F-1.3. Post-Removal Site Control Cost Assumptions

The following assumptions apply to the estimation of PRSC costs for this removal action:

1. Some of the costs have been averaged over a number of years rather than applying charges to the specific year that they will be incurred. These costs include carbon regeneration, waste profiling, capital equipment replacement, and ground water modeling for extraction wellfield management.

2. For the purposes of this document, we have assumed that the treatment facilities will be operated for 20 years. Modeling and the establishment of cleanup standards in the Site-Wide ROD will be used to determine the actual length of time needed to reach the cleanup standards.

3. PRSC costs are presented for one year (Table F-1), and a 20% contingency is added. The adjusted cost is multiplied by 20 years to obtain a total cost for the assumed lifetime of the removal action.

4. A 3.5% discount rate was applied to calculate present-worth costs. This discount rate is based on the Office of Management and Budget (OMB) estimate of government's long-term opportunity costs (OMB, 1992). Operating cost estimates are discounted to 1997 present-worth costs following procedures described in U.S. EPA (1987).

   Present-worth cost estimates occur as a lump-sum investment at the beginning of the project, and the return on the investment exceeds inflation. Therefore, a discount rate is applied to account for the projected net interest income generated over time. The discount rate is based on the anticipated difference in investment return (net interest income) and inflation. For this document, we have assumed an interest rate of 6.5% and an inflation rate of 3%, resulting in a discount rate of 3.5%.

   Project funding will occur incrementally (annually) as the project proceeds rather than as a lump sum investment at the beginning of the project. Therefore, we also present total costs with no discount rate (0.0%).

F-1.3.1. Annual Operations and Maintenance Cost Assumptions for the Treatment Facilities

1. A 90% operating factor is used for the ground water extraction and treatment system at B815-TF1 and 75% at B815-TF2, to allow for routine maintenance and carbon replacement.

2. O&M costs are based on historical costs for the operation of a similar treatment facility at Site 300. O&M costs include labor for annual maintenance and sampling of the ground water extraction and treatment system. Maintenance for the misting towers at B815-TF2 is included under O&M costs.

3. The cost for replacing of spent liquid phase GAC is based on vendor quotes for servicing the GAC treatment units used in the conceptual design. This cost estimate of $2.50/lb of GAC includes waste profiling, removal of spent GAC, offsite thermal regeneration, and replacement with fresh GAC; it also includes all freight and outside labor costs. The cost for carbon regeneration is presented as an average yearly consumption rate.

4. Aqueous-phase GAC consumption rates for ground water treatment at B815-TF1 are based on conservative models generated by Westates Carbon Products. For B815-TF1, a conservative flow rate of 30 gpm with an average concentration of 1.4 ppb TCE was used to calculate GAC consumption. Based on these values, breakthrough was estimated to occur in 7-yr/1,000-lb GAC unit. We have assumed a more conservative rate of carbon use, 5 yr/1,000 lb (200 lb/yr), because of the possibility of biofouling and/or increase in TCE concentrations in the extraction wells. Using a conservative flow rate of 50 gpm

with an average concentration of 62 ppb TCE for B815-TF2, GAC consumption was estimated at 822 lb/yr. We assume that the spent carbon will be hazardous and will be regenerated by the manufacturer. ERD will complete the required manifests.

5. About 10% of the capital equipment cost is included in the annual operating cost to cover materials and replacement parts for maintenance of the ground water extraction and treatment systems. We assume the total installed capital equipment costs subject to this type of maintenance to be $55,000 for B815-TF1 and $49,000 for B815-TF2. Capital equipment costs for B815-TF1 are higher because the additional piping required for this treatment facility.
6. The cost for electricity is estimated at the rate of $0.05 per kW•h. Power consumption for each treatment system is based on 1) the horsepower rating for treatment system components, including ground water extraction well pumps (two for B815-TF1 and one for B815-TF2), and water transfer pump (one for B815-TF2), and 2) percent of time the facility is expected to operate.
7. Discharge permits will require monthly collection of water samples at the ground water treatment system influent and effluent ports. Ten percent of samples will be collected for quality assurance/quality control (QA/QC). We assume that samples will be analyzed for VOCs by EPA Method 8010 at $55/sample. Data input costs are included at a rate of $110/analysis.

F-1.3.2. Annual Monitoring and Compliance

The ground water monitoring program for the proposed removal action, including sampling frequency and analyses, is summarized in Chapter 3 and presented in detail in Tables 4–6 of the main text. The locations of the monitor wells are presented in Figure 10 of the main text.

1. Costs of the ground water monitoring program include:
    - Quarterly water level measurements.
    - Sample collection, analysis, and reporting.
    - Project management.
2. Ground water samples will be collected using dedicated pumps installed in each well. An ERD contractor will sample the wells at $100/well. This cost includes well purging and sample collection. Samples will be collected from 36 wells, for a total of 106 samples each year. The cost for two technicians (at 60 hours each) to pump the purge water into tanks and haul it to the treatment facility is $7,500 every 3 months.
3. Analytical costs are based on rates in existing contracts LLNL has in place with commercial analytical laboratories for standard method detection limits and turn-around-times. The method numbers are presented in Tables 4–6 of the main text. Total costs for each analyte are presented in Table F-1.
4. To account for QA/QC, such as field blanks and duplicate samples, 10% has been added to the total analytical cost.
5. Data input costs are $110/sample analysis.

6. Quarterly reports will be submitted to regulatory agencies. We estimate a preparation cost of $15,000 per report. Costs include data interpretation, TCE mass removal estimates, preparation of elevation contour maps, reporting, and all applicable LLNL overhead charges.
7. Monthly reporting of analytic results and flow measurements for each extraction and treatment system will not be required by discharge permits, they can be included with the quarterly reports.
8. Costs for well and pump maintenance and replacement are not included.

F-1.3.3. Annual Project Management

- We estimate 520 hours for project management of the treatment systems, optimization, data interpretation, meetings, and other project tasks.
- A hydrogeologist will be required to recalibrate the ground water model yearly for extraction wellfield optimization for the first 5 years at 160 hr/yr. Thereafter, the time required for model recalibration will be 80 hours every 5 years. This cost has been averaged over 20 years to standardize yearly costs.

F-2. Cost Summary

Costs for the removal action are summarized below and are presented in detail in Table F-1.

F-2.1. Direct Capital Costs

The estimated direct capital costs, plus a 20% contingency for this removal action, is about $577K.

F-2.2. Indirect Capital Costs

The estimated indirect capital costs, plus a 20% contingency for this removal action, is about $376K.

F-2.3. Post-Removal Site Control Costs

The estimated PRSC costs, plus a 20% contingency for one year of this removal action, is $333K. The 1997 present-worth of the PRSC cost for a 20-year project life is $4.9M. The 1997 present-worth of the PRSC cost for the 2-year period between when the removal action is implemented and when the Site-Wide ROD supercedes the Action Memorandum is $653K.

F-2.4. Total Costs

The total 1997 present-worth costs for this removal action for 20 years is $5.7M. Because project funding will occur incrementally (annually) as the project proceeds rather than as a lump-sum investment at the beginning of the project, we also present the total cost of this removal action with no discount rate. The total cost of this removal action over 20 years at 1997 rates is $7.8M. The total cost for the 2 year-period between when the removal action is implemented and when the Site-Wide ROD supercedes the Action Memorandum is $1.6M.

F-3. References

Office of Management and Budget (OMB) (1992), *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,* Office of Management and Budget, 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).

Table F-1. Proposed removal action costs.

	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
		Direct capital costs		
Offsite monitor well cluster installation				
Offsite well cluster #1	1	cluster	92,000	92,000
Offsite well cluster #2	1	cluster	100,000	100,000
Total offsite monitor well cluster installation				**192,000**
B815-TF1 equipment/materials				
Aqueous-phase GAC (1,000 lb.)	2	each	4,000	8,000
Particulate filter assembly	2	each	4,000	8,000
Plumbing	1	each	7,000	7,000
Controls and instrumentation	1	all	23,500	23,500
Concrete slab	1	each	2,800	2,800
Fencing and landscaping	1	all	10,000	10,000
Total B815-TF1 equipment/materials				**59,300**
B815-TF1 labor				
Running electric to B815-TF1	1	each	20,000	20,000
Wiring B815-TF1	1	each	15,000	15,000
Installation of B815-TF1 major components	300	hour	62.45	18,735
Installation of unistrut and piping	1	all tasks	23,300	23,300
Total B815-TF1 labor				**77,035**
Total costs for B815-TF1				**136,335**
B815-TF2 equipment/materials costs				
Aqueous-phase GAC (1,000 lb)	3	each	4,000	12,000
Particulate filter assembly	2	each	4,000	8,000
Plumbing	1	each	7,000	7,000
Controls and instrumentation	1	all	23,500	23,500
Concrete slab	1	each	2,800	2,800
5,500-gal polyethylene storage tank	1	each	5,700	5,700
Water transfer pump	1	each	1,400	1,400
Misting tower materials	1	all	5,700	5,700
Total B815-TF2 equipment/materials				**66,100**

Table F-1. Proposed removal action costs.

	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
B815-TF2 labor				
Running electric to B815-TF2	1	each	25,000	25,000
Wiring B815-TF2	1	each	15,000	15,000
Installation of B815-TF2 major components	300	hour	62.40	18,720
Installation of unistrut and piping	1	all tasks	4,000	4,000
Misting tower installation	1	all tasks	13,800	13,800
System automation	1	all	10,000	10,000
Total B815-TF2 labor				**86,520**
Total costs for B815-TF2				**152,620**
Subtotal direct capital costs				**480,955**
Contingency (20%)				96,191
Total direct capital costs				**577,146**
Indirect capital costs				
Aquifer tests (W-6ER, W-35C-04, W-6L, and W-818-06)				
Aquifer test set-up	1	all tasks	9,800	9,800
Aquifer testing	4	tests	8,000	32,000
Total aquifer tests				**41,800**
Ground water flow and transport model				
Model preparation and calibration			in progress	0
Extraction wellfield model management	300	hour	89.85	26,955
Total ground water flow and transport model				**26,955**
Removal action design workplan (RADW) preparation				
Document preparation	160	hour	89.47	14,315
Engineering and design	80	hour	89.47	7,158
Total RADW document preparation				**21,473**

Table F-1. Proposed removal action costs.

	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
Treatment facility activation				
Proof of system	1	all	12,500	12,500
Activation	1	all	10,000	10,000
Total activation costs				**22,500**
Permits				
Offsite wells	1	permit	2,000	2,000
Substantive Requirements or other permit	220	hour	89.47	19,683
Total permits				**21,683**
Interim project management and document preparation				
OU management and document preparation	2,000	hour	89.85	179,700
Total interim project management				**179,700**
Subtotal indirect capital costs				**314,111**
Contingency (20%)				62,822
Total indirect capital costs				**376,933**
Post-removal site control costs				
Annual operations and maintenance (O&M) B815-TF1				
O&M labor	520	hour	62.45	32,474
Carbon regeneration and waste profiling	200	lb/yr	2.50	500
Capital equipment replacement	1	each	5,500	5,500
Electric	12,000	kW/hr	0.05	600
Monthly sampling and analysis	12	month	250	3,000
Total annual O&M for B815-TF1				**42,074**
Annual O&M B815-TF2				
O&M labor	620	hour	62.45	38,719
Carbon regeneration and waste profiling	882	lb/yr	2.50	2,205
Capital equipment replacement	1	each	4,900	4,900
Electric	12,500	kW/hr	0.05	625
Monthly sampling and analysis	12	month	250	3,000
Total annual O&M for B815-TF2				**49,449**

Table F-1. Proposed removal action costs.

	Quantity	Unit type	Unit price (1997 $)	Total (1997 $)
Annual monitoring and compliance				
Water level measurement	190	each	13.20	2,508
VOC analysis	136	each	54.50	7,412
HE compound analysis	58	each	98.10	5,690
Nitrate analysis	102	each	10.90	1,112
Data management	296	each	110	32,560
Sampling charges	1	all tasks	40,000	40,000
Quarterly monitoring reports	4	each	15,000	60,000
Total annual monitoring and compliance				**149,282**
Annual project management				
Data analysis and project management	520	hour	79.65	41,418
Additional modeling	52	hour	79.65	4,142
Total project management				**45,560**
Subtotal annual PRSC costs				**286,364**
Contingency (20%)				57,273
Subtotal of annual PRSC costs with contingency				**343,637**
Total PRSC costs, years 1–20				**6,872,746**
Total PRSC present worth, years 1–20 (factor = 14.216)				**4,885,148**
Total PRSC present worth, 2 years (factor = 1.8667)				**652,808**
Total present worth cost for proposed removal action including: direct capital, indirect capital, and PRSC for 20 years (factor = 14.216)				**5,839,227**
Total present worth cost for proposed removal action including: direct capital, indirect capital, and PRSC for 2 years (factor = 1.8997)				**1,606,887**
Total nondiscounted worth of the proposed removal action				**7,826,825**

Acronyms and Abbreviations

Acronyms and Abbreviations

1,1,1-TCA	1,1,1-trichloroethane
ARAR	Applicable or Relevant and Appropriate Requirement
AVI	Active vacuum induced
B815-TF1	Building 815 Treatment Facility 1
B815-TF2	Building 815 Treatment Facility 2
bgs	Below ground water surface
CCR	California Code of Regulations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980, also known as Superfund
CP	Contingency Plan
CRWQCB	California Regional Water Control Board
CVRWQCB	Central Valley Regional Water Quality Control Board
DOE	U.S. Department of Energy
EE/CA	Engineering Evaluation/Cost Analysis
EPA	U.S. Environmental Protection Agency
ft	Feet, foot
FTE	Full-time LLNL employees
g	Gram(s)
G&A	General and Administrative
g/cc	Grams per cubic centimeter
g/ml	Grams per milliliter
GAC	Granulated activated carbon
gal	Gallon(s)
gpd	Gallons per day
gpm	Gallons per minute
GSA	General Services Area
H_2O_2	Hydrogen peroxide
HE	High explosive
HI	Hazard index
hr	Hour(s)

HSC	Health and Safety Code
K	Thousand
K	Hydraulic conductivity
Kd	Distribution coefficient
L	Liter
LDRD	Lab-directed Research and Development
LLNL	Lawrence Livermore National Laboratory
ln	Natural log rhythm
M	Million
mg/L	Milligrams per liter
ml/g	Milliliters per gram
ml/L	Milliliters per liter
MPC	Material procurement charge
NA	Not available
NCF	Not considered further
NRC	National Research Council
O&M	Operations and Management
OMB	Office of Management and Budget
OU	Operable Unit
PCE	Tetrachloroethylene
ppb	Parts per billion
ppm	Parts per million
PRSC	Post-removal site control
QA/QC	Quality Assurance/Quality Control
Qal	Quaternary alluvial deposits
Qt	Quaternary terrace deposits
RADW	Remedial Action Design Workplan
RAO	Removal action objective
RDX	A high explosive
ROD	Record of Decision
RPMs	Remedial Project Managers
RTN	Routine

SVS	Soil vapor survey
SWRCB	State Water Resources Control Board
SWRI	Site-Wide Remedial Investigation
T	Transmissivity
TCE	Trichloroethylene
TDS	Total dissolved solid
$Tnbs_1$	Miocene Neroly Formation lower blue sandstone
$Tnbs_2$	Miocene Neroly Formation upper blue sandstone
$Tnsc_1$	Miocene Neroly Formation middle claystone/siltstone member
Tps	Pliocene nonmarine unit
UV	Ultraviolet
VOCs	Volatile organic compound(s)
WDR	Water discharge requirement
WGMG	Water Guidance and Monitoring Group
WW	Well wizard
yr	Year(s)
µg/g	Micrograms per gram
µg/L	Micrograms per liter

Attachment A

Draft Evaluation of Remedial Alternatives for Building 815 Operable Unit Lawrence Livermore National Laboratory Site 300 (December 1995)

UCRL-AR-122369DR

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Draft Evaluation of Remedial Alternatives for Building 815 Operable Unit Lawrence Livermore National Laboratory Site 300

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Draft Evaluation of Remedial Alternatives for Building 815 Operable Unit Lawrence Livermore National Laboratory Site 300

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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 11/21/95
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Appendices

Executive Summary

This Evaluation of Remedial Alternatives was prepared by Lawrence Livermore National Laboratory (LLNL) for the Building 815 operable unit (OU) of the LLNL Site 300 test facility near Tracy, California. This evaluation is based on the remedial investigation of the High Explosives (HE) Process Area study area presented in Chapter 13 of the Site-Wide Remedial Investigation (SWRI) report (Webster-Scholten, 1994). This document forms the basis for evaluating and selecting remedies to mitigate potential adverse human health effects from contamination in the Building 815 OU. Any remedial action, if required for this OU, would be performed as a non time-critical removal action.

The Building 815 OU is a subarea of the SWRI HE Process Area study area containing the former Building 815 central steam plant and related ground water plumes. This OU is located in the southeast quadrant of Site 300, immediately west of the Site 300 entrance on Corral Hollow Road. Numerous investigations have been conducted in the HE Process Area to identify sources of contamination. These investigations have included sample analyses of surface soil, subsurface soil, and rock; water collected from springs, open boreholes, and monitor wells; and soil vapor from passive and active vacuum-induced (AVI) soil vapor surveys (SVS). As a result of these investigations, compounds of volatile organics and HE were identified as chemicals of potential concern in soil and ground water.

Trichloroethylene (TCE) is the most frequent and widespread volatile organic compound (VOC) detected in ground water. Among the 20 confirmed release sites identified in the study area and described in the SWRI report, the former TCE hardstand near Building 815 is considered to be the primary source of ground water contamination. TCE releases from Building 815 have resulted in a dissolved TCE ground water plume of approximately 145 acres in the $Tnbs_2$ aquifer.

RDX is the most frequent and widespread HE compound detected in ground water. Prior to 1984, process water containing RDX was discharged to the former rinsewater lagoons. RDX releases have resulted in a dissolved ground water plume of about 14.5 acres in the northern portion of the $Tnbs_2$ aquifer.

The SWRI baseline risk assessment for the HE Process Area concluded that the potential additional cancer risk narrowly exceeds the 10^{-6} point-of-departure. This risk would result from 1) residential use of contaminated ground water from a hypothetical water-supply well completed in the $Tnbs_2$ aquifer, or 2) inhalation of VOC vapors in the vicinity of Building 815 or Spring 5. Therefore, remedial objectives for the Building 815 OU are designed to: 1) prevent human exposure to contaminated ground water and vapors at unacceptable concentrations, and 2) address federal, state, and local Applicable or Relevant and Appropriate Requirements (ARARs). In this report, we present and evaluate two remedial alternatives (Alternatives A and B). Both alternatives are evaluated on the basis of 1) overall protection of human health and the environment, 2) compliance with ARARs, 3) implementability, and 4) cost.

Alternative A is a plume containment alternative that achieves the remedial objectives by developing monitoring and contingency plans to properly manage contaminated ground water in the Building 815 OU. The alternative designates compliance wells located at the leading edge of the plume, and specifies trigger criteria for implementing active measures to prevent off-site migration of ground water exceeding maximum concentration limits (MCLs). Under Alternative A, active measures, such as ground water extraction and treatment, would only be implemented if trigger criteria are met. These active measures would be implemented to remediate the southern portion of the plume to the 5.0 µg/L TCE MCL. Alternative A relies on natural attenuation processes to further reduce TCE concentrations.

Alternative B is an aquifer remediation alternative that achieves the remedial objectives by implementing ground water extraction and treatment in the $Tnbs_2$ aquifer to background levels. Both Alternatives include administrative measures to mitigate potential inhalation exposure to VOCs in the vicinity of Building 815 and Spring 5.

For Alternative A, the estimated present-worth cost in 1995 dollars (3.5% discount rate) is $6.4 million (non-discounted cost in 1995 dollars is $10.9 million). This cost estimate is based on a 45-year project life (10 years of initial ground water monitoring, 10 years of remediation, and 25 years of post-remediation monitoring to track natural attenuation of any remaining contaminants in the northern part of the aquifer). The estimated present worth cost of Alternative A in 1995 dollars is $2.9 million, assuming that the contingency actions are not required and only 45 years of monitoring is necessary. For Alternative B, the estimated present-worth cost in 1995 dollars is $20.5 million (non-discounted cost is $65.5 million). This cost estimate is based on a 115-year project life (110 years of remediation, and 5 years of post-remediation monitoring). All costs presented in this report are based on conceptual designs and are not appropriate for budgetary purposes.

1. Introduction

This Evaluation of Remedial Alternatives report was prepared by Lawrence Livermore National Laboratory (LLNL) for the ground water plume at the Building 815 operable unit (OU) at LLNL's Site 300 test facility near Tracy, California. This Evaluation of Remedial Alternatives report is based on the remedial investigation of the High Explosive (HE) Process Area study area presented in Chapter 13 of the Site-Wide Remedial Investigation (SWRI) report (Webster-Scholten, 1994). The SWRI identified Building 815 as a contaminant release source area that could potentially affect human health and/or the environment. As a result of these findings, the contaminated ground water beneath the southern part of the HE Process Area is designated as the Building 815 OU.

1.1. Purpose

The purpose of this report is to evaluate remedial alternatives for addressing potential adverse human health effects that may arise as a result of contamination in the Building 815 OU. The SWRI baseline risk assessment for the HE Process Area calculated that the potential incremental cancer risk exceeded acceptable additional cancer risk levels for 1) residential use of contaminated ground water from the $Tnbs_2$ aquifer, and 2) inhalation of volatile organic compound (VOC) vapors in the vicinity of Building 815 and Spring 5. Therefore, the remedial objectives are to 1) prevent human exposure to contaminated ground water and vapors at concentrations that exceed MCLs, and 2) address Applicable or Relevant and Appropriate Requirements (ARARs).

The ground water contaminant plume in the Building 815 OU is relatively large (145 acres) and dilute (<65 μg/L). The plume is contained in the $Tnbs_2$ bedrock aquifer, which ranges in depth from 50 ft to >100 ft. Given the hydrogeologic characteristics of the HE Process Area and the nature and extent of contamination at the Building 815 OU, the most applicable remedial approach to actively remediate ground water involves ground water extraction and treatment. As presented in Appendix B (Evaluation and Screening of Remedial Technologies), other technologies, such as *in situ* treatment and physical containment, are too costly, difficult to implement, and/or ineffective to be included in the alternatives presented in this report. As a result of this comprehensive screening process, two remedial alternatives evolved. Both alternatives include provisions for ground water extraction and treatment to address the $Tnbs_2$ ground water plume.

Alternative A is a plume containment alternative that achieves the remedial objective for ground water by developing monitoring and contingency plans to properly manage contaminated ground water in the Building 815 OU. The contingency plan designates compliance wells located at the leading edge of the plume, and specifies trigger criteria that would implement active measures, such as ground water extraction and treatment, to prevent off-site migration of contaminant concentrations in ground water exceeding maximum concentration limits (MCLs). Table 1-1 presents MCLs for the primary contaminants in ground water at the Building 815 OU. Alternative B is an aquifer remediation alternative that achieves the remedial objective for ground water by implementing ground water extraction and treatment to remediate all detectable contaminants in ground water in the $Tnbs_2$ aquifer. Alternative B meets requirements specified in the State Water Resources Control Board (SWRCB) Resolution No. 92-49 that requires "complete cleanup of all waste discharged and restoration of affected water to background conditions." Both alternatives include administrative measures to meet the remedial objective for potential inhalation of VOC vapors.

Each alternative is described and evaluated in Chapter 2 on the basis of 1) overall protection of human health and the environment, 2) compliance with ARARs, 3) implementability, and 4) cost. This evaluation provides the basis for selecting and implementing, if necessary, active measures that will adequately protect human health from contaminants in the Building 815 OU. Any remedial action implemented in this OU will be performed as a non-time-critical removal action.

1.2. Description of the HE Process Area

The HE Process Area occupies approximately 934 acres in the southeastern part of Site 300. The area has a steep, hilly terrain with deep northwest-southeast-trending canyons and ravines that drain into Corral Hollow Creek (Fig. 1-1). The area was established in the mid- to late-1950s to chemically formulate HE compounds and to mechanically press and machine these compounds into shaped detonation devices.

The five study areas that border the HE Process Area study area are:

- Pit 6 study area to the west,
- East and West Firing Areas (EFA/WFA) study area to the north,
- Building 834 Complex study area to the northeast,
- Building 832 canyon study area to the east, and
- General Services Area study area to the southeast.

Several privately owned parcels are located south of the HE Process Area study area and offsite, including the:

- Gallo Ranch,
- Elissagary Ranch,
- Connolly Ranch,
- Nelson property,
- Cahill property, and
- Parcels owned by the State of California and the City and County of San Francisco.

Figure 1-2 is a map showing land use and ownership in the area surrounding Site 300.

1.3. Description of Building 815 Operable Unit

Building 815 is the site of the former HE Process Area central steam plant located in the southern part of the study area (Fig. 1-1). Building 815 was identified in the SWRI report as a release source area. The SWRI baseline human health assessment concluded that contaminated ground water in the $Tnbs_2$ aquifer beneath this area could potentially affect human health and the environment. As a result, the contaminated ground water in the $Tnbs_2$ aquifer is defined as the Building 815 OU.

Sixty-four monitor wells have been installed in the southeastern part of the study area (Fig. 1-3). Sixteen of these wells monitor the shallow Tps hydrologic unit, and 26 of these wells monitor the deeper $Tnbs_2$ hydrologic unit in the Building 815 OU. All but two monitor wells (W-6H and W-6I) were installed prior to the completion of the SWRI report. Monitor wells W-6H and W-6I were installed to further define the southern extent of ground water contamination north of the Gallo-1 water-supply well. Well W-6H was installed in the $Tnbs_2$ aquifer, and well W-6I was installed in a water-bearing zone within the Tps hydrologic unit. No volatile organic compounds (VOCs) or HE compounds have been detected in ground water samples from these wells. Data from these wells are presented in Appendix A.

Remediation of the Tps perched water-bearing zone is not included as a component of the proposed remedial alternatives presented in this Evaluation of Remedial Alternatives report. However, the relevant information for excluding Tps ground water remediation from the proposed alternatives is presented in Appendix F.

1.3.1. Hydrogeology of the Building 815 Operable Unit

The hydrologic units of interest in the Building 815 OU include shallow water-bearing zones within the Pliocene non-marine Tps unit of Dibblee (1980) and the $Tnbs_2$ aquifer within the late Miocene Neroly Formation (Tn). These bedrock units are locally overlain by Pleistocene to Holocene terrace, floodplain, ravine-fill, landslide, and colluvial deposits (Carpenter et al., 1991; Dibblee, 1980). Detailed descriptions of the Tps and $Tnbs_2$ hydrologic units are provided in Chapter 3 and Chapter 13 of the SWRI Report. Figure 1-4 is a geologic map of the Building 815 OU showing the location of hydrogeologic cross-section A-A' (Fig. 1-5).

The Tps hydrologic unit is a laterally heterogeneous interval consisting mainly of interbedded siltstone and claystone with discontinuous sand and gravel channels. In the Building 815 OU, shallow perched Tps ground water occurs in multiple, thin gravel channels that generally exhibit low to moderate estimated primary permeability. Figure 1-6 shows the extent of saturation and the potentiometric surface for the Tps hydrologic unit. Monitor wells completed in this unit exhibit relatively low sustainable yields, <200 gallons per day (gpd). As shown in Figure 1-6, perched Tps ground water discharges north of Building 823 at Spring 5. Additional information regarding the Tps water-bearing zone is presented in Appendix F.

The $Tnbs_2$ hydrologic unit is a 60-foot thick, laterally continuous, fine- to medium-grained, moderately to well-sorted, sandstone aquifer with moderate estimated primary permeability. Figure 1-7 shows the extent of saturation and potentiometric surface for the $Tnbs_2$ aquifer, and the approximate location of the Spring 5 fault. As shown, the potentiometric surface contour spacing changes in the vicinity of the Spring 5 fault. The fault appears to be a low-permeability boundary or "leaky" barrier to ground water flow. This aquifer ranges from unconfined conditions beneath Building 815 to confined and flowing artesian conditions near the Site 300 boundary. In properly constructed water-supply wells, the $Tnbs_2$ aquifer is capable of yielding >20 gallons per minute (gpm).

The $Tnbs_2$ aquifer is underlain by the 90- to 100-ft thick, predominantly fine-grained, $Tnsc_1$ confining layer. The $Tnsc_1$ is comprised of interbedded siltstone, claystone, and minor fine-grained sandstone that hydraulically separates the $Tnbs_2$ aquifer from the underlying $Tnbs_1$ aquifer. The $Tnbs_1$ aquifer consists of more than 300 feet of fine- to coarse-grained, conglomeratic sandstone with interbedded siltstone and claystone. This regional aquifer ranges from unconfined conditions north of the HE Process Area to confined and flowing artesian conditions beneath the Building 815 OU. In properly constructed water-supply wells, such as Well 20, the $Tnbs_1$ is capable of yielding >200 gpm.

1.3.2. Nature and Extent of Contamination

Numerous investigations have been conducted in the HE Process Area to identify sources of contamination. These investigations have included sample analyses of surface soil, subsurface soil, and rock; water collected from springs, open boreholes, and/or monitor wells; and soil vapor from passive and active vacuum induced (AVI) soil vapor surveys (SVS). As a result of these investigations, TCE, 1,1-DCA, 1,1-DCE, 1,2-DCA, 1,2-DCE, chloroform, low-level phenolics, tetrahydrofuran, toluene, xylenes (total), HMX, and RDX were identified as chemicals of potential concern in ground water. Ground water contaminant plume maps for TCE, RDX, and nitrate in the Tps and $Tnbs_2$ hydrologic units, are presented in Figures 1-8 through 1-13, though nitrate was not considered a chemical of concern in the SWRI report. Table 1-1 summarizes the MCLs, detection limits, and background concentrations for these chemicals.

As reported in the SWRI report, 87 potential release sites were identified in the initial source screening of the HE Process Area. Of the 87 potential areas, 20 were confirmed as chemical release sites. Among the confirmed release sites, the former TCE hardstand located near Building 815 is considered to be the primary source of VOC ground water contamination. TCE is the most widespread VOC detected in ground water in the Building 815 OU at concentrations exceeding the 5 micrograms/liter (µg/L, or parts per billion, ppb) MCL. VOC releases from the Building 815 area have resulted in a 145-acre, dissolved TCE ground water plume in the $Tnbs_2$ aquifer (Fig. 1-9). TCE has been detected in $Tnbs_2$ monitor well W-830-13 located near the southern end of 832 Canyon. Ongoing investigations suggest that the TCE at this location is part of a plume originating in 832 Canyon and is separate from the Building 815 OU ground water plume.

RDX is the primary HE compound that has been detected in ground water. Prior to 1984, process water containing RDX was discharged to the former HE rinsewater lagoons. Because RDX has a low aqueous solubility (42 milligrams/liter, mg/L, or parts per million, ppm) and low subsurface mobility, the dissolved RDX ground water plume west of Building 815 is relatively small. We are using the USEPA Region IX Preliminary Remediation Goal (PRG) of 0.61 µg/L for drinking water as the health-based standard for RDX because no MCL exists for this compound. As shown in Figure 1-11, RDX has been detected above the PRG in seven $Tnbs_2$ monitor wells located in the northern part of the Building 815 OU.

In addition to VOCs and HE compounds, nitrate has been detected in ground water at concentrations exceeding the MCL of 45 mg/L (ppm) nitrate as NO_3. Process water that was discharged to the former rinsewater lagoons may have also contained dissolved nitrate compounds. Figure 1-13 shows the distribution of nitrate in ground water in the $Tnbs_2$ aquifer.

1.3.3. Ground Water Contaminant Fate and Transport

Using the 2-dimensional saturated flow model PLUME (Webster-Scholten, 1994), we estimated exposure-point concentrations for TCE and RDX in ground water at a hypothetical water-supply well completed in the $Tnbs_2$ aquifer located at the site boundary. These exposure-point concentrations were used in the SWRI baseline risk assessment to estimate additional lifetime cancer risk resulting from residential use of $Tnbs_2$ ground water. Modeling results indicate that TCE would reach the site boundary at a concentration exceeding the 5.0 µg/L MCL in about 10 years, and would reach an average maximum concentration of about 6.0 µg/L at 20 years. Modeling results also indicate that RDX would reach the site boundary at a maximum concentration of 1.32 µg/L in about 600 years.

Also, we conservatively estimated the potential impact of contaminants in the Tps perched water-bearing zone and the $Tnbs_2$ aquifer on the $Tnbs_1$ regional aquifer. We evaluated this impact by modeling the transport of the total mass of TCE and RDX through the $Tnsc_1$ confining unit into the $Tnbs_1$ aquifer. We used these results to model the transport of TCE and RDX to the nearest $Tnbs_1$ water-supply well, Well 20, and a hypothetical well at the site boundary. The model predicted that TCE and RDX would not reach these exposure points at detectable concentrations; therefore, the risk associated with the life-time consumption of water from Well 20 or the hypothetical well would not increase above acceptable levels.

1.3.4. Baseline Risk Assessment

1.3.4.1. Human Health Assessment

The SWRI baseline risk assessment for the HE Process Area consisted of conservative estimates of potential additional lifetime cancer risk and non-cancer hazard associated with:

- Residential use of contaminated ground water from a hypothetical water-supply well at the site boundary,
- Inhalation of VOC vapors in the vicinity of Building 815 and Spring 5,
- Incidental ingestion of and/or dermal contact with contaminated surface soil particles,
- Inhalation of resuspended soil particles.

The results of the baseline risk assessment are summarized in Table 1-2. A more detailed discussion is presented in Chapter 6 of the SWRI report.

The main focus of this Evaluation of Remedial Alternatives report is the Building 815 $Tnbs_2$ ground water plume. The estimated incremental cancer risk from exposure to contaminants in this aquifer exceeds 1×10^{-6}. We address this risk in two proposed alternatives that are described and evaluated in Chapter 2. Relevant information for excluding remediation of the Tps perched water-bearing zone in the proposed alternatives is presented in Appendix F.

The SWRI baseline risk assessment also estimated an incremental cancer risk to adults onsite from inhalation of VOCs volatilizing from Spring 5 water and VOCs volatilizing from shallow subsurface soil in the vicinity of Building 815. The estimated cancer risk from exposure at each of these exposure locations exceeded 1×10^{-6}. We are proposing active measures involving administrative controls in both alternatives that will reduce the potential risk of human exposure to acceptable levels. Because the combined incremental cancer risk resulting from inhalation, dermal contact, or incidental ingestion of resuspended soil particles did not exceed 1×10^{-6}, these pathways are not considered further.

1.3.4.2. Ecological Assessment

In addition to the human health assessment, an ecological assessment was also conducted for the HE Process Area. The ecological assessment consisted of:

- Calculating Toxicity Quotients (TQ) for Spring 5, and
- Calculating Hazard Indices (HI) for ground squirrel, deer, and kit fox.

A more detailed discussion of the ecological assessment for the HE Process Area is presented in Chapter 6 of the SWRI report.

The TQ for copper in Spring 5 exceeded 1 (one) when using the non-promulgated California Applied Action Levels. However, it was below 1 when using the promulgated Federal Ambient Water Quality Criteria. Although these results suggest the potential for ecological impact from Spring 5, no surface water is present and, thus, no complete pathway to ecological receptors exists.

Results of the baseline ecological assessment indicated a potential hazard may exist to ground squirrels and deer from cadmium in surface soil. However, evidence presented in the SWRI report indicates that the overall Site 300 ground squirrel population at Site 300 has not been negatively impacted. In addition, surface soil sampling conducted subsequent to the SWRI report has verified that areas of elevated cadmium concentrations are localized within the developed portions of the site. Therefore, we propose continuing the established biological monitoring program at the site to ensure that no sensitive species move into areas with elevated concentrations of cadmium in surface soil.

1.3.5. Corrective Actions and Facility Upgrades

Activities that led to VOC contamination of ground water in the Building 815 OU include:

- Use of TCE to clean carbon deposits from the former Building 815 steam boiler tubing,
- Surface discharge of steam plant and cooling tower blowdown water from operations at the former Building 815 steam plant.
- Pumping of former water-supply well 6, and
- Discharge to former unlined rinsewater disposal lagoons.

All of these activities have been discontinued.

In 1986, the steam boilers, TCE hardstand, and diesel tank were removed from Building 815, and the building was converted to a compressed-air-supply facility. Prior to 1994, a dry well located about 20 ft north of Building 815 was used for disposal of steam boiler blowdown, cooling tower discharge, and air compressor condensate. In October 1994, all liquid discharges from Building 815 were rerouted to an engineered percolation pit located in the canyon southwest of the building. This rerouting was done to prevent potential mobilization of subsurface contaminants.

The shape of the $Tnbs_2$ TCE ground water plume near former water-supply well 6 resembles the shape of a single-well capture zone. This shape is believed to result from changes in the local hydraulic gradient associated with the pumping of well 6 between 1957 and 1987. Also, poor construction of well 6 probably led to the local upward migration of TCE from the $Tnbs_2$ aquifer into the overlying Tps unit. As shown in Figure 1-8, low concentrations of TCE have been detected in Tps monitor wells W-6BS and W-6BD located near former well 6. This former well was sealed and abandoned to eliminate further influence of the plume by pumping from this well, and to remove it as a potential conduit for vertical contaminant migration.

2. Remedial Alternatives

2.1. Criteria and Evaluation Process

In this chapter, we present and evaluate two remedial alternatives developed for the Building 815 OU. As required, the remedial alternatives are designed to meet the remedial objectives of: 1) preventing human ingestion of $Tnbs_2$ ground water containing contaminant concentrations above MCLs, and 2) preventing the potential inhalation of soil-flux-generated VOCs above MCLs in the vicinity of Building 815 and Spring 5. We also propose continuing the existing biological monitoring program to mitigate potential ecological risk by ensuring that no sensitive species inhabit areas with elevated concentrations of cadmium in surface soils.

Alternative A is a plume containment alternative that accomplishes the remedial objective through ground water monitoring and contingency plans. The contingency plan specifies trigger criteria and active measures, such as ground water extraction and treatment, to prevent contaminants from migrating off site at concentrations exceeding MCLs (Table 1-1). These active measures would only be implemented if the trigger criteria are met. Alternative B is an aquifer remediation alternative that accomplishes the remedial objective by implementing a full-scale extraction and treatment system to remediate ground water contaminants to background concentrations. Both alternatives include administrative controls to 1) reduce to acceptable levels the potential inhalation risk due to soil-flux-generated VOCs, and 2) continue biological monitoring to protect sensitive species from contaminated surface soils.

The main components of each alternative are described and evaluated on the basis of:

- Overall protection of human health and the environment.
- Compliance with ARARs.
- Implementability.
- Cost.

Each of these criteria is discussed below.

2.1.1. 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 met.

2.1.2. Compliance with ARARs

Unless a waiver is obtained, the alternative that is finally selected for this OU must comply with all ARARs.

2.1.3. 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 modified remedial actions.
- Technical feasibility of achieving remedial objectives.
- Effectiveness of monitoring.
- Generation and disposal of hazardous waste.
- Permitting requirements.

2.1.4. Cost

Capital, operation and maintenance, monitoring, and contingency costs are estimated for each alternative. In Appendix G, these estimates are presented as 1995 present-worth costs using a 3.5% discount rate. We also estimated 1) non-discounted costs to account for incremental (i.e., annual) project funding in 1995 dollars, and 2) costs to account for incremental funding with a 3% inflation rate.

2.2. Alternative A—Plume Containment

For the Building 815 OU, Alternative A achieves the remedial objective by implementing plans for ground water monitoring and contingency remedial action. The plans are designed to:

- Identify changes in contaminant concentrations in the $Tnbs_2$ aquifer.
- Evaluate the potential for contaminants to migrate off site at concentrations exceeding MCLs.
- Document that potential human health risks are being properly managed.
- Specify active measures that would be implemented, if necessary, to prevent off-site migration of contaminants at concentrations exceeding MCLs.

Alternative A establishes trigger criteria to evaluate the potential for off-site migration as determined by statistical trend analysis of contaminant concentrations in designated compliance wells located near the site boundary and the leading edge of the plume. Contingent active remedial measures involve the extraction and treatment of ground water. These measures would be implemented to prevent off-site migration only if contaminant concentrations in designated compliance wells exceed trigger criteria (presented in Section 2.2.2.). The extracted ground water would be treated for VOCs and then reinjected into wells strategically located to inhibit further migration of the RDX plume and enhance remediation of the TCE plume. The proposed locations of extraction wells, injection wells, monitor wells, and treatment system for Alternative A are presented in Figure 2-1. Anticipated well yields and contaminant concentrations for the active measures described in Alternative A are presented in Appendix E (Tables E-1 and E-3).

2.2.1. Ground Water Monitoring Plan

The objective of the ground water monitoring plan is to adequately monitor the $Tnbs_2$ aquifer for early detection of contaminants that could migrate off site at concentrations exceeding MCLs. To accomplish this objective, specific $Tnbs_2$ monitor wells located near the site boundary would be designated as compliance monitor wells. Analytical results from these well samples would help determine whether active measures are needed to prevent off-site migration of the plume. In addition, all other existing Tnbs$_2$ monitor wells would continue to be monitored at the monitoring frequencies specified in Table 2-1. Should these monitor wells display a "steady state" or "declining" TCE concentration trend, sampling could be reduced with regulatory concurrence to reduce monitoring costs. If required, any new extraction or monitor wells installed under Alternative A would be monitored quarterly (Table 2-2). All other wells located in the Building 815 OU that monitor zones other than the Tnbs$_2$ aquifer, would continue to be monitored as specified in the Site 300 ground water monitoring program.

Compliance Monitor Wells. Four of the Tnbs$_2$ monitor wells (W-35C-04, W-4B, W-6ER, and W-6H) are designated as compliance monitor wells. These wells would be sampled and analyzed quarterly for VOCs using EPA Method 601, high explosives compounds HMX and RDX using EPA Method 8330, and nitrate (as NO_3) using EPA Method 353.2. As shown in Figure 2-2, these compliance monitor wells are located near the site boundary and the TCE MCL contour of 5.0 μg/L (ppb). Data from these wells would be used to assess whether the trigger criteria have been met and the contingency actions should be implemented.

Two additional monitor wells (W-6CD and W-823-03) would be monitored quarterly. As shown in Figure 2-2, monitor well W-6CD is located downgradient from the 5.0 μg/L TCE contour, and well W-823-03 is located crossgradient from the 5.0 μg/L TCE contour. Because both wells are located 800 ft or more north of the southern site boundary, data from these wells would help determine whether additional compliance monitor wells are needed. If needed, these additional wells would be installed nearer to the site boundary. If installed, data from the new wells may also be used to assess whether the trigger criteria have been met and the contingency actions should be implemented.

2.2.2. Contingency Plan

The response action(s) specified in this contingency plan would only be implemented if monitoring indicates that contaminant concentrations in any of the compliance monitor wells meet the trigger criteria. For purposes of discussion and cost evaluation, we assume that TCE is the most likely contaminant to trigger response actions. The trigger criteria are designed to identify contaminants that could potentially migrate off site at concentrations exceeding MCLs. These criteria are based on two main factors: 1) detection of contaminant(s) at concentrations exceeding MCLs in a ground water sample collected from any of the compliance monitor wells, followed by 2) a statistical analysis of additional confirmatory samples collected during the succeeding 6 mo. The statistical analysis would be used to evaluate whether the average contaminant concentration(s) exceed MCLs or whether an increasing trend is evident in contaminant concentrations.

The trigger criteria are presented in a flow chart (Fig. 2-3) and summarized below:

- If contamination is detected at concentrations exceeding MCLs in any of the compliance wells, two additional samples will be collected within 14 days (at least 7 days apart) and sent to separate analytical laboratories to confirm the initial finding. Collecting the two additional samples will help confirm the validity of the initial data.

- The initial data will be considered anomalous if both confirmatory sample results are below MCLs; in that event, the compliance monitor well(s) will return to their quarterly sampling schedule.
- If one of the two confirmatory samples exceeds MCLs, the initial data will be considered valid.
- Confirmation of the initial finding will be reported to the regulatory agencies within 14 days, and will be followed by monthly sampling for a 6-mo period to provide data for statistical analysis.
- The trigger criteria will be met if statistical analysis of the 6-mo sample data supports the conclusion that contaminants could potentially migrate off site at concentrations above the MCLs. For example, 1) an increasing trend results in the 6-mo mean concentration being above the MCL, or 2) no trend is evident but the 6-mo mean is statistically significantly above the MCLs.
- The compliance monitor well(s) will return to quarterly sampling if the statistical analysis does not support the conclusion that off-site migration of contaminants is imminent at concentrations above MCLs.
- If the statistical analysis is inconclusive, monthly sampling will continue until a conclusion is reached.

Linear regression analysis will be used to determine a "best-fit" line to evaluate the existence of a decreasing or increasing trend in the 6-mo data. If no trend is evident, a standard *t*-test will be used to determine whether the 6-mo mean is significantly above, below, or indistinguishable from the MCL. If the mean of the 6-mo samples is significantly below the MCL and the trend is decreasing or flat, the trigger criteria will not be met and the compliance monitor well(s) will return to their quarterly sampling schedule. Conversely, monthly sampling will continue until a conclusion can be reached if the statistical analysis is inconclusive. For example, 1) the mean of the 6-mo samples is significantly above the MCL but the trend is clearly decreasing; 2) the mean is indistinguishable from the MCL and no trend is evident; or 3) the mean is below the MCL, but an increasing trend indicates that the mean concentration may exceed the MCL in the near future).

If contaminant concentrations exceed ten times the MCL at any time during the 6-mo sampling period, two additional confirmatory samples will be collected within 14 days (but at least 7 days apart), and sent to separate laboratories. The trigger criteria will also be met if one of the two additional samples exceeds ten times the MCL.

2.2.2.1. Contingency Actions

The following response actions will be implemented only if the trigger criteria are met.

- Install two ground water extraction wells near the site boundary, to capture dissolved contaminants.
- Install and operate a ground water treatment system to remove VOCs from extracted ground water.
- Install and operate four injection wells to reinject treated ground water.

- Install additional ground water monitor well(s), if needed, to monitor the performance of the ground water extraction system and verify the proper management of the plume.

The response actions described below are conceptual. Each component is based on our best professional judgment as to the potential nature and extent of contamination that would be present if trigger criteria were met. Because the exact future shape of the ground water plume is uncertain, the scope of one or more of these remedial action components may need revision to address site-specific conditions at the time of implementation.

Under this contingency plan, the objective of ground water extraction would be to prevent off-site migration of ground water contaminants above MCLs. This objective would be accomplished by extracting and treating ground water from two new extraction wells (EW-1 and EW-2 on Fig. 2-1) until concentrations are reduced to below MCLs near the leading edge of the plume. Based on available data from nearby wells, we estimate that each proposed extraction well would yield approximately 20 gpm and create a combined capture zone that would adequately meet the objective of this alternative (Fig. 2-4). Capture zone calculations are presented in Appendix E.

Extracted ground water would be treated for VOCs using aqueous-phase granular activated carbon (GAC). The treatment system for Alternative A is depicted in Figure 2-5. Ground water pumped from the two extraction wells would pass through a particulate filter and then be treated by three, in-series, 1,000-lb GAC canisters to remove VOCs. Treated ground water would be pumped uphill and reinjected into the $Tnbs_2$ aquifer via four injection wells (Figs. 2-1 and 2-4, wells IW-1 through IW-4) at an estimated rate of 10 gpm each. These injection wells would be installed upgradient of the 50 µg/L TCE contour and downgradient of the RDX plume and would serve the following four purposes:

- Increase the ground water gradient to the south, thereby enhancing extraction of TCE.
- Create a ground water mound that would inhibit migration of the upgradient RDX plume.
- Eliminate the high cost of *ex-situ* nitrate treatment.
- Conserve ground water resources by reinjection into the $Tnbs_2$ aquifer.

2.2.2.2. Expanded Ground Water Monitoring Program for Alternative A

If the Alternative A contingency actions were implemented, six additional $Tnbs_2$ wells (two new extraction wells and four new monitor wells) would be installed and monitored. All new wells would be sampled and analyzed quarterly for VOCs, HE compounds, and nitrate (Table 2-2). Tentative locations proposed for monitor wells MW-1 through MW-4 and extraction wells EW-1 and EW-2 are presented in Figure 2-1. Three piezometers would be installed near the extraction wells to help determine the extent of ground water capture, and eight piezometers would be installed near the proposed injection wells to help determine the extent of ground water mounding.

The proposed ground water monitoring program for Alternative A would then require sampling from 12 wells quarterly, 5 semi-annually, and 12 annually during the active remediation process (Tables 2-1 and 2-2). Post-remediation monitoring of all $Tnbs_2$ wells would continue for 25 years to monitor natural attenuation of any remaining contaminants. All non-

$Tnbs_2$ monitor wells would continue to be monitored as specified in the Site 300 ground water monitoring program.

2.2.3. Mitigation of Potential Inhalation Risk at Building 815 and Spring 5

Potential inhalation exposure to VOCs generated by soil flux in the vicinity of Building 815 and Spring 5 would be mitigated by imposing additional access restrictions to the areas. Because the HE Process Area is already a limited-access area, additional controls such as warning signs will provide adequate protection from on-site inhalation exposure to VOCs above MCLs.

2.2.4. Mitigation of Potential Ecological Risk

Within developed portions of the HE Process Area, potential biological exposure to elevated concentrations of cadmium in surface soil will be mitigated through continued biological monitoring. The objective of the monitoring program is to ensure that no sensitive species inhabit areas with elevated concentrations of cadmium in surface soils.

In addition, as part of an ongoing site-wide program of ecological studies, Spring 5 water will be sampled quarterly and analyzed for VOCs, drinking water metals, general minerals, HE compounds, tritium, and gross alpha and beta.

2.2.5. Evaluation of Alternative A

In this section, Alternative A is evaluated against the four evaluation criteria for the Building 815 OU. Table 2-3 summarizes our comparative evaluation of remedial Alternatives A and B, Table 2-4 summarizes the potential federal and state ARARs, Table 2-5 presents the actual ARARs, and Table 2-6 compares estimated costs.

2.2.5.1. Overall Protectiveness of Human Health and the Environment

Alternative A meets the remedial objective of protecting human health through monitoring and contingency plans, and the implementation of administrative controls.

The monitoring and contingency plans specify criteria for early detection and verification of off-site plume migration and specify active measures that would be implemented, if necessary, to extract and treat ground water. Combined with a San Joaquin County prohibition on installation of any new water-supply wells immediately south of the Building 815 OU ground water plume, this alternative meets the remedial objective of preventing human ingestion of ground water containing contaminants above MCLs.

Alternative A meets the remedial objective of preventing potential inhalation of VOCs above MCLs by restricting access to potential exposure areas. Additionally, continued biological monitoring would ensure that no sensitive species inhabit areas with high concentrations of cadmium in surface soils.

2.2.5.2. Compliance with ARARs

Alternative A does not use active measures to meet ARARs; instead, it relies on natural attenuation processes and monitoring with contingency extraction and treatment of ground water to meet the requirements of the Safe Drinking Water Act and State Resolutions 68-16 and 92-49 (Table 2-5).

Reinjection of treated ground water would be regulated under State Resolution 68-16, which protects the beneficial uses of the State's waters. To comply with this ARAR, reinjection wells would be sited to prevent degradation of the $Tnbs_2$ aquifer.

2.2.5.3. Implementability

Equipment, materials, and services are available to install extraction, injection, and additional monitor wells, and to install and operate a treatment system, including the handling of spent GAC. Additional permitting would be required if contingency actions were implemented to reinject treated ground water.

Long-term ground water monitoring is readily implementable and provides a means for 1) monitoring changes in ground water concentrations; 2) measuring the progress of natural attenuation; and 3) evaluating, if necessary, the effectiveness of ground water extraction, treatment, and reinjection. By monitoring the ground water plume, decisions can be made at any time to modify remedial activities or implement additional active measures, if necessary.

The main limitation of Alternative A is the difficulty in maintaining and operating injection wells over long periods of time. Several factors including chemical precipitation, air entrainment, and sand pumping can lead to screen clogging and severely limit injection well performance (Driscoll, 1986).

2.2.5.4. Cost

A detailed cost analysis for both alternatives (A and B) is presented in Appendix G; Alternative A costs are summarized in Figure G-1 and Table G-1. To estimate the cost of Alternative A, we conservatively assumed that the trigger criteria were met after 10 years of monitoring. Furthermore, we assumed that the contingency actions were implemented for a 10-year period (10 years of ground water remediation to MCLs near the site boundary), and 25 years of post-remediation monitoring to monitor natural attenuation of any remaining contaminants.

For cost estimation purposes, we have assumed that all new extraction and monitor wells installed under Alternative A would be monitored quarterly during remediation system operations. Any new piezometers would only be used for water-level measurements; however, samples would occasionally be collected from these wells if deemed appropriate. We also assumed that water-level measurements would be made quarterly in all OU wells throughout the project, and more frequently in selected wells for the first few months of initial system testing and optimization. Post-remediation monitoring would entail annual monitoring of all $Tnbs_2$ wells for a period of 25 years. Should monitor wells display steady-state or declining TCE concentration trends, sampling could be reduced with regulatory concurrence to reduce monitoring costs.

As discussed in Appendix G, present-worth costs represent the amount of money, which, if invested in the initial year of the remedial action and disbursed as needed, would be sufficient to cover all the costs associated with the remedial action. However, it is more probable that funds would be provided incrementally (i.e., annually) throughout the project life. Therefore, we have also prepared cost estimates that assume no present-worth discount rate. Based on these factors, the cost for Alternative A is $10.9 million in 1995 dollars.

The baseline monitoring costs for Alternative A are presented in Appendix G, Table G-1, pages G-1 and G-2. The estimated present-worth cost of Alternative A in 1995 dollars is $2.9 million ($4.9 million non-discounted cost), assuming that the contingency actions are not required and only 45 years of monitoring is necessary (Table 2-6). It should be noted that without ground water extraction and treatment, the monitoring period could exceed 45 years. All costs presented in this report are based on conceptual designs and are not appropriate for budgetary purposes.

2.3. Alternative B—Aquifer Remediation

Alternative B achieves the remedial objective for ground water by implementing active measures that will remediate the ground water in the $Tnbs_2$ aquifer to background concentrations. For this alternative, we would:

- Install 11 extraction wells designed to capture contaminated ground water from the $Tnbs_2$ aquifer.
- Install and operate two ground water treatment systems designed to remove or destroy contaminants in extracted ground water.
- Construct and operate a subsurface-flow wetland to treat nitrate-bearing effluent from the treatment system.
- Install additional ground water monitor well(s) to monitor the performance of the ground water extraction system and verify proper management of the plume.
- Continue ground water-level measurements, especially in the northern part of the OU, to evaluate the impact of ground water extraction activities.
- Consider future installation of injection wells to conserve ground water resources in the $Tnbs_2$ aquifer through reinjection of treated ground water.

The proposed locations of extraction wells, monitor wells, and treatment systems for Alternative B are presented in Figure 2-6. Ground water would be extracted from 11 new extraction wells (EW-1 through EW-11). Anticipated well yields and contaminant concentrations are presented in Appendix E (Tables E-2 and E-4). As shown in Figure 2-7, the combined capture zones would capture all contaminants above MCLs. Capture-zone width calculations are presented in Appendix E.

Extracted ground water would be treated with aqueous-phase GAC to remove VOCs and, if present, HE compounds (Fig. 2-5). Prior to final surface discharge, treated water would then be pumped or gravity-drained to a constructed wetland for natural degradation of nitrates. The treatment systems for Alternative B are illustrated in Figure 2-5 and Appendix C. Because GAC that has adsorbed HE compounds requires additional regeneration steps, we propose two separate GAC facilities: one facility for extraction wells containing HE compounds, and another for extraction wells devoid of HE compounds (Fig. 2-6).

Treatment Facility A, located in the southern part of the OU, would treat ground water extracted from wells EW-1 through EW-4 with an estimated combined flow rate of 36 gpm. Based on the estimated extraction well capture zones and their relation to the RDX plume shown in Figure 1-11, we would not expect to detect concentrations of HE compounds in ground water extracted from these wells. Therefore, spent GAC would be regenerated off site.

Treatment Facility B, located in the north part of Facility A, would treat ground water extracted from seven wells, EW-5 through EW-11, with a combined flow rate of 16 gpm. Ground water extracted from these wells would likely contain detectable concentrations of HE compounds. Prior to shipping spent GAC off site for regeneration, HE compounds would be desorbed from the GAC using a base hydrolysis treatment method developed at LLNL (successfully pilot-tested at the U.S. Department of Energy [U.S. DOE] Pantex Plant in Amarillo, Texas). The effluent from the GAC regeneration process would then be treated using an on-site bioreactor to destroy HE compounds. This process is further described in Appendix C.

Water discharged from the two GAC facilities would be pumped or gravity-drained to a constructed wetland located in the southwestern part of the Building 815 OU (Fig. 2-6). Nitrate concentrations would be reduced in the subsurface-flow wetland via anaerobic denitrification. The system would be designed to reduce the ground water nitrates to background concentrations prior to surface discharge. A discussion of the denitrification process and constructed wetland design, including a schematic cross-section, are presented in Appendix C.

2.3.1. Expanded Ground Water Monitoring Program for Alternative B

Under Alternative B, 15 additional $Tnbs_2$ wells (11 extraction wells and 4 monitor wells) would be installed and monitored. All new wells would be sampled quarterly and analyzed for VOCs, HE compounds, and nitrates (Table 2-7). Proposed locations for the extraction wells and tentative locations for additional monitor wells are shown in Figure 2-6. To help determine the extent of ground water capture, up to 25 piezometers would be installed near the new extraction wells.

The proposed ground water monitoring program for Alternative B would consist of all wells listed in Tables 2-1 and 2-7. Under this Alternative, 21 wells would be sampled and analyzed quarterly, 5 wells semi-annually, and 12 wells annually during remediation. Post-remediation monitoring would consist of annual monitoring of all $Tnbs_2$ wells for 5 years. All non-$Tnbs_2$ wells would continue to be monitored as specified in the Site 300 ground water monitoring program.

2.3.2. Mitigation of Potential Inhalation Risk at Building 815 and Spring 5

Potential inhalation exposure to VOCs generated by soil flux-in the vicinity of Building 815 and Spring 5 would be mitigated by imposing additional access restrictions to the areas. Because the HE Process Area is designated as a limited-access area, additional controls, such as warning signs, will provide adequate protection from on-site inhalation exposure to VOCs above MCLs.

2.3.3. Mitigation of Potential Ecological Risk

Within developed portions of the HE Process Area, potential biological exposure to high concentrations of cadmium in surface soil will be mitigated through continued biological monitoring. The objective of the monitoring program is to ensure that no sensitive species inhabit areas with high concentrations of cadmium in surface soils.

In addition, as part of an ongoing site-wide program of ecological studies, Spring 5 water will be sampled quarterly and analyzed for VOCs, drinking water metals, general minerals, HE compounds, tritium, and gross alpha and beta.

2.3.4. Evaluation of Alternative B

In this section, Alternative B is evaluated against the four evaluation criteria for the Building 815 OU. Table 2-3 summarizes our comparative evaluation of the remedial alternatives, Table 2-4 summarizes the potential federal and state ARARs for the Building 815 OU, and Table 2-6 compares estimated costs for the two alternatives, A and B.

2.3.4.1. Overall Protectiveness of Human Health and the Environment

Alternative B meets the remedial objective of protecting human health and the environment by actively remediating ground water, and by implementing administrative controls. Active remediation would restore and protect the beneficial uses of the $Tnbs_2$ aquifer by reducing contaminants in ground water to background concentrations. Administrative controls would restrict access to potential exposure areas, thereby preventing potential inhalation of VOCs above MCLs. Additionally, continued biological monitoring would ensure that no sensitive species inhabit areas with high concentrations of cadmium in surface soils.

2.3.4.2. Compliance with ARARs

Alternative B uses active remediation to comply with all ARARs. By reducing contaminants to background concentrations, Alternative B meets Safe Drinking Water Act requirements and the requirements of State Resolutions 68-16 and 92-49 (Table 2-5).

2.3.4.3. Implementability

Equipment, materials, and services are available to install extraction and additional monitor wells, and to install and operate treatment systems, including the handling of spent GAC. However, steep terrain in the area will significantly limit the implementability of ground water extraction to remediate the RDX plume. To capture the RDX plume, capture zone analysis indicates necessary placement of extraction wells in the relatively inaccessible steep ravine east of Building 815. If required, the equipment, materials, and services necessary for installing reinjection wells are available. Additional permitting would be required for reinjection of treated ground water.

The technical feasibility of remediating the $Tnbs_2$ aquifer to background levels is uncertain. Site-specific data are not yet sufficient to prove technical impracticability, but future evaluations of remediation progress may conclude that less stringent remediation goals need to be employed. Recent EPA studies of remediation progress at sites across the nation indicate that ground water extraction systems may not be able to reduce contaminant concentrations to federal and state standards (NRC, 1994).

Another factor that could significantly limit the technical feasibility of Alternative B is the relatively slow rate that a pore volume of contaminated ground water can be extracted from the

$Tnbs_2$ aquifer. Capture-zone analysis indicates that the proposed extraction system would flush one pore volume of contaminated ground water every 12 years. In a study of 24 ground water extraction and treatment systems, EPA reports that the only sites where cleanup standards have been achieved in the dissolved part of the plume are sites where the extraction rates exceed one pore volume per year (EPA, 1992a,b in NRC, 1994).

Another significant limiting factor for Alternative B is the finite storage capacity of the $Tnbs_2$ aquifer and the estimated low natural recharge rate. Because of the semi-arid climate, Alternative B would probably dewater the $Tnbs_2$ aquifer before remediating to background levels.

Long-term ground water monitoring is readily implementable and provides a means to monitor changes in ground water concentrations and elevations. This information would be used to evaluate the performance of the ground water extraction system and document the adequate capture of the plume. In addition, ground water elevation data would be used to determine whether reinjection of treated water would be necessary to conserve ground water resources in the $Tnbs_2$ aquifer.

2.3.4.4. Cost

A detailed cost analysis for both alternatives (A and B) is presented in Appendix G; Alternative B costs are summarized in Figure G-2 and Table G-2. The estimated project life for Alternative B is 115 years, and the 1995 present-worth cost is estimated to be 20.5 million dollars. This project life is based on an estimated 110 years to remediate ground water in the $Tnbs_2$ aquifer to background concentrations and five additional years of post-remediation monitoring.

For cost estimation purposes, we have assumed that all new extraction and monitor wells installed under Alternative B would be monitored quarterly during remediation system operations. Any new piezometers would only be used for water-level measurements; however, samples would occasionally be collected from these wells if deemed appropriate. We also assumed that water-level measurements would be made quarterly in all OU wells throughout the project, and more frequently in selected wells for the first few months of initial system testing and optimization. Should monitor wells display steady-state or declining TCE concentration trends, sampling could be reduced concurrence to reduce monitoring costs. The Alternative B cost estimation does not include the cost of implementing a water reinjection system to replace ground water resources in the $Tnbs_2$ aquifer. Post-remediation monitoring would entail annual monitoring of all $Tnbs_2$ wells for a period of 5 years.

As discussed in Appendix G, present-worth costs represent the amount of money, which, if invested in the initial year of the remedial action and disbursed as needed, would be sufficient to cover all the costs associated with the remedial action. However, it is more probable that funds would be provided incrementally (i.e., annually) throughout the project life. Therefore, we have also prepared cost estimates that assume no present-worth discount rate. Based on these factors, the cost for Alternative B is $65.6 million in 1995 dollars. All costs presented in this report are based on conceptual designs and are not appropriate for budgetary purposes.

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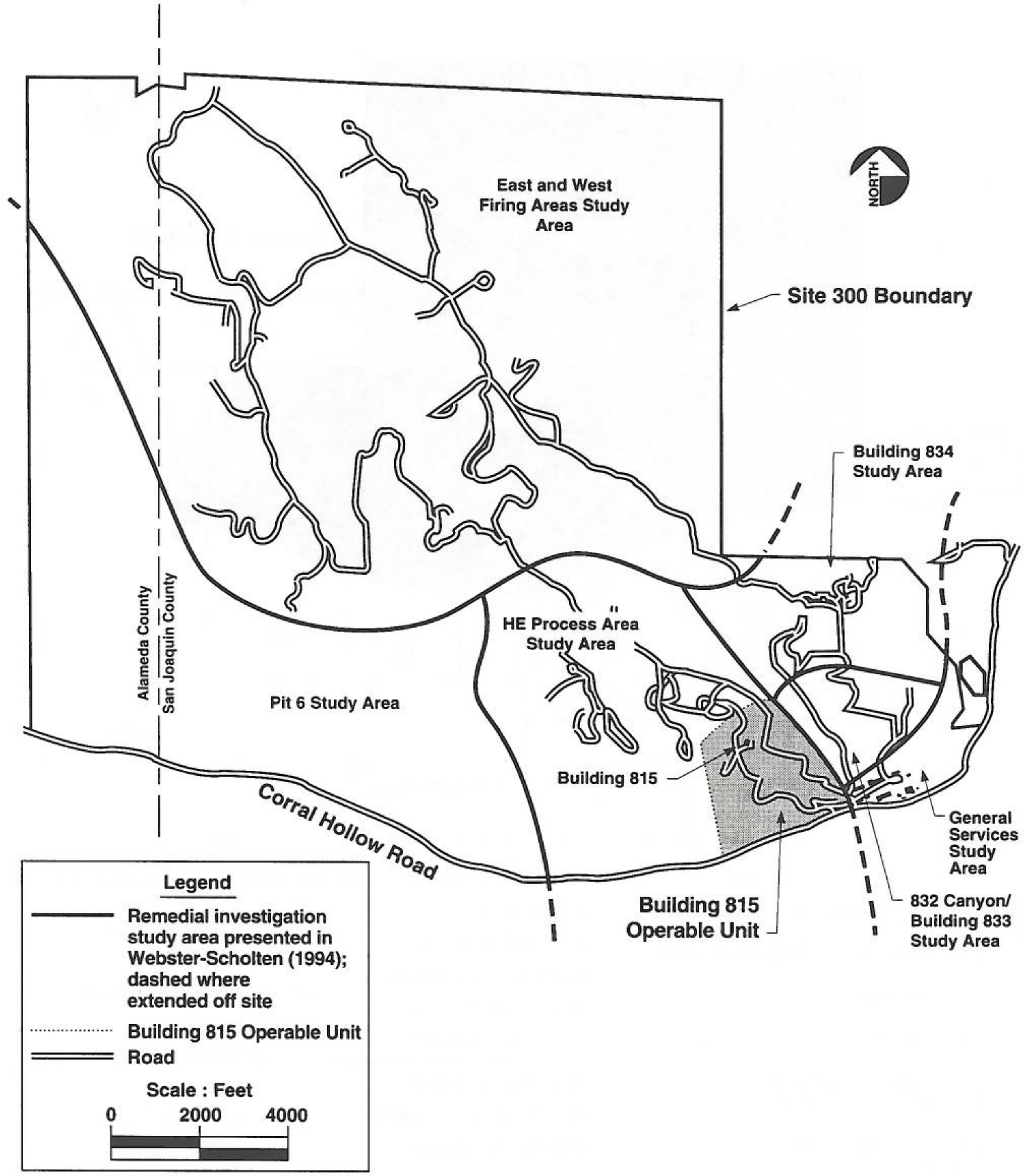
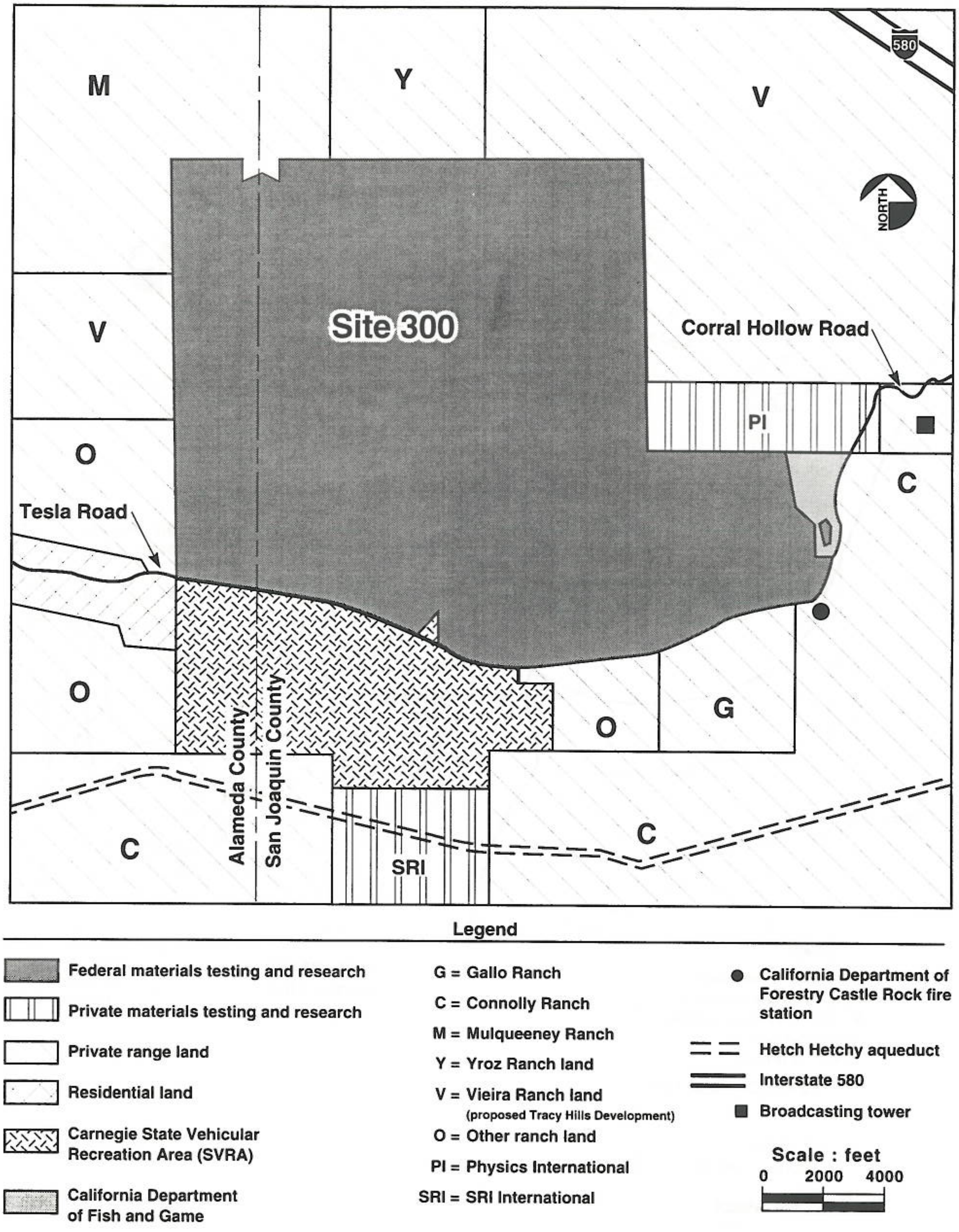
Webster-Scholten, C. P., Ed. (1994), *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-21010).

Figures



ERD-ERA-815-0001

Figure 1-1. Delineation of study areas at LLNL Site 300 and location of Building 815 Operable Unit.



ERD-ERA-815-0002

Figure 1-2. Land use in the vicinity of Site 300.

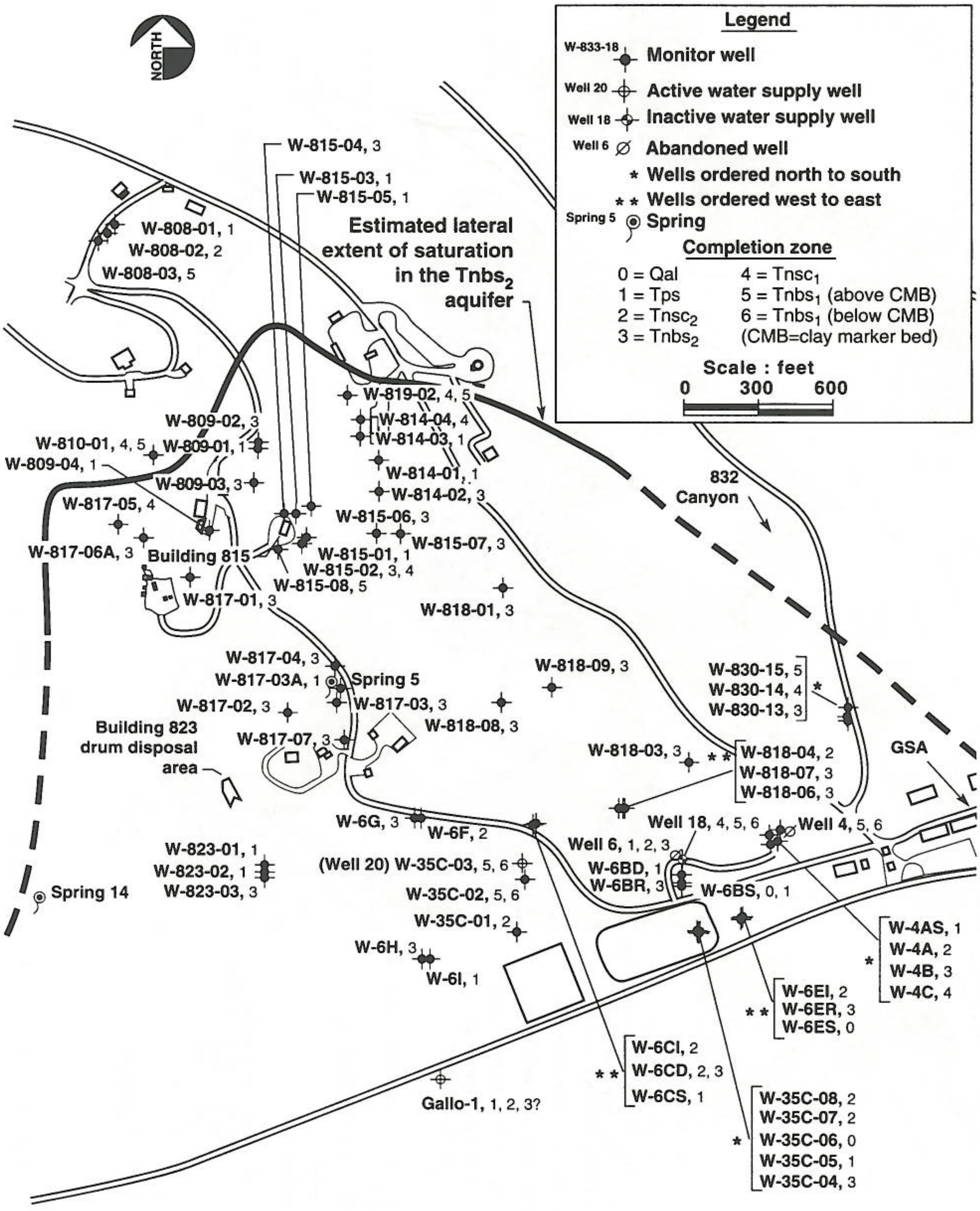


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Figure 1-3. Monitor well locations and completion zones in the southeastern part of the HE Process Area.

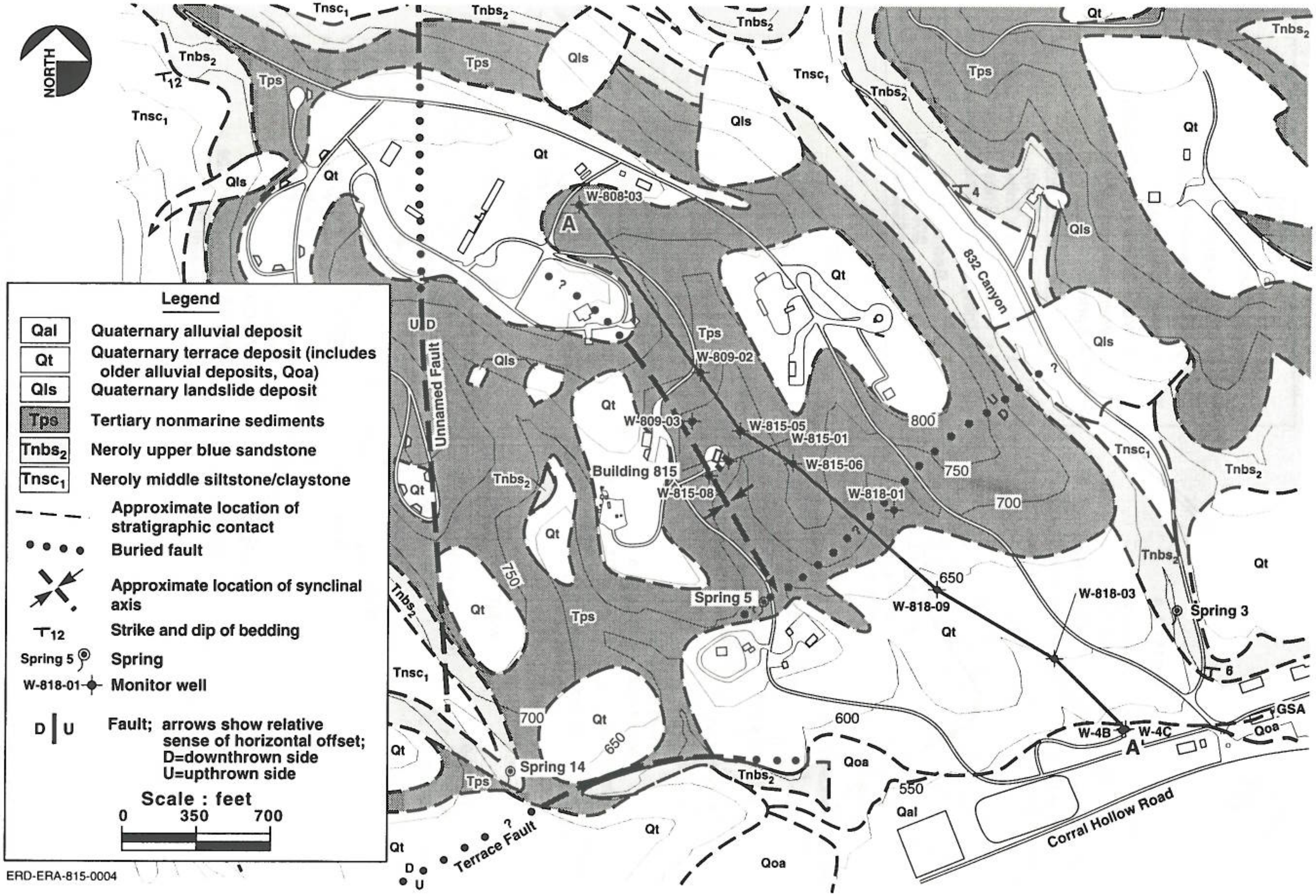


Figure 1-4. Geologic map of HE Process Area showing location of hydrogeologic cross section A-A'.

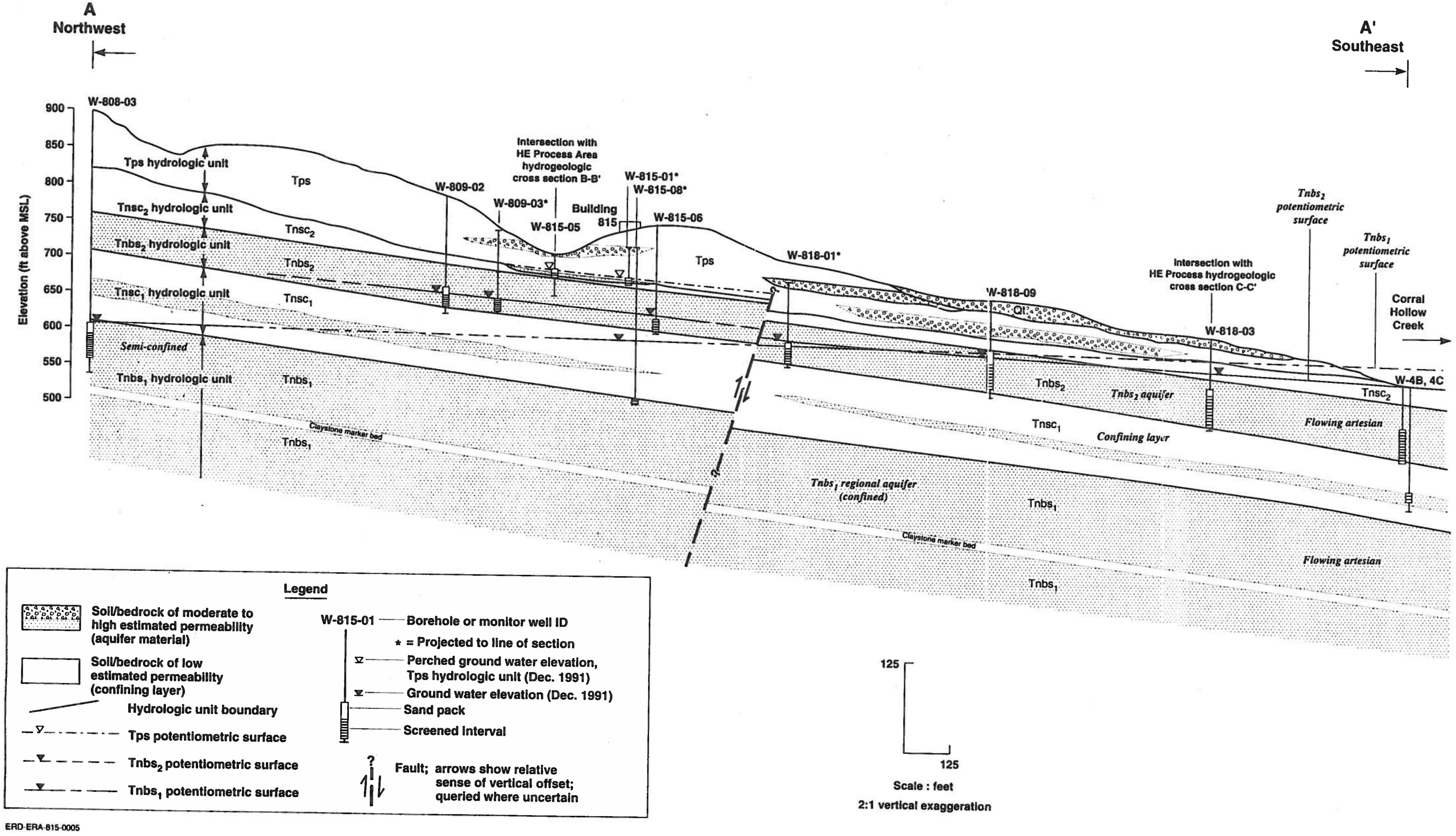
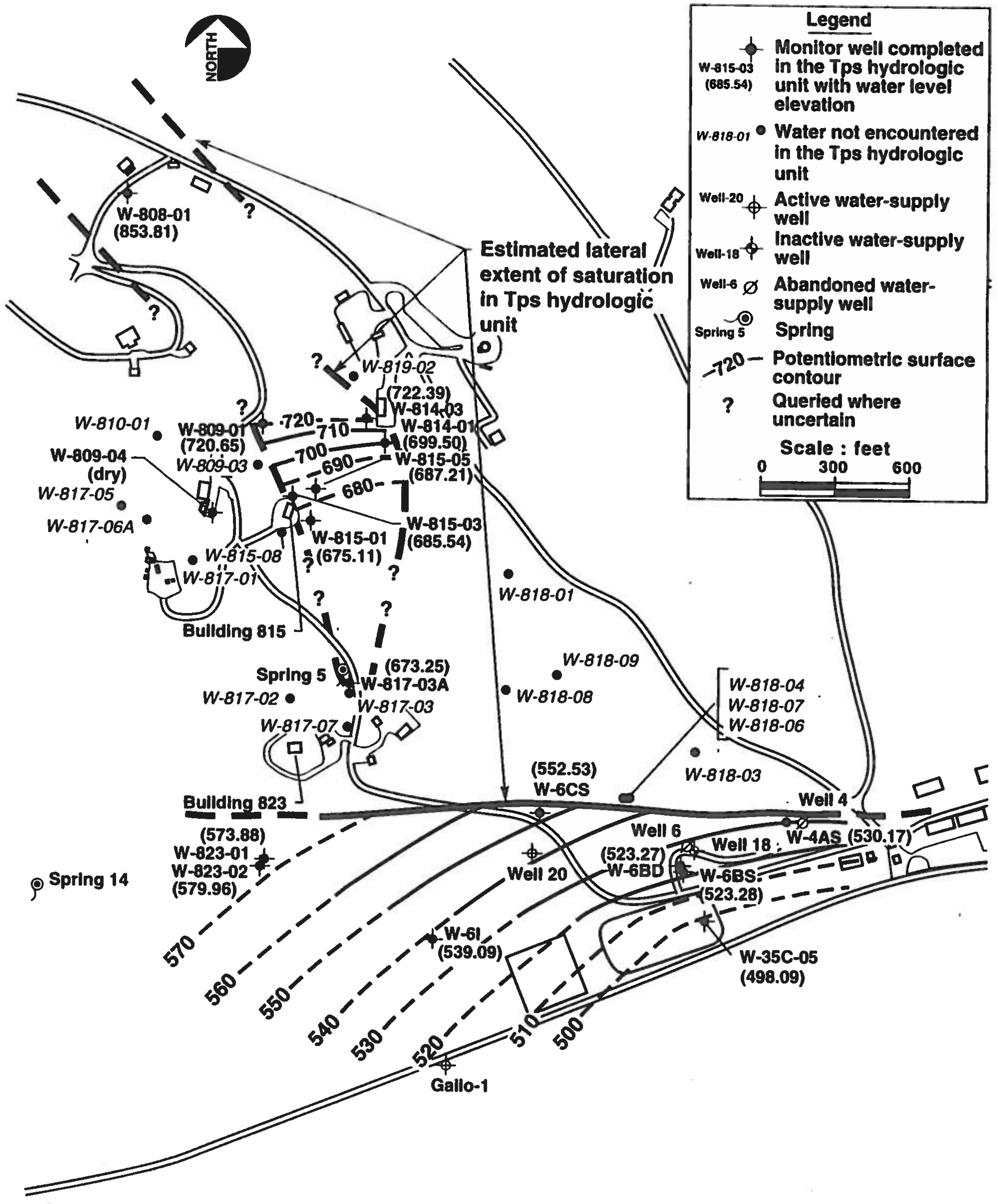
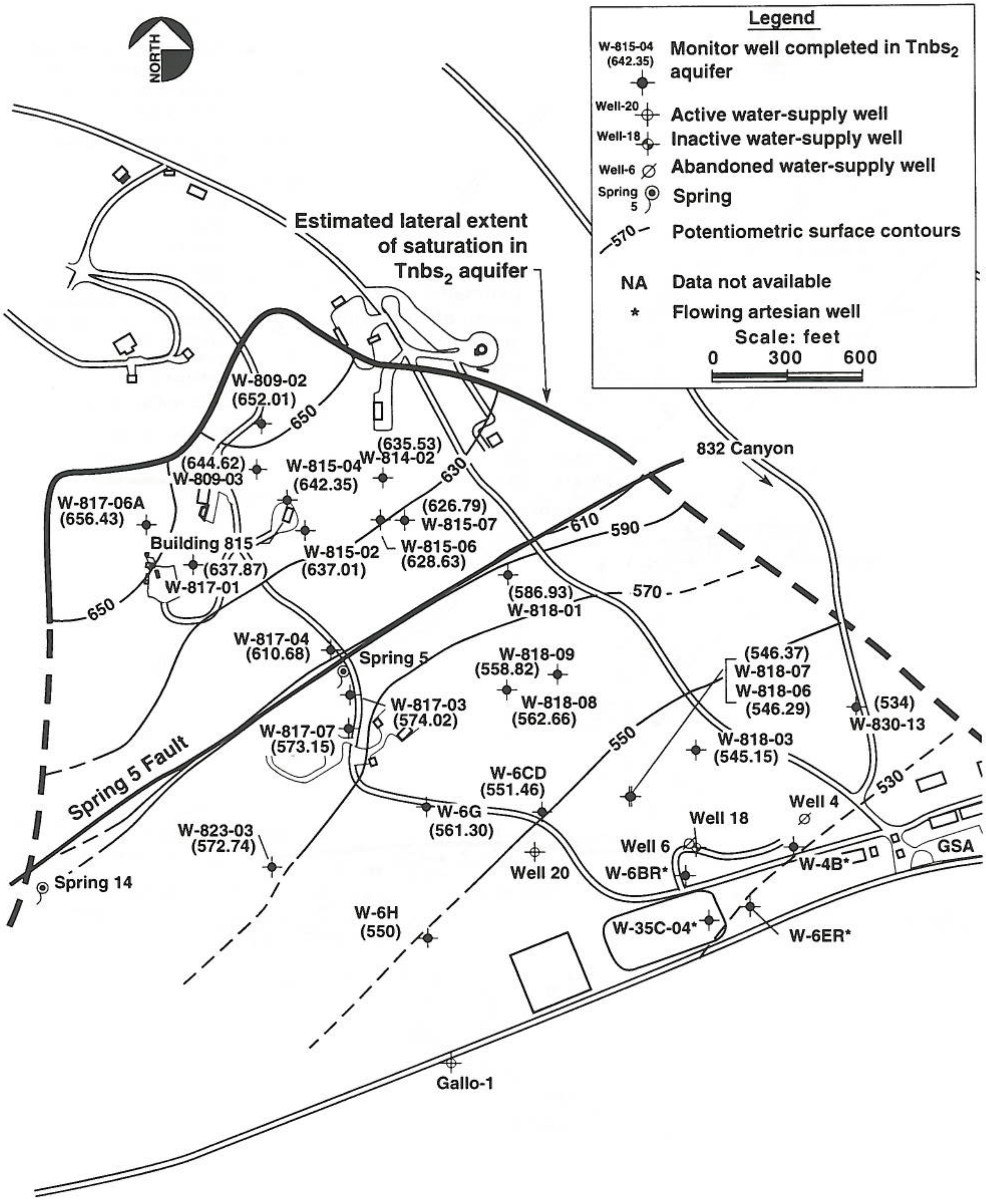


Figure 1-5. Hydrogeologic cross section A-A', HE Process Area study area.



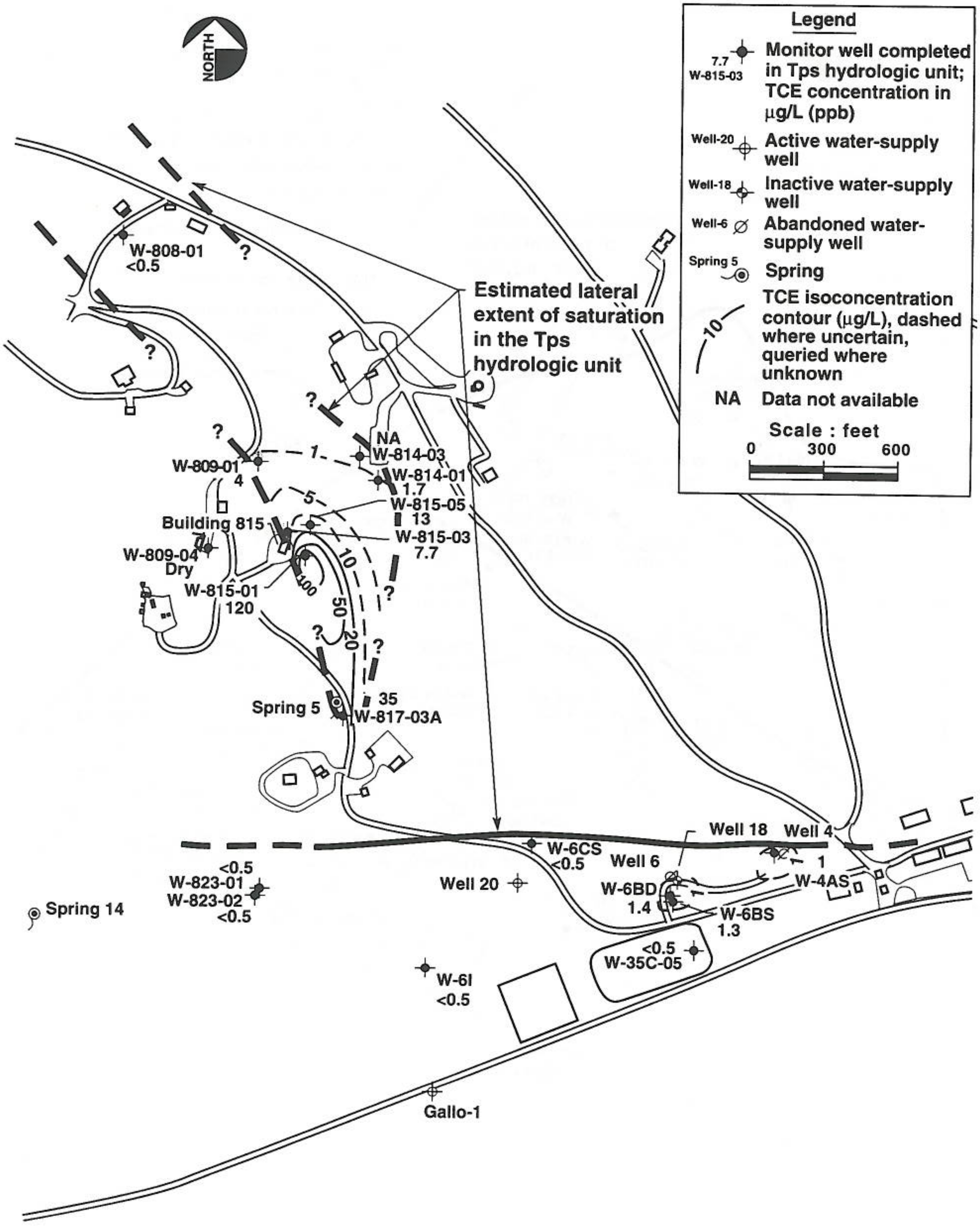
ERD-ERA-815-0006

Figure 1-6. Potentiometric surface map and extent of saturation in the Tps hydrologic unit (First quarter 1995).



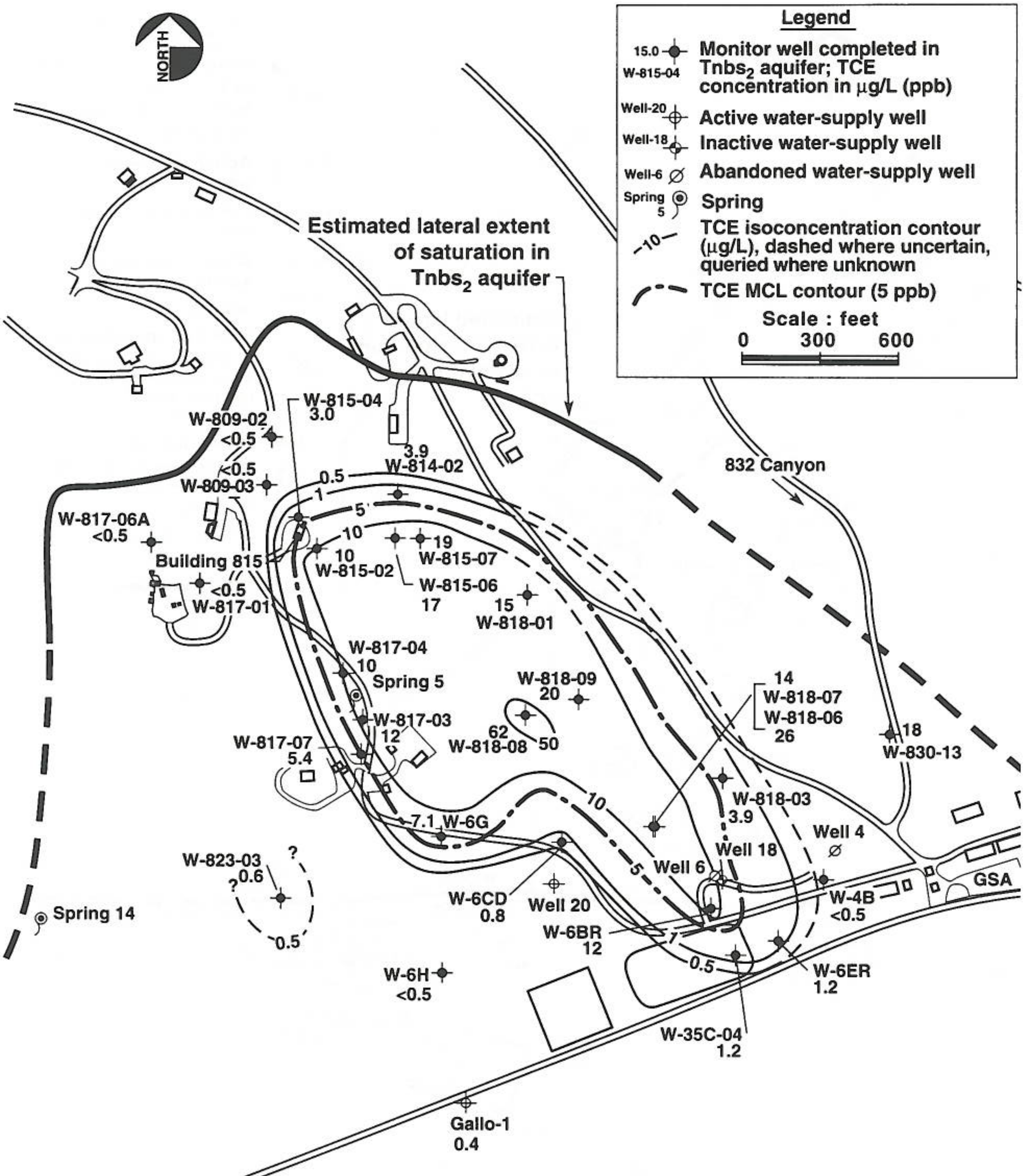
ERD-ERA-815-0007

Figure 1-7. Potentiometric surface map and extent of saturation in the Tnbs$_2$ aquifer (Fourth quarter 1994).



ERD-ERA-815-0008

Figure 1-8. TCE isoconcentration contour map and extent of saturation in the Tps hydrologic unit (Second quarter 1994).



ERD-ERA-815-0009

Figure 1-9. TCE isoconcentration contour map in the Tnbs$_2$ aquifer (Second quarter 1994).

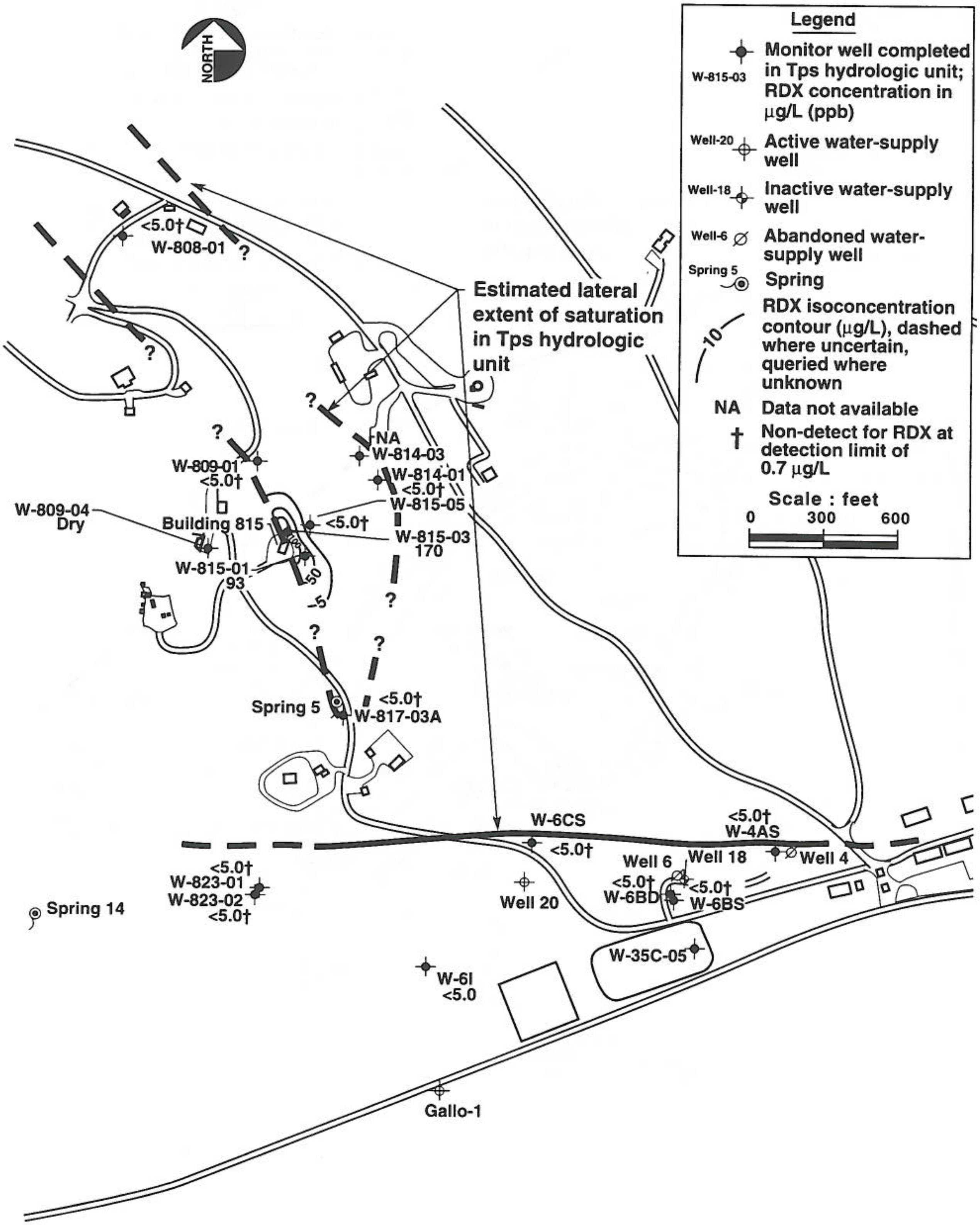


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Figure 1-10. RDX isoconcentration contour map in the Tps hydrologic unit (Fourth quarter 1994–Second quarter 1995).

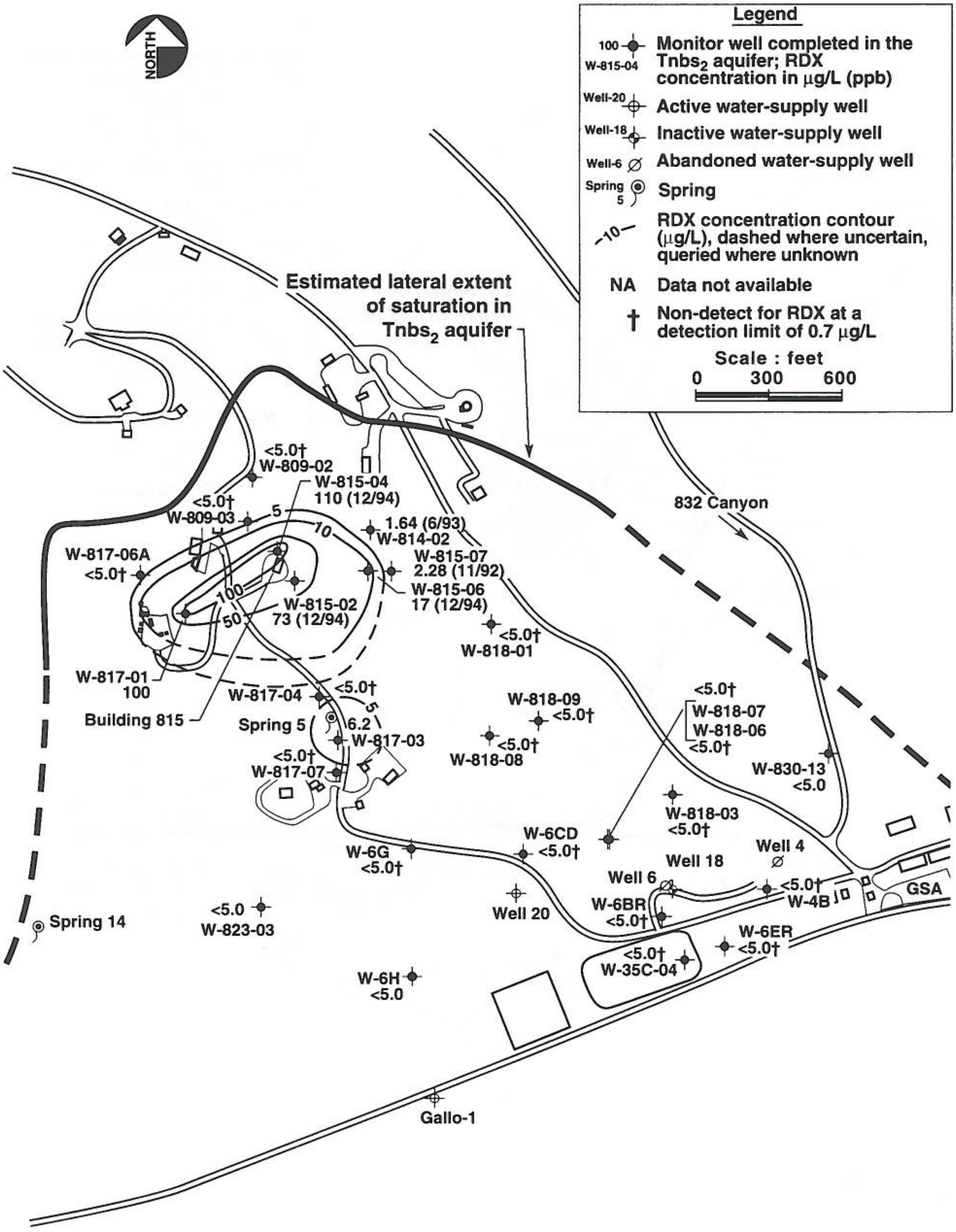

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Figure 1-11. RDX isoconcentration contour map in the $Tnbs_2$ aquifer (Fourth quarter 1994–Second quarter 1995).

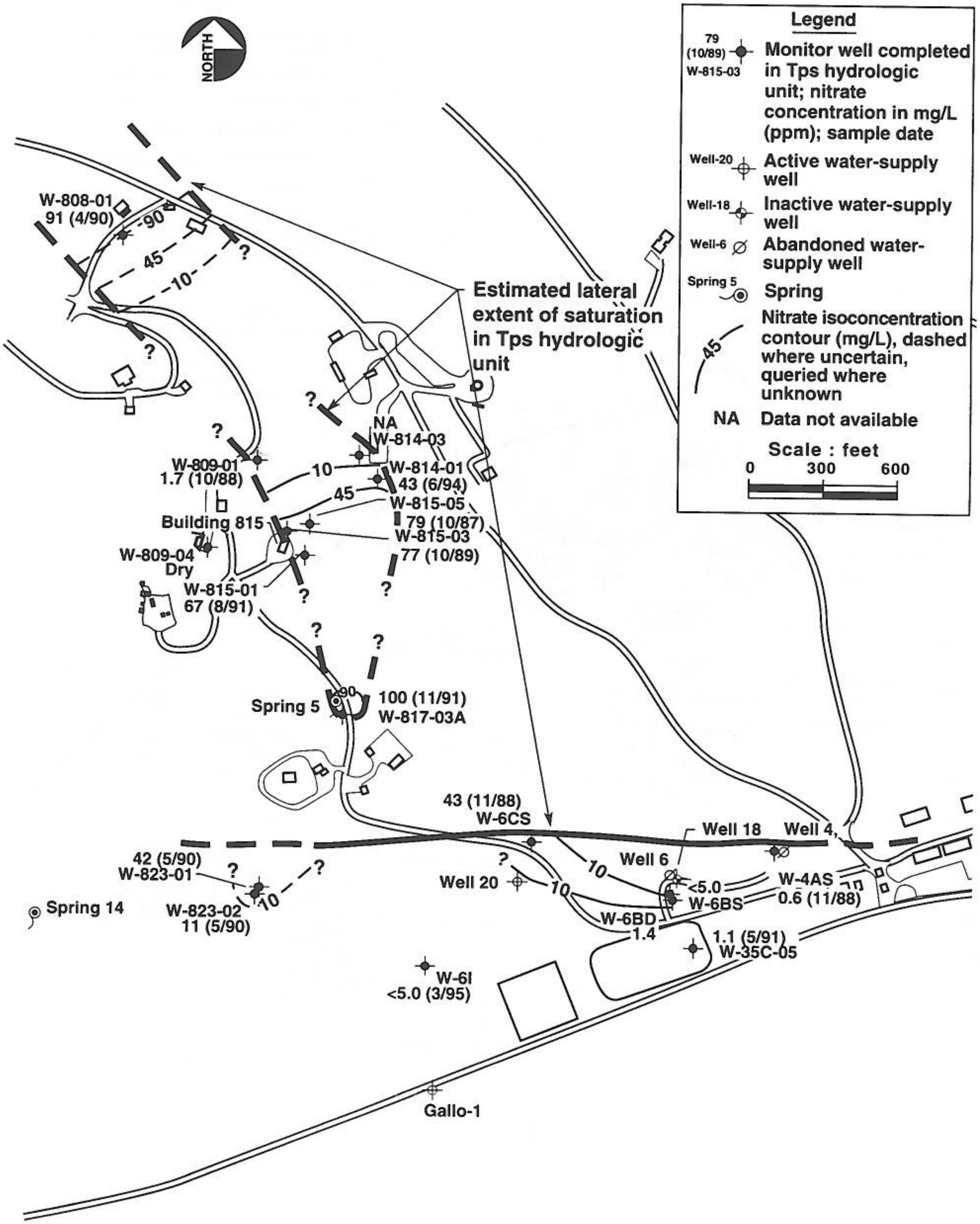

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Figure 1-12. Nitrate (as NO_3) isoconcentration contour map in the Tps hydrologic unit (Fourth quarter 1988–First quarter 1995).

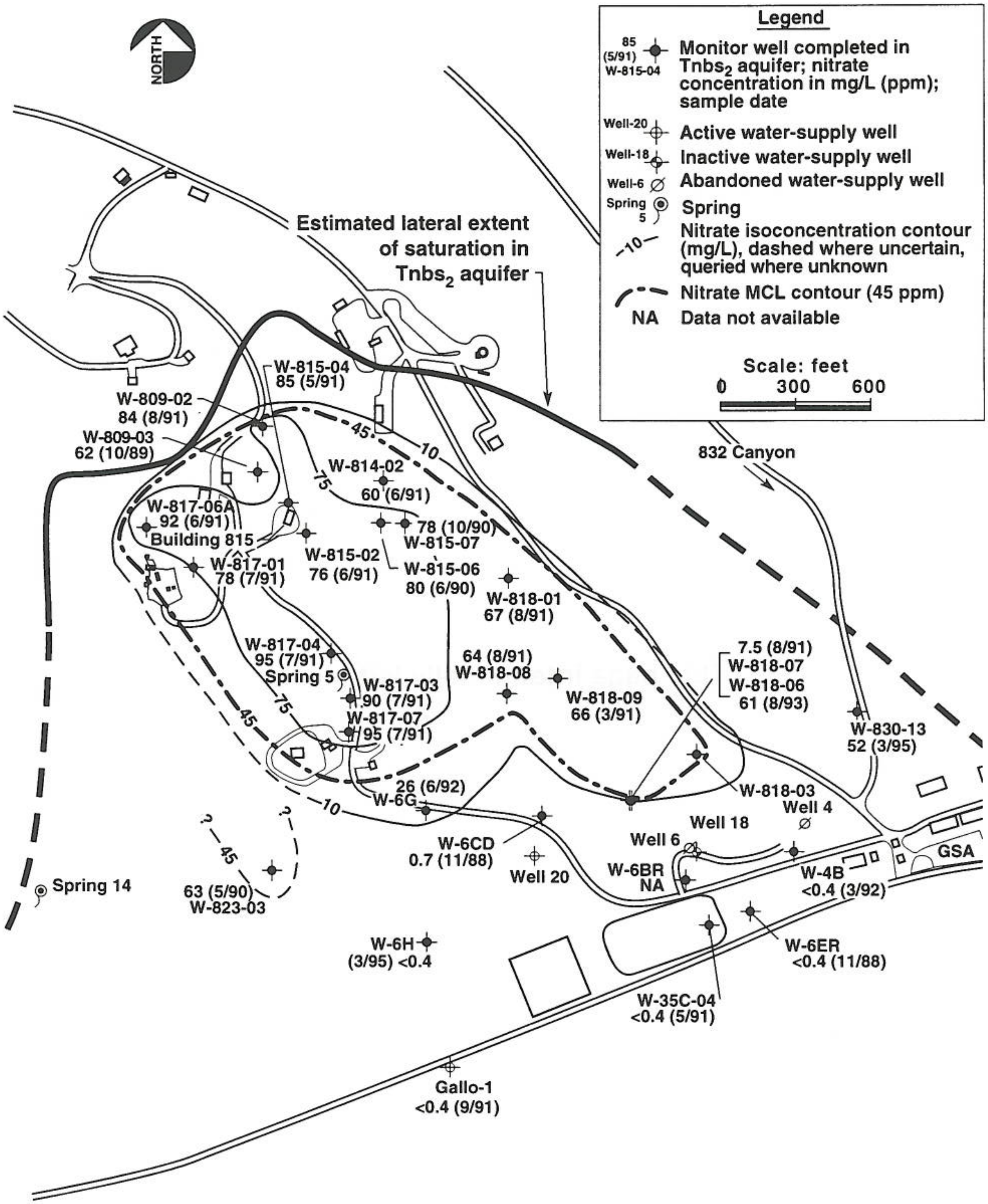

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Figure 1-13. Nitrate (as NO_3) isoconcentration contour map in the $Tnbs_2$ aquifer (Fourth quarter 1988–First quarter 1995).

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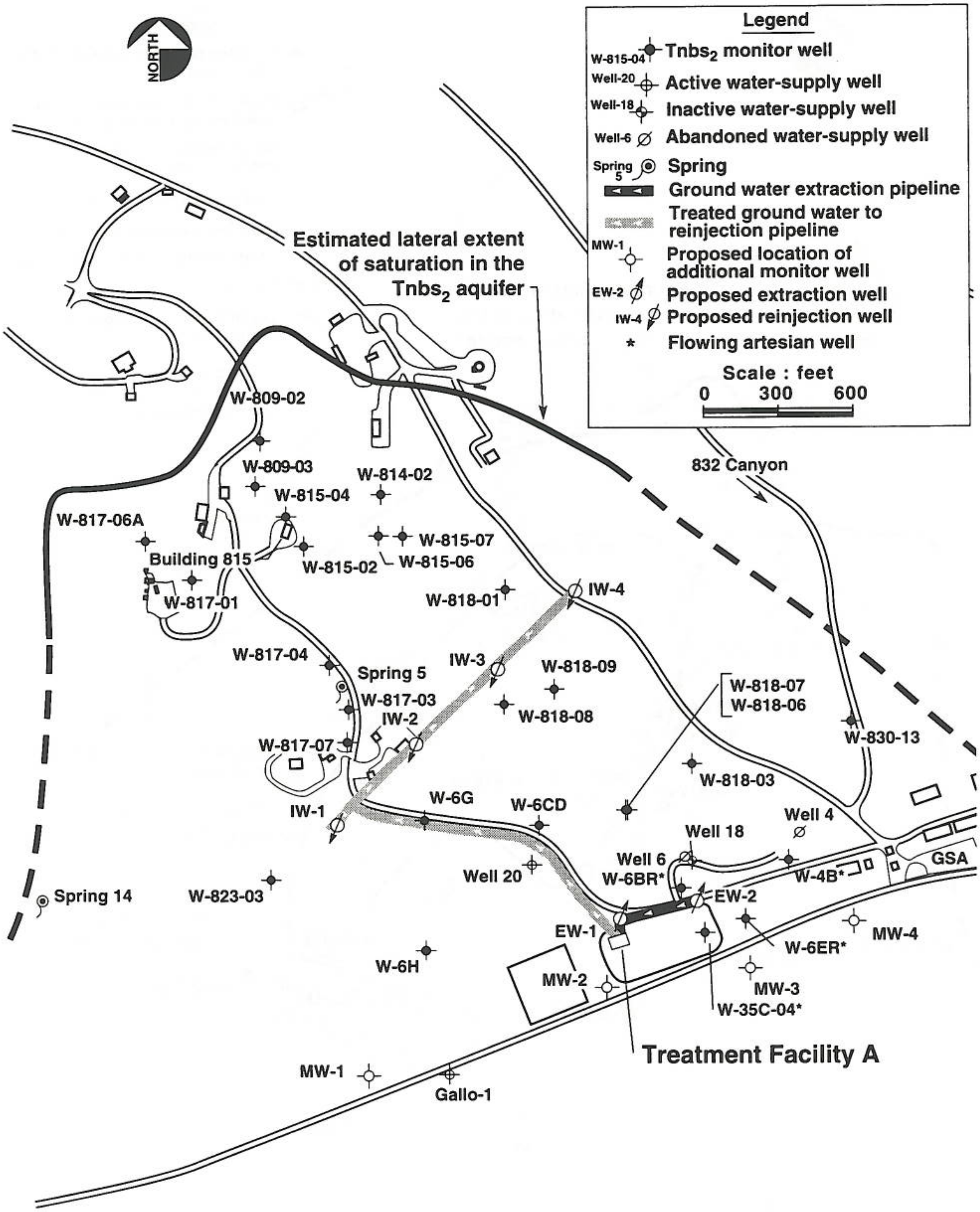
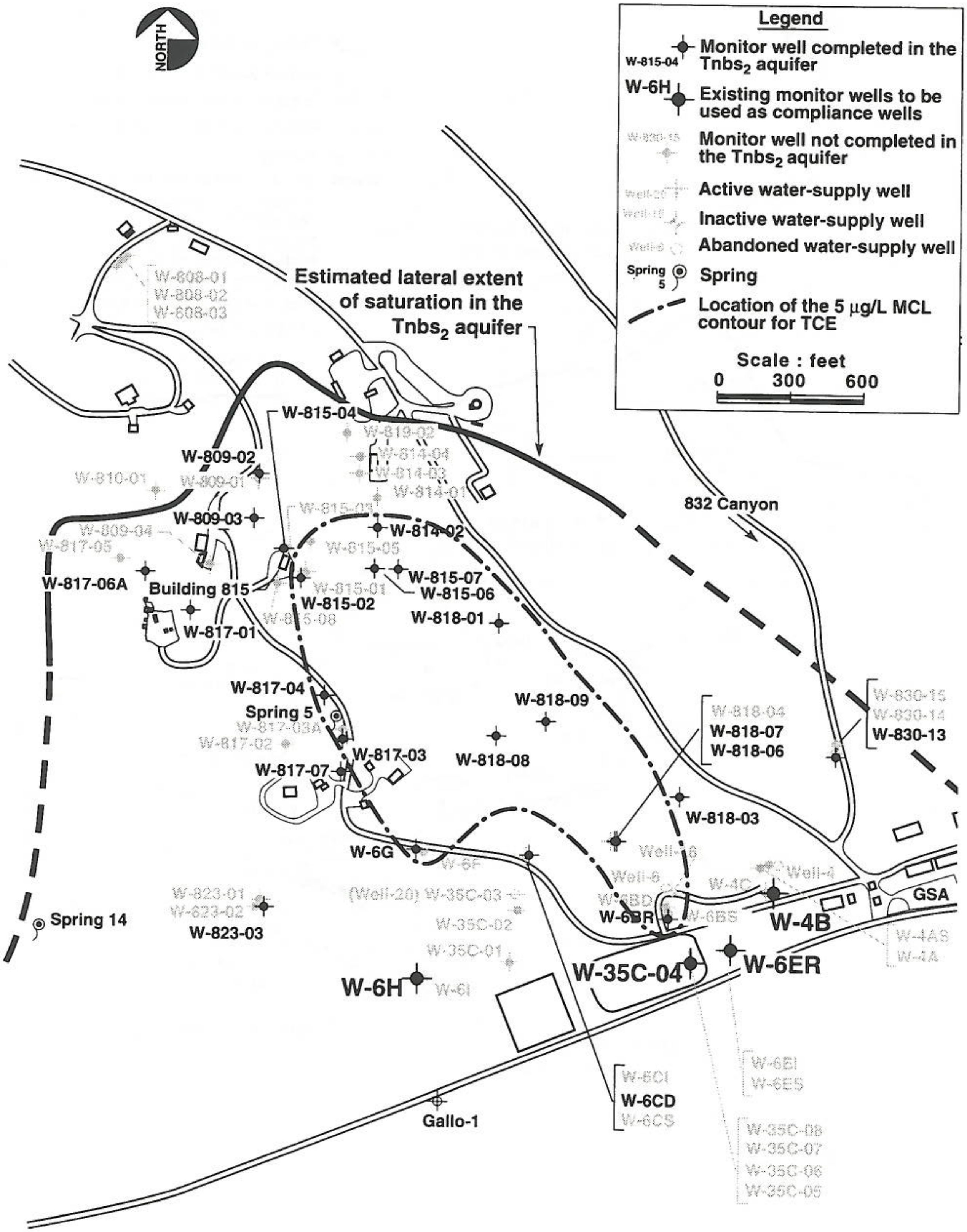


ERD-ERA-815-0036

Figure 2-1. Alternative A well field showing proposed locations of extraction wells, reinjection wells, monitor wells, and treatment system.



ERD-ERA-815-0015

Figure 2-2. Location of proposed compliance wells for Alternative A.

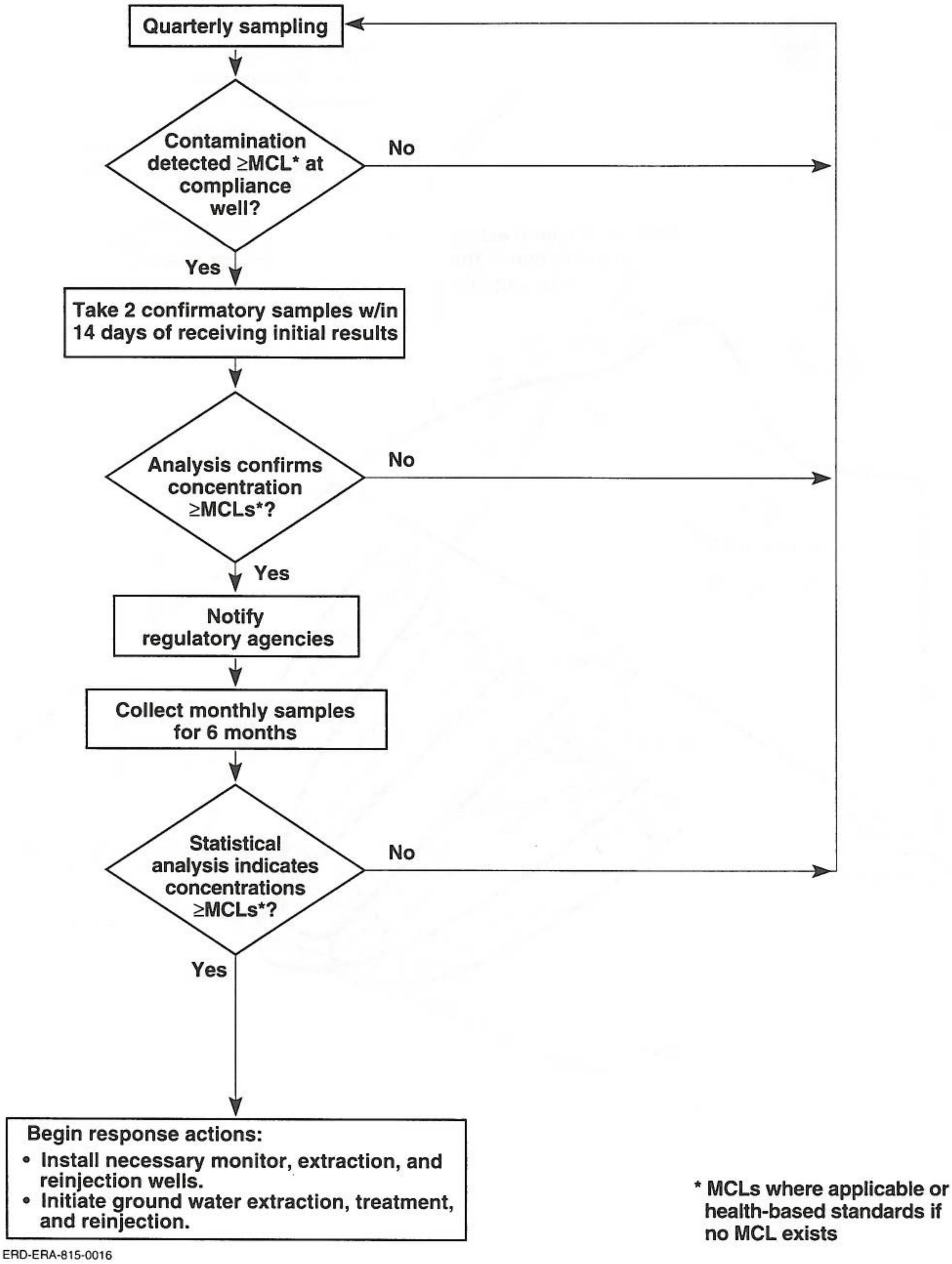
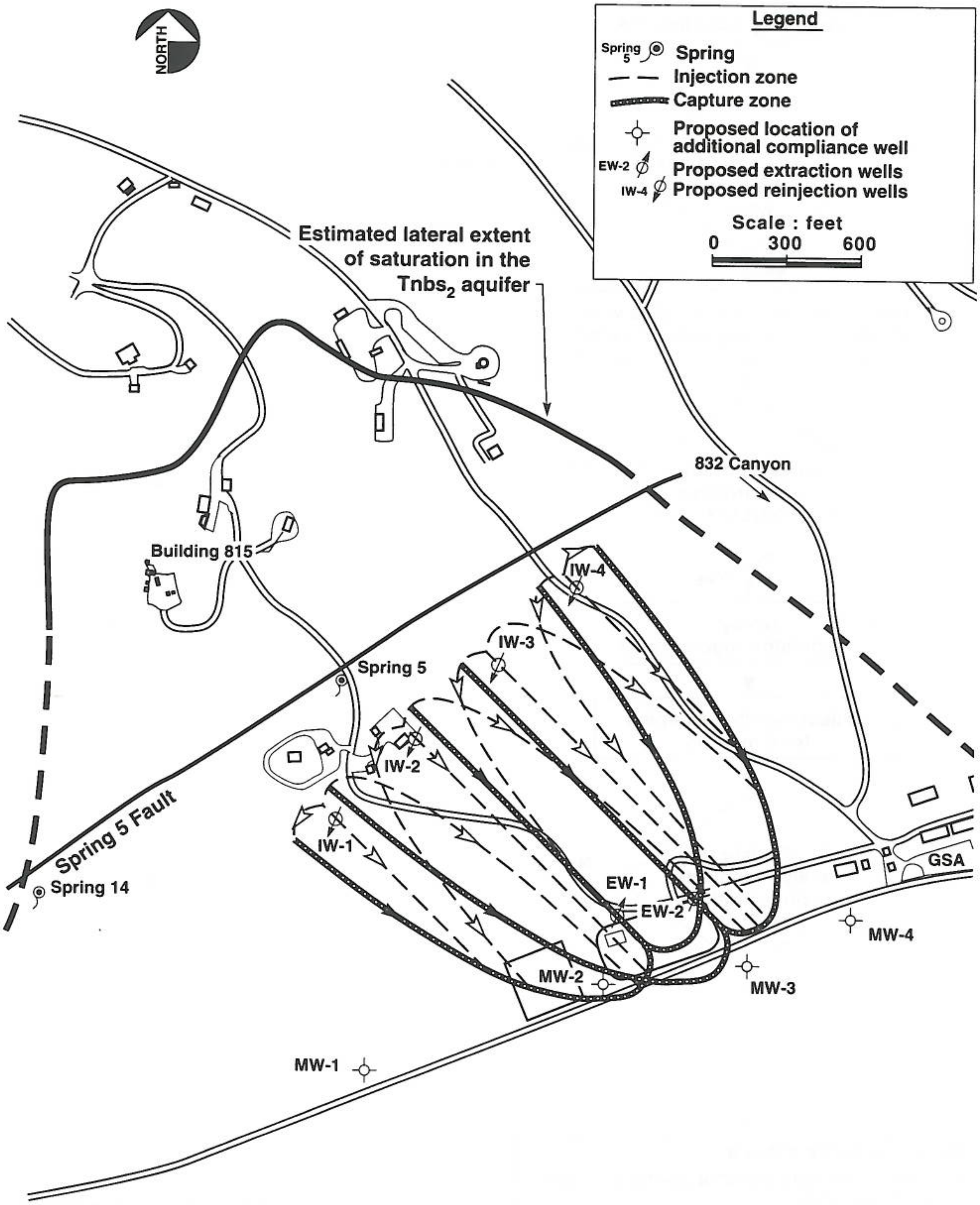
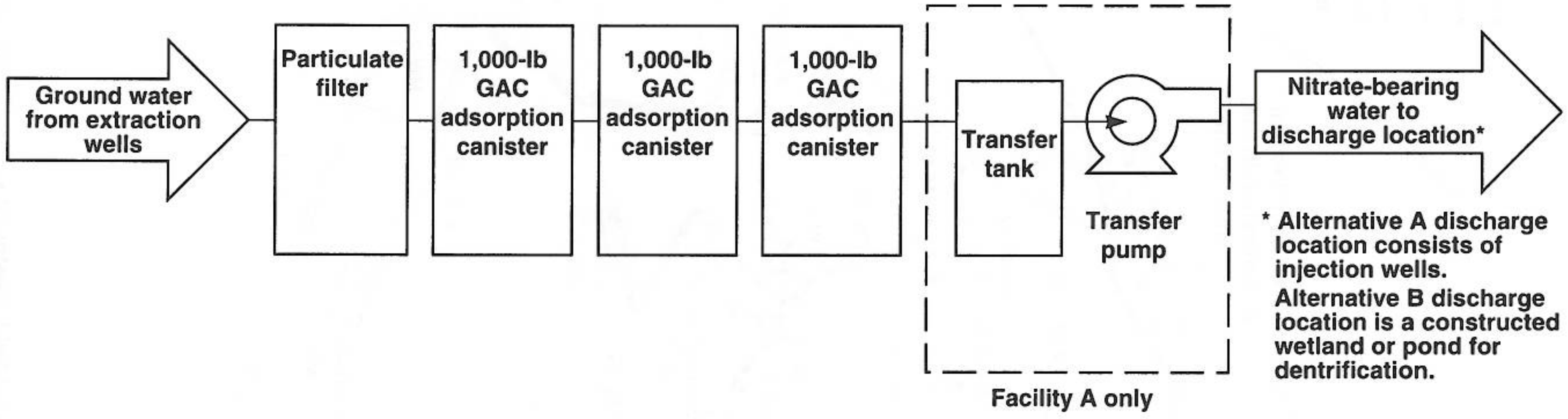


Figure 2-3. Flow chart for Alternative A contingency plan.



ERD-ERA-815-0025

Figure 2-4. Alternative A capture and injection zones. Zones represent individual well influences; interference between wells is not accounted for.



* Alternative A discharge location consists of injection wells.
Alternative B discharge location is a constructed wetland or pond for dentrification.

ERD-ERA-815-0022

Figure 2-5. Schematic of typical ground water treatment system—Alternatives A and B. (See Appendix C for schematic of biological treatment system to regenerate GAC with HE).

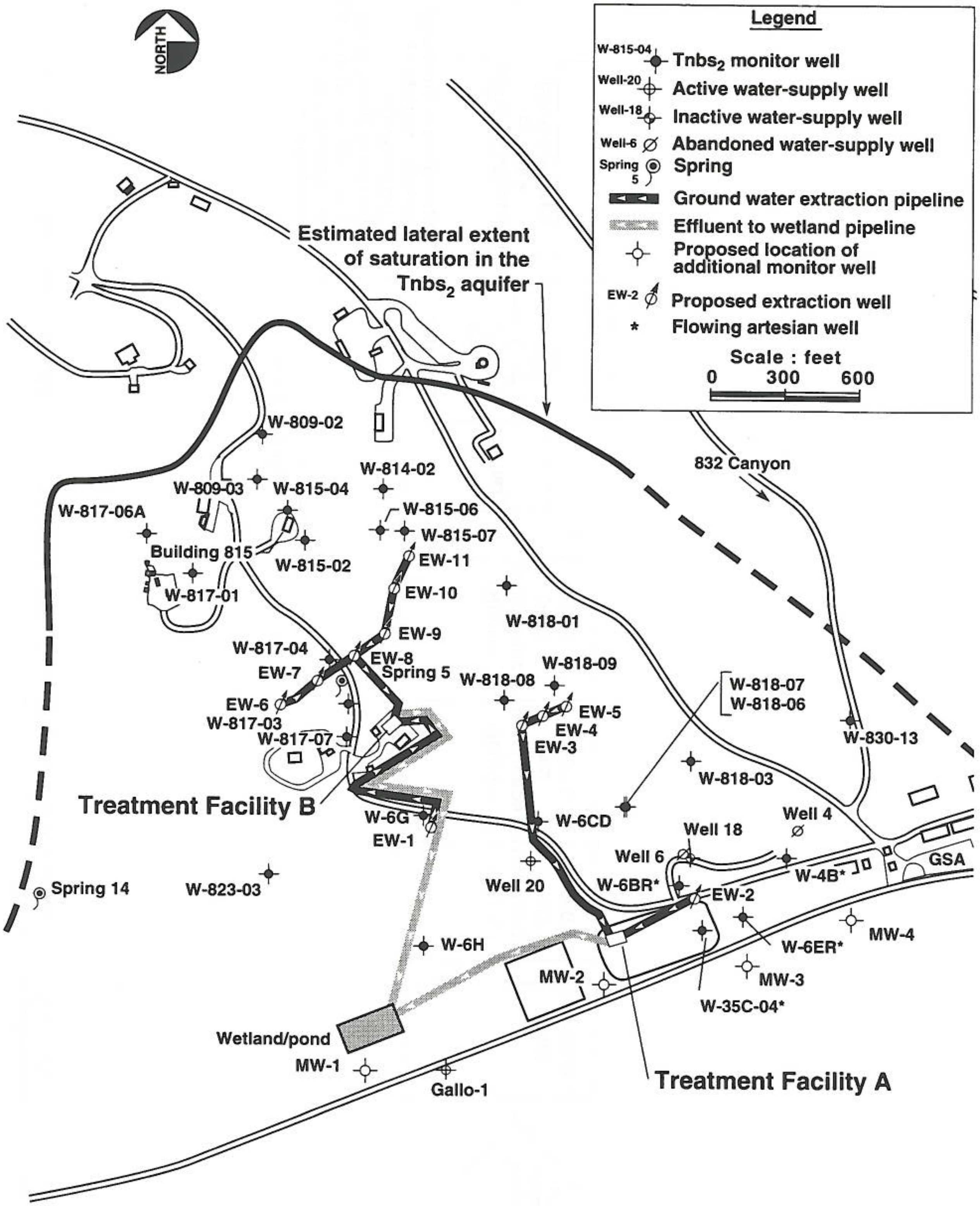


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Figure 2-6. Alternative B well field, treatment systems, and wetland/pond locations.

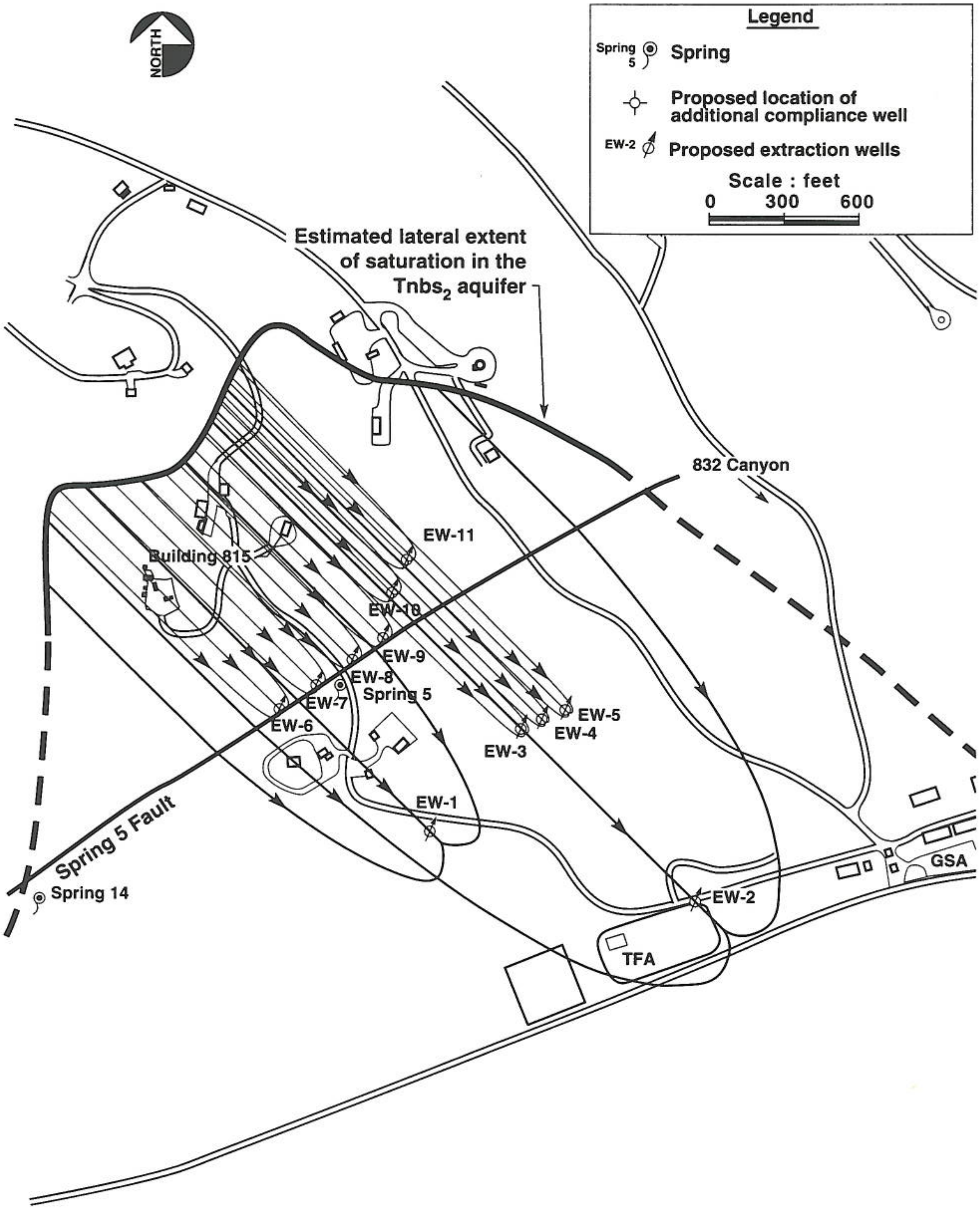

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Figure 2-7. Alternative B capture zones. Zones represent individual well influences; interference between wells is not accounted for.

Tables

Table 1-1. Summary of MCLs, current analytical laboratory detection limits, and background concentrations for the primary ground water contaminants in the Building 815 operable unit.

Chemical of concern	MCL	Detection limit	Background concentration
TCE	5.0 µg/L[a]	0.5 µg/L	<0.5 µg/L
RDX	0.61 µg/L[b]	5.0 µg/L[c]	<5.0 µg/L
Nitrate	45 mg/L[d]	0.5 mg/L	12 mg/L[e]

[a] USEPA and Cal-EPA MCL for TCE in drinking water.

[b] Because no MCL exists for RDX, we are using USEPA Region IX PRG for drinking water (1/95).

[c] Current analytical laboratory detection limit for RDX. Figure 1-11 indicates monitor wells that have been analyzed at a lower detection limit (0.7 µg/L) for RDX.

[d] USEPA and Cal-EPA MCL for nitrate as NO_3 in drinking water.

[e] Based on the average nitrate concentration in ground water from four water-supply wells located northwest of Site 300.

Table 1-2. Summary of results from Baseline Human Health Assessment for the HE Process Area.

Source media	Exposure pathway	Exposure media	Receptor[a]	Non-cancer hazard index	Incremental cancer risk
Spring 5	Inhalation	Outdoor air	AOS	1.9×10^{-1}	1×10^{-5}
Building 815 subsurface soil	Inhalation	Outdoor air	AOS	1.5×10^{-1}	5×10^{-6}
HE Process Area surface soil	Inhalation	Outdoor air	AOS	5.6×10^{-5}	3×10^{-7}
	Incidental ingestion/dermal contact	Outdoor air	AOS	9.0×10^{-3}	2×10^{-8}
Offsite water-supply well	Various	Ground water[b]	RES	7.9×10^{-2}	1×10^{-5}
Offsite water-supply well	Various	Ground water[c]	RES	1.3×10^{-2}	2×10^{-6}

[a] AOS = Adult on site; RES = residential.

[b] VOCs in ground water.

[c] RDX in ground water (predicted to reach a hypothetical off-site water-supply well located at the site boundary in 600 years).

Table 2-1. Existing monitoring program for the Tnbs$_2$ ground water at the Building 815 operable unit.

Well	Analyte[a]	Sample frequency
Tnbs$_2$ compliance well		
W-6H	HE compounds, VOCs, Nitrates	Quarterly
W-4B	HE compounds, VOCs, Nitrates	Quarterly
W-6ER	HE compounds, VOCs, Nitrates BTEX	Quarterly
W-35C-04	HE compounds, VOCs, Nitrates	Quarterly
Tnbs$_2$ monitor well		
W-823-03	HE compounds, VOCs	Quarterly
	Nitrates, oil and grease, PCBs, TPH: gas and diesel	Annually
W-6CD	HE compounds, VOCs, BTEX	Quarterly
W-6BR	HE compounds, VOCs, BTEX	Semi-annually
	Nitrates	Annually
W-6G	HE compounds, VOCs	Semi-annually
	Nitrates	Annually
W-818-03	HE compounds, VOCs	Semi-annually
	Nitrates	Annually
W-818-08	HE compounds, VOCs	Semi-annually
W-817-02	HE compounds, VOCs	Semi-annually
W-809-02	HE compounds, VOCs	Annually
W-809-03	HE compounds, VOCs	Annually
W-814-02	HE compounds, VOCs	Annually
W-815-02	HE compounds, VOCs	Annually
W-815-04	HE compounds, VOCs	Annually
W-815-06	HE compounds, VOCs	Annually
W-815-07	HE compounds, VOCs	Annually
W-817-06A	HE compounds, VOCs, Nitrates	Annually
W-818-01	HE compounds, VOCs, Nitrates	Annually
W-818-06	HE compounds, VOCs, Nitrates	Annually
W-818-07	HE compounds, VOCs	Annually
W-818-09	HE compounds, VOCs , Nitrates	Annually

Notes: PCB = polychlorinated biphenyl; TPH = total petroleum hydrocarbons; BTEX = benzene, toluene, ethylbenzene, xylene(s).

[a] U.S. EPA analytical methods:

HE: 8330.
VOCs: 601.
Nitrates: 353.2.
BTEX: 602.
Oil and grease: 413 or 418.1.
PCBs: 8080.
TPH: 8015 (modified).

Table 2-2. Additional wells to be monitored quarterly under Alternative A for HE compounds[a], VOCs[b], and nitrates[c].

Well type	Well
Extraction	EW-1
	EW-2
Monitor	MW-1
	MW-2
	MW-3
	MW-4

[a] HE compounds: EPA Method 8330.

[b] VOCs: EPA Method 601.

[c] Nitrates: EPA Method 353.2.

Table 2-3. Comparative evaluation of remedial alternatives for the Building 815 operable unit.

	Overall protection				
Alternative	Human health	Environment	Compliance with ARARs	Implementability	Cost
A	Yes	No	Relies on natural attenuation processes and monitoring with contingency ground water extraction and treatment to meet ARARs. Reinjection wells will be sited to avoid degradation of the $Tnbs_2$ aquifer.	Long-term monitoring; all contingency actions are implementable. Additional permitting is required for reinjection. Main limitation is long-term maintenance of reinjection wells.	Assumes trigger criteria are met and a 45-year project life based on 10 years of initial monitoring, followed by 10 years of ground water extraction and treatment operations, and 25 years of post -remediation monitoring.
B	Yes	Yes	Meets all ARARs by extraction and treatment of ground water to background levels.	Ground water extraction and treatment is implementable. Feasibility is uncertain for remediating $Tnbs_2$ aquifer to background levels . Long-term extraction may result in depletion of $Tnbs_2$ aquifer.	Assumes a 115-year project life based on 110 years of ground water extraction and treatment operations to achieve background levels, followed by 5 years of post-remediation monitoring.

Table 2-4. Potential federal, state, and local ARARs for the Building 815 operable unit.

Regulation	Comments	Alternative[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 MCLs and nonzero MCL goals. MCLs are applicable to off-site water-supply wells for all alternatives.	A and B	A
Federal action-specific requirements			
<u>Action: Closure</u>			
Health and Safety Code Section 25159 [22 CCR 66264.178]	Requires removal of all hazardous waste and waste residues from containment systems at closure.	B (and A if active measures are implemented)	A
<u>Action: Ground water extraction and treatment</u>			
Health and Safety Code Sections 25150–59 [22 CCR 66264.190–192]	Design and operating standards for tank systems.	B (and A if active measures are implemented)	A

Table 2-4. (Continued)

Regulation	Comments	Alternative[a]	ARAR category[b]
Action: Discharge of treatment system effluent			
Clean Water Act [33 USCA 1251–1376], NPDES [40 CFR 122–125]	Both on- and off-site discharges from Comprehensive Environmental Response, Compensation, and Liability Act (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]. Waste Discharge Requirement (WDR) and National Pollution Discharge Elimination System (NPDES) permits may be required to discharge treated water to the ground surface.	B	A
Action: Reinjection of treated ground water			
Safe Drinking Water Act Underground Injection Control Program [40 CFR 144.26-27]	Inventory and monitoring requirements for reinjection of treated ground water.	A (and B if reinjection is required)	A
General action-specific ARARs			
U.S. Department of Energy (DOE) Order 5400.4	Prescribes conduct of operations on DOE facilities for compliance with CERCLA, and provides for the integration of procedural and documentation requirements of National Environmental Policy Act (NEPA) and CERCLA. This is an unpromulgated order.	A and B	TBC
Federal location-specific requirements			
Executive Orders 11988 (floodplain management) and 11990 (protection of wetlands) [40 CFR 6, 44 Federal Register 12594]	Requires actions to avoid adverse effects, minimize potential harm, and 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.	A and B	TBC

Table 2-4. (Continued)

Regulation	Comments	Alternative[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 operable unit, habitat for some endangered species may exist. Specific mitigation measures for these species will be met prior to any construction. All of these requirements will be additionally met through NEPA and DOE implementing requirements.	A and B	RAR
State and local chemical-specific requirements			
Hazardous Waste Control Act [Health and Safety Code, Sections 25100–25395], 22 CCR 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.	A and B	A
Criteria for Identifying Hazardous Wastes [22 CCR 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 22 CCR requirements.	A and B	A
Persistent and Bioaccumulative Toxic Substances [22 CCR 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 22 CCR. All treatment alternatives use these criteria.	A and B	A

Table 2-4. (Continued)

Regulation	Comments	Alternative[a]	ARAR category[b]
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 23 CCR 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 monitoring and 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.	B	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 state-wide water quality control plans and policies.	A and B	A
SWRCB Resolution 68-16	Requires that high quality surface and ground waters be maintained to the maximum extent possible. Degradation of waters will be allowed (or allowed to remain) only if it is consistent with the maximum benefit to the people of the state, will not unreasonably affect present and anticipated beneficial uses, and will not result in water quality less than that prescribed in RWQCB and SWRCB policies and plans. If degradation is allowed, the discharge must meet best practicable treatment or control, which must prevent pollution or nuisance and result in the highest water quality consistent with maximum benefit to the people of the State.	A and B	RAR
SWRCB 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.	A and B	A
California Safe Drinking Water Act (California Health & Safety Code Section 4010 et seq.)	Requirements for public water systems include MCLs and Secondary MCLs, which are used to protect beneficial uses of water bodies per water quality objectives in the Basin Plan.	A and B	RAR

Table 2-4. (Continued)

Regulation	Comments	Alternative[a]	ARAR category[b]
State Board Resolution No. 88-63 (Sources of Drinking Water Policy)	Designates that all ground and surface waters of the state as drinking water except where the total dissolved solids (TDS) is greater than 3000 ppm, the water source does not provide sufficient water to supply a single well more than 200 gpd, the water is a geothermal resource or in a waste water conveyance facility, or the water cannot reasonably be treated for domestic use using either Best Management Practices or best economically achievable treatment practices.	A and B	A
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].	A and B	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. Includes regeneration of GAC.	A and B	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.	A and B	A

Table 2-4. (Continued)

Regulation	Comments	Alternative^a	ARAR category^b
Action: Transportation			
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], recordkeeping 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 A and B include regeneration of GAC.	A and B	A
Requirements for Generators of Hazardous Waste [22 CCR 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 A and B include regeneration of GAC.	A and B	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.	A and B	A
Porter-Cologne Water Quality Control Act [13000 et seq.], as administered by the SWRCB and the nine RWQCBs under 23 CCR 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.	B	A

Table 2-4. (Continued)

Regulation	Comments	Alternative[a]	ARAR category[b]
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 state-wide water quality control plans and policies.	A and B	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.	A and B	RAR
State location-specific requirements			
California Endangered Species Act, California Fish and Game Code Sections 2050–2068	Requires action to preserve endangered species or threatened species. Prior to conducting any ground-disturbing activities, surveys will be conducted for the species of concern.	A and B	RAR

[a] A—Monitoring with contingencies.

B—Ground water extraction and treatment to achieve full restoration of beneficial use of ground water in the $Tnbs_2$ aquifer.

[b] A = Applicable.

RAR = Relevant and appropriate requirement.

TBC = To be considered.

Table 2-5. ARARs for the Building 815 operable unit.

Action	Source	Description	Application to the selected remedy
Extraction of ground water from the Tnbs$_2$ aquifer	*State:* CCR, Title 23, Ch. 15, Sections 2550.7, 2550.10. (Porter-Cologne Water Quality Control Act)	Requires monitoring of the effectiveness of remedial actions.	This ARAR requires measurement of contaminant concentrations in ground water during and after remediation.
Discharge of treated ground water	*State:* SWRCB Resolution 68-16 (Antidegradation policy).	Requires that high quality surface and ground water be maintained to the maximum extent possible.	This ARAR applies to discharges or reinjection of treated ground water. The compliance standards for discharge water and reinjection water will be contained in Substantive Requirements issued by the RWQCB.
Remediation of ground water	*State:* SWRCB Resolution 92-49 (Investigation and cleanup policy).	Authorizes Regional Water Boards to require cleanup of ground water to background conditions.	This ARAR applies to the establishment of ground water cleanup standards.
Disposition of hazardous waste	*State:* 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 point of generation through accumulation, transportation, treatment, storage, and ultimate disposal.	This ARAR applies primarily to spent GAC vessels.

Table 2-5. (Continued)

Action	Source	Description	Application to the selected remedy
Protection of endangered species	*Federal:* Endangered Species Act of 1973, 16 USC Section 1531 et seq. 50 CFR Part 200, 50 CFR Part 402 [40 CFR 257.3-2].	Requires that facilities or practices not cause or contribute to the taking of any endangered or threatened species of plants, fish, or wildlife. NEPA implementation requirements apply.	Prior to any well installation, facility construction, or similar potentially disruptive activities, wildlife surveys will be conducted and mitigation measures implemented, if required.
	State: California Endangered Species Act, California Department of Fish and Game Sections 2050-2068.		

Table 2-6. Comparative costs for remedial Alternatives A and B.

Alternative	Cost assumptions	Present-worth cost in 1995 dollars ($millions) (3.5% discount rate)	Non-discounted cost in 1995 dollars ($millions)
A	*Trigger criteria are met.* Cost assumes a 45-year project life. Contingency actions are implemented after 10 years of initial monitoring, 10 years of ground water extraction and treatment to MCLs near the site boundary, followed by 25 years of post-remediation monitoring to monitor natural attenuation of any remaining contaminants.	6.4	10.9
A	*Trigger criteria are not met.* Cost assumes a 45-year project life. Contingency actions are not implemented. Natural attenuation of the plume to concentrations below MCLs is monitored for 45 years.	2.9	4.9
B	Cost assumes 115-year project life: 110 years of ground water extraction and treatment to background levels followed by 5 years of post-remediation monitoring.	20.5	65.5

Table 2-7. Additional wells to be monitored quarterly under Alternative B for HE compounds[a], VOCs[b], and nitrates[c].

Well type	Well
Extraction well	EW-1
	EW-2
	EW-3
	EW-4
	EW-5
	EW-6
	EW-7
	EW-8
	EW-9
	EW-10
	EW-11
Monitor well	MW-1
	MW-2
	MW-3
	MW-4

[a] HE compounds: EPA Method 8330.

[b] VOCs: EPA Method 601.

[c] Nitrates: EPA Method 353.2.

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Appendix A

Supporting Characterization Data

Appendix A

Section A-1
Soil Analyses for VOCs Recorded by October 24, 1995

Table A-1. Soil analyses (mg/kg) for volatile organic compounds (VOCs) from HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

VOCs in Soil from Boreholes,
HE Process Area, Building 815,
Site 300
October 30, 1995
gemini1

s3vocSOL.30oct95
s3vocSOR.30oct95

Table A-1. Soil analyses (mg/kg) for volatile organic compounds (VOCs) from HE Process

Location Date	Lab	Note	Val.	Depth	1,1- DCE	cis- 1,2- DCE	trans- 1,2- DCE	Total 1,2- DCE	TCE	PCE	1,1- DCA
HE Process Area Study Area											
W-6H											
03-jun-94	CS	a	V	0.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	14.2	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	16.3	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	27.3	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	27.7	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
06-jun-94	CS	a	V	28.9	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	34.1	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	38.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	45.8	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
07-jun-94	CS	a	V	49.4	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
08-jun-94	CS	a	V	60.4	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
08-jun-94	GT	a	V	60.4	<0.005 U	-	-	<0.005 U	<0.005 U	<0.005 U	<0.005 U
14-jun-94	CS	ah	V	71.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
14-jun-94	CS	ah	V	71.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
14-jun-94	CS	a	V	78.9	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
14-jun-94	CS	a	V	82.8	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
15-jun-94	CS	a	V	98.2	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U
15-jun-94	CS	a	V	110.0	<0.0005 U	-	-	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U

Area, Building 815, Site 300. Results recorded by October 24, 1995.

1,2- DCA	1,1,1- TCA	Chloro- form	Freon 11	Freon 113	Methylene chloride	Location Date
						HE Process Area Study Area
						W-6H
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	03-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	06-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	07-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	08-jun-94
<0.005 U	<0.005 U	<0.005 U	<0.005 U	–	<0.005 U	08-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	14-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	15-jun-94
<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	<0.0005 U	15-jun-94

See following page for notes

Table A-1. Soil analyses (mg/kg) for volatile organic compounds (VOCs) from HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample taken during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
n	Sample analyzed after standard holding time
o	Alpha particle analysis of uranium isotopes
p	Gamma particle analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA
GT	Groundwater Technology Environmental Labs, Concord, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-2

Soil Analyses for HE Compounds (HMX, RDX, and TNT) Recorded by October 24, 1995

Table A-2. Soil analyses for HE compounds (HMX, RDX, and TNT) from HE Process Area, Building 815, Site 300. Units are in mg/kg. Results recorded by October 24, 1995.

HE Process Area, Building 815,
Site 300
HE Compounds in Soil
October 31, 1995
gemini1

s3hmxso.31oct95

Table A-2. Soil analyses for HE compounds (HMX, RDX, and TNT) from HE Process Area, Building 815, Site 300. Units are in mg/kg. Results recorded by October 24, 1995.

Location Date	Lab	Note	Val.	Depth	HMX	RDX	TNT
HE Process Area Study Area							
W-6H							
03-jun-94	CS	a	V	0.0	<0.2 U	<0.15 U	<0.1 U
08-jun-94	MS	a	N	0.0	0.05	<0.02 U	<0.02 U
06-jun-94	CS	a	V	14.7	0.85	<0.15 U	<0.1 U
06-jun-94	CS	a	V	15.4	<0.2 U	<0.1 U	<0.1 U
06-jun-94	CS	a	V	28.0	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS	ah	V	33.3	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS	ah	V	33.3	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS	a	V	38.4	<0.2 U	<0.15 U	<0.1 U
07-jun-94	CS	a	V	50.7	<0.2 U	<0.15 U	<0.1 U
08-jun-94	CS	a	V	61.0	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS	ah	V	74.7	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS	ah	V	74.7	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS	a	V	77.0	<0.2 U	<0.15 U	<0.1 U
14-jun-94	CS	a	V	82.3	<0.2 U	<0.15 U	<0.1 U
15-jun-94	CS	a	V	98.5	<0.2 U	<0.15 U	<0.1 U
15-jun-94	CS	a	V	110.4	<0.2 U	<0.15 U	<0.1 U

See following page for notes

Table A-2. Soil analyses for HE compounds (HMX, RDX, and TNT) from HE Process Area, Building 815, Site 300. Units are in mg/kg. Results recorded by October 24, 1995.

Notes:

\- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample taken during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
n Sample analyzed after standard holding time
o Alpha particle analysis of uranium isotopes
p Gamma particle analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA
MS	C & MS-Gas Chromatography, LLNL, Livermore, CA

Validation Codes:

V Validated
N Not validated (default value)
U Undeclared
H Historical comparison only

CLP flags: (follow result)

B Analyte detected in method blank
C Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D Analysis performed at a secondary dilution or concentration (i.e., vapor)
E Concentration exceeds calibration range
F Analyte detected in field blank
H Sample analyzed outside of the holding time; sample results should be rejected
J Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L Spike accuracy not within control limits
O Duplicate spike precision not within control limits
P Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R Sample
results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-3
TTLC Analyses for Metals in Soil Recorded by October 24, 1995

Table A-3. TTLC analyses (mg/kg) for metals in soil from the HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

Metals in Soil from Boreholes,
HE Process Area, Building 815,
Site 300
October 30, 1995
gemini1

s3metttlc.soL.30oct95
s3metttlc.soR.30oct95

Table A-3. TTLC analyses (mg/kg) for metals in soil from the HE Process Area, Building 815,

Location Date	Lab	Val. Note		Depth	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt
HE Process Area Study Area											
W-6H											
03-jun-94	CS	a	V	0.0	<1 U	<0.5 U	160	0.51	<1 U	17	10
03-jun-94	CS	ah	V	0.0	–	–	–	–	<0.1 U	–	–
06-jun-94	CS	ah	V	5.0	<1 U	1.3	64	0.64	<1 U	18	9.1
06-jun-94	CS	ah	V	5.0	<1 U	<0.5 U	100	<0.5 U	<1 U	10	7.6
06-jun-94	CS	ah	V	5.0	–	–	–	–	<0.1 U	–	–
06-jun-94	CS	ah	V	5.0	–	–	–	–	<0.1 U	–	–

Site 300. Results recorded by October 24, 1995.

Copper	Iron	Lead	Mercury	Nickel	Selenium	Silver	Zinc	Location Date
								HE Process Area Study Area
								W-6H
17	–	<10 U	<0.05 U	20	<0.5 U	<2.5 U	36	03-jun-94
–	–	–	–	–	–	–	–	03-jun-94
26	–	<10 U	<0.05 U	19	<0.5 U	<2.5 U	47	06-jun-94
14	–	<10 U	<0.05 U	13	<0.5 U	<2.5 U	27	06-jun-94
–	–	–	–	–	–	–	–	06-jun-94
–	–	–	–	–	–	–	–	06-jun-94

See following page for notes

Table A-3. TTLC analyses (mg/kg) for metals in soil from the HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample taken during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
n Sample analyzed after standard holding time
o Alpha particle analysis of uranium isotopes
p Gamma particle analysis of uranium isotopes

Lab Codes:

CS California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V Validated
N Not validated (default value)
U Undeclared
H Historical comparison only

CLP flags: (follow result)

B Analyte detected in method blank
C Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D Analysis performed at a secondary dilution or concentration (i.e., vapor)
E Concentration exceeds calibration range
F Analyte detected in field blank
H Sample analyzed outside of the holding time; sample results should be rejected
J Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L Spike accuracy not within control limits
O Duplicate spike precision not within control limits
P Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R Sample
results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-4
Bailed Ground and Drilling Water Analyses for VOCs Recorded by October 24, 1995

Table A-4. Bailed ground and drilling water analyses (ug/L) for volatile organic compounds from HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

VOCs in Bailed Ground and Drilling Water
HE Process Area, Building 815, Site 300
October 30, 1995
gemini1

s3vocSOL.30oct95
s3vocSOR.30oct95

Table A-4. Bailed ground and drilling water analyses (ug/L) for volatile organic compounds from

Location Date	Lab	Val. Note	Depth	1,1- DCE	cis- 1,2- DCE	trans- 1,2- DCE	Total 1,2- DCE	TCE	PCE	1,1- DCA
HE Process Area Study Area										
W-6H										
07-jun-94	CS	ar V	38.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
16-jun-94	CS	ar V	122.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
16-jun-94	CS	ar V	157.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
27-jun-94	CS	as V	190.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
W-6I										
05-jul-94	CS	as V	38.0	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U

HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

1,2-DCA	1,1,1-TCA	Chloroform	Freon 11	Freon 113	Methylene chloride	Location Date
					HE Process Area Study Area	
						W-6H
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	07-jun-94
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	16-jun-94
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	16-jun-94
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	27-jun-94
						W-6I
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	05-jul-94

See following page for notes

Table A-4. Bailed ground and drilling water analyses (ug/L) for volatile organic compounds from HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample taken during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
n	Sample analyzed after standard holding time
p	Alpha particle analysis of uranium isotopes
q	Gamma particle analysis of uranium isotopes
r	Bailed ground water obtained during borehole drilling operations
s	Aqueous liquid used during borehole drilling operations

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-5
Ground Water Analyses for VOCs Recorded by October 24, 1995

Table A-5. Ground water analyses for volatile organic compounds (VOCs) at HE Process Area, Building 815, Site 300. Units are ug/L. Results recorded by October 24, 1995.

HE Process Area, Building 815
Site 300
VOCs in Ground Water
October 31, 1995
gemini1

s300vocL.31oct95
s300vocR.31oct95

Table A-5. Ground water analyses for volatile organic compounds (VOCs) at HE Process Area, Building

Location Date	Lab	Note	Val.	1,1- DCE	cis- 1,2- DCE	trans- 1,2- DCE	Total 1,2- DCE	TCE	PCE	1,1- DCA
HE Process Area Study Area										
W-6H										
07-mar-95	CS	a	V	<1 ULO	-	-	<1 U	<0.5 ULO	<1 U	<1 U
01-jun-95	CS	a	V	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
20-jul-95	CS	a	V	<0.5 U	-	-	<0.5 U	<0.5 U	<0.5 U	<0.5 U
W-6I										
07-mar-95	CS	a	V	<1 U	-	-	<1 ULO	<0.5 ULO	<1 U	<1 U

815, Site 300. Units are ug/L. Results recorded by October 24, 1995.

1,2-DCA	1,1,1-TCA	Chloroform	Freon 11	Freon 113	Methylene chloride	Location Date
						HE Process Area Study Area
						W-6H
<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	07-mar-95
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	01-jun-95
<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	20-jul-95
						W-6I
<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	07-mar-95

See following page for notes

Table A-5. Ground water analyses for volatile organic compounds (VOCs) at HE Process Area, Building 815, Site 300. Units are ug/L. Results recorded by October 24, 1995.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample taken during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
n	Sample analyzed after standard holding time
o	Alpha particle analysis of uranium isotopes
p	Gamma particle analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-6
Ground Water Analyses for HE Compounds (HMX, RDX, and TNT) Recorded by October 24, 1995

Table A-6. Ground water analyses for HE compounds (HMX, RDX, and TNT) from HE Process Area, Building 815, Site 300. Units are in ug/L. Results recorded by October 24, 1995.

HE Process Area, Building 815,
Site 300
HE Compounds in Water
November 1, 1995
gemini1

s3hmx.01nov95

Table A-6. Ground water analyses for HE compounds (HMX, RDX, and TNT) from HE Process Area, Building 815, Site 300. Units are in ug/L. Results recorded by October 24, 1995.

Location Date	Lab	Note	Val.	HMX	RDX	TNT
HE Process Area Study Area						
W-6H						
07-mar-95	CS	a	V	<5 U	<5 U	<5 U
01-jun-95	CS	a	V	<5 U	<5 U	-
20-jul-95	CS	a	V	<5 U	<5 U	-
W-6I						
07-mar-95	CS	a	V	<5 U	<5 U	<5 U

See following page for notes

Table A-6. Ground water analyses for HE compounds (HMX, RDX, and TNT) from HE Process Area, Building 815, Site 300. Units are in ug/L. Results recorded by October 24, 1995.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a ERD data
b ORAD WGMG data
c Analytical results for this sample are suspect
d Sample taken during hydraulic testing
e Blind sample, sent to lab without well identity
f Sample dilution necessary for analysis; detection limits increased
g Interlaboratory collocated sample
h Intralaboratory collocated sample
i Sample collected as part of pilot study
j Note field may contain important information regarding this sample
k Pre-development sample
l Norm month, norm quarter or norm year inconsistent with sample date
n Sample analyzed after standard holding time
o Alpha particle analysis of uranium isotopes
p Gamma particle analysis of uranium isotopes

Lab Codes:

CS California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V Validated
N Not validated (default value)
U Undeclared
H Historical comparison only

CLP flags: (follow result)

B Analyte detected in method blank
C Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D Analysis performed at a secondary dilution or concentration (i.e., vapor)
E Concentration exceeds calibration range
F Analyte detected in field blank
H Sample analyzed outside of the holding time; sample results should be rejected
J Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L Spike accuracy not within control limits
O Duplicate spike precision not within control limits
P Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S Analytical results for this sample are suspect
T Analyte is tentatively identified as this compound; result is approximate
U Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-7
Ground Water Analyses for Metals Recorded by October 24, 1995

Table A-7. Ground water analyses (mg/L) for metals HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

HE Process Area, Building 815,
Site 300
Ground Water Metals Report
November 1, 1995
gemini1

s3metsL.01nov95
s3metsR.01nov95

Table A-7. Ground water analyses (mg/L) for metals HE Process Area, Building 815, Site 300.

Location Date	Lab	Note	Val.	Antimony	Arsenic	Barium	Beryllium	Cadmium	Total chromium	Hexavalent chromium	Copper
HE Process Area Study Area											
W-6H											
07-mar-95	CS	a	V	–	0.014	<0.025 U	–	<0.0005 U	<0.01 U	–	–
07-mar-95	CS	a	V	–	–	–	–	–	–	–	<0.05 U
W-6I											
07-mar-95	CS	a	V	–	0.0057	0.084	–	<0.0005 U	<0.01 U	–	–
07-mar-95	CS	a	V	–	–	–	–	–	–	–	<0.05 U

Results recorded by October 24, 1995.

Iron	Lead	Manganese	Mercury	Nickel	Selenium	Silver	Zinc	Location Date
								HE Process Area Study Area
								W-6H
-	<0.002 U	-	<0.0002 U	-	<0.002 LOU	<0.001 LOU	-	07-mar-95
<0.1 U	-	<0.03 U	-	<0.1 U	-	-	<0.05 U	07-mar-95
								W-6I
-	<0.002 U	-	<0.0002 U	-	0.003 LO	<0.001 LOU	-	07-mar-95
<0.1 U	-	<0.03 U	-	<0.1 U	-	-	<0.05 U	07-mar-95

See following page for notes

Table A-7. Ground water analyses (mg/L) for metals HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample taken during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
n	Sample analyzed after standard holding time
o	Alpha particle analysis of uranium isotopes
p	Gamma particle analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was positively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-8
Ground Water Analyses for Anions and Water Quality Recorded by October 24, 1995

Table A-8. Ground water analyses for anions and water quality from HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

HE Process Area, Building 815,
Site 300
Anions Report
November 1, 1995
gemini1

s3anionL.01nov95
s3anionR.01nov95

Table A-8. Ground water analyses for anions and water quality from HE Process Area, Building 815,

Location Date	Lab	Note	Val.	Floride (mg/L)	Silica (mg/L)	Nitrate as (NO3) (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
HE Process Area Study Area								
W-6H								
07-mar-95	CS	a	V	0.9	-	<0.5 U	120	150
01-jun-95	CS	a	V	-	-	0.66	-	-
20-jul-95	CS	a	V	-	-	<0.5 U	-	-
W-6I								
07-mar-95	CS	a	V	0.56	-	<0.5 U	200 D	140 D

Site 300. Results recorded by October 24, 1995.

Carbonate (mg/L)	Bicarbonate (mg/L)	TDS (mg/L)	Spec Cond (umhos/cm)	pH	Location Date
					HE Process Area Study Area
					W-6H
56	200	800	1100	8.9	07-mar-95
-	-	-	-	-	01-jun-95
-	-	-	-	-	20-jul-95
					W-6I
<1 U	300	930	1400	8.3	07-mar-95

See following page for notes

Table A-8. Ground water analyses for anions and water quality from HE Process Area, Building 815, Site 300. Results recorded by October 24, 1995.

Notes:

-	Indicates no analysis performed for this compound

Val. = Validation code

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample taken during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
n	Sample analyzed after standard holding time
o	Alpha particle analysis of uranium isotopes
p	Gamma particle analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was positively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Appendix A

Section A-9
Ground Water Analyses for Cations Recorded by October 24, 1995

Table A-9. Ground water analyses for cations from HE Process Area, Building 815, Site 300. Units are mg/L. Results recorded by October 24, 1995.

HE Process Area, Building 815,
Site 300
Cations Report
November 1, 1995
gemini1

s3cationL.01nov95
s3cationR.01nov95

Table A-9. Ground water analyses for cations from HE Process Area, Building 815, Site 300.

Location Date	Lab	Note	Val.	Sodium	Potassium	Calcium	Magnesium	Iron
HE Process Area Study Area								
W-6H								
07-mar-95	CS	a	V	270	14	2.9	0.7	<0.1 U
W-6I								
07-mar-95	CS	a	V	330	8.3	12	4	<0.1 U

Units are mg/L. Results recorded by October 24, 1995.

Manganese	Copper	Zinc	Boron	Strontium	Aluminum	Location Date
					HE Process Area Study Area	
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	W-6H 07-mar-95
<0.03 U	<0.05 U	<0.05 U	-	-	<0.2 U	W-6I 07-mar-95

See following page for notes

Table A-9. Ground water analyses for cations from HE Process Area, Building 815, Site 300. Units are mg/L. Results recorded by October 24, 1995.

Notes:

- Indicates no analysis performed for this compound

Val. = Validation

Footnotes:

a	ERD data
b	ORAD WGMG data
c	Analytical results for this sample are suspect
d	Sample taken during hydraulic testing
e	Blind sample, sent to lab without well identity
f	Sample dilution necessary for analysis; detection limits increased
g	Interlaboratory collocated sample
h	Intralaboratory collocated sample
i	Sample collected as part of pilot study
j	Note field may contain important information regarding this sample
k	Pre-development sample
l	Norm month, norm quarter or norm year inconsistent with sample date
n	Sample analyzed after standard holding time
o	Alpha particle analysis of uranium isotopes
p	Gamma particle analysis of uranium isotopes

Lab Codes:

CS	California Laboratory Services, Rancho Cordova, CA

Validation Codes:

V	Validated
N	Not validated (default value)
U	Undeclared
H	Historical comparison only

CLP flags: (follow result)

B	Analyte detected in method blank
C	Analytical results for this sample are not in agreement with the intra or interlaboratory collocated sample results and the historical data
D	Analysis performed at a secondary dilution or concentration (i.e., vapor)
E	Concentration exceeds calibration range
F	Analyte detected in field blank
H	Sample analyzed outside of the holding time; sample results should be rejected
J	Analyte was postively identified; the associated numerical value is the approximate concentration of the analyte
L	Spike accuracy not within control limits
O	Duplicate spike precision not within control limits
P	Absence of a data qualifier flag does not mean that the data does not need qualification, but that the addition of electronic data qualifier flags was not yet implemented
R	Sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria; the presence or absence of the analyte cannot be verified
S	Analytical results for this sample are suspect
T	Analyte is tentatively identified as this compound; result is approximate
U	Compound was analyzed for, but not detected above detection limit

Appendix B

Evaluation and Screening of Remedial Technologies

Appendix B

Evaluation and Screening of Remedial Technologies

B.1. Overview and Evaluation of Screening Process

Our primary objectives in evaluating and screening remedial technologies for the Building 815 OU are to prevent the 1) ingestion of ground water contaminated with VOCs, and 2) inhalation of VOCs volatilizing from Spring 5 water and from the subsurface in the vicinity of Building 815.

In this Appendix, we evaluate and screen relevant remedial technologies and process options. These technologies include methods of controlling migration and/or removing contamination from ground water. In Section B.2., we screen remedial technologies and process options based on applicability, effectiveness, implementability, and cost. In Section B.3., we present technologies retained through this screening process. Retained technologies are combined as appropriate to form the remedial alternatives presented in Chapter 2; proposed innovative technologies are described in Appendix C.

B.2. Evaluation and Screening of Remedial Technologies and Process Options

We reviewed technologies to mitigate potential exposure to, control migration of, and/or remediate the chemicals of potential concern identified in the SWRI report (Webster-Scholten, 1994) and summarized in Chapter 1 of this report.

Table B-1 summarizes the screening and evaluation of the technology types and process options available for the remedial alternatives. This table documents our reasons for retaining a technology/option or eliminating it from further consideration, based on four criteria: applicability, effectiveness, implementability, and cost. The last column indicates if the technology is retained for consideration.

B.2.1. Access and Use Restrictions

For the Building 815 OU, several applicable controls have been retained to mitigate potential exposure to contaminants in ground water or contaminants volatilizing at Spring 5 and in the vicinity of Building 815. Warning signs could be installed to warn people about the potential hazard of drinking ground water from water-supply wells; keep people away from Spring 5, thus reducing inhalation risks; and limit access to the vicinity of Building 815, also reducing inhalation risks. These measures would be particularly effective combined with existing security guards and patrols at Site 300, and San Joaquin County prohibition on installation of any new water-supply wells immediately south of the Building 815 OU ground water plume.

B.2.2. Ground Water Containment/Control

Containment may protect human health by restricting or controlling contaminant migration, thus minimizing the potential for future exposure. The use of hydraulic barriers, created by injection and extraction of ground water, can contain dissolved contaminants by restricting their movement.

B.2.3. Ground Water Extraction

Ground water extraction involves pumping contaminated ground water from extraction wells strategically placed to accelerate mass removal. This process option is also a form of containment/control as mentioned in Section B.2.2.

B.2.4. Ground Water Treatment

Treatment of contaminated ground water can include *in-situ* as well as *ex-situ* methods. *In-situ* methods destroy or convert contaminants in ground water to less toxic compounds. Possible *in-situ* methods are air sparging, biological enhancement, and dehalogenation using zero-valent metals. *Ex-situ* treatment methods for ground water separate, destroy, or convert contaminants in extracted ground water and vapor byproducts. Possible *ex-situ* ground water treatment methods include sorption to aqueous-phase or vapor-phase GAC, air stripping/air sparging, ultraviolet (UV)/oxidation, ozone/hydrogen peroxide (H_2O_2) peroxidation, biological treatment, natural degradation in constructed wetlands/natural degradation ponds, photolysis in evaporation ponds, ion-exchange, and reverse osmosis.

B.2.5. Disposal of Treated Ground Water

If treatment only separates the contaminant from ground water and places it onto another media, such as sorption onto GAC, the contaminant must then be treated further or properly disposed of at a licensed facility. Typically, GAC will be thermally treated at an off-site facility to destroy the sorbed VOCs, but may require on-site pre-treatment to remove HE compounds. Methods to dispose of treated ground water include on-site surface discharge, reinjection, and air misting.

The method to dispose of treated air emissions is discharge to the atmosphere.

B.3. Summary of Retained Technologies and Process Options

Through development and screening of remedial technologies/process options, we have retained several as shown in Table B-1. These technologies/options were considered when developing the remedial alternatives discussed in Chapter 2. Table B-2 summarizes the technologies/options retained and incorporated into Chapter 2 alternatives. These technologies/options were chosen based on applicability, implementability, effectiveness, cost, site-specific requirements, and best professional judgment.

We have evaluated several innovative technologies in our screening process to be consistent with objectives of U.S. DOE/LLNL's Environmental Restoration Program. These objectives direct us to conduct environmental remediation projects better, faster, and more cost-effectively. Therefore, we have incorporated two innovative technologies into one of the two alternatives:

1) nitrate treatment using a constructed wetland/natural degradation ponds, and 2) on-site regeneration of RDX-laden GAC with RDX, using base-hydrolysis flushing followed by bioreactor treatment of the base-hydrolysis solution.

B.4. References

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).

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Table B-1. Preliminary remediation technology screening and evaluation.

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
Access and use restrictions	Fencing and signs	Applicable to deter access to source areas.	Effective	Implementable for on-site portion of plume.	Low	Yes
	Security guards/patrols	Applicable	Effective	Implementable	High	Yes
Ground water containment/ control	Slurry walls	Applicable	Due to construction constraints, effective only for horizontal source migration control in unconsolidated material .	Difficult to implement. Would require excavation of bedrock (primarily) up to 100-ft depth.	High	No
	Grout curtain	Applicable	Effective for horizontal source migration control.	Difficult to implement because steep terrain restricts access of installation equipment.	Very high	No
	Hydraulic barrier (via injection)	Applicable. Regulatory permits required. Possible use for treated ground water. Additional modeling may be required.	Effective for on-site plume control of RDX.	Implementable	Medium	Yes
	Hydraulic control (via extraction)	Applicable for $Tnbs_2$ aquifer.	Effective	Implementable	Medium	Yes
Ground water extraction	Extraction from wells (vertical)	Applicable	Effective when combined with treatment. Provides hydraulic control of contaminant plume.	Implementable. Steep terrain may limit access to installation locations.	Medium	Yes

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Extraction from wells (horizontal)	Applicable for Tps perched water-bearing zone.	Not effective if all water-bearing zones are not intercepted.	Difficult to implement. Water-bearing zones are laterally heterogeneous and possibly discontinuous. Therefore, interception is not guaranteed. Steep terrain may limit access to installation locations.	High	No
	Extraction from trenches	Applicable	Lateral heterogeneity may limit effectiveness.	Difficult to implement. Only implementable for $Tnbs_2$ aquifer, using caisson installation method. Steep terrain may limit access to installation locations.[a]	Very high	No
In-situ ground water treatment	Air sparging	Applicable for VOCs only. Innovative technology.	Effectiveness uncertain due to localized subsurface permeability, heterogeneities, and low concentrations.	Difficult to control movement and capture of sparged VOCs.	NCF	No
	Biologically enhanced degradation.	Applicable. Innovative technology.	Compound-specific. Not proven effective at low concentrations.	Compound-specific	NCF	No

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Dehalogenation with zero-valent metal(s)	Applicable. Innovative technology.	Effective, if shown not to generate toxic by-products such as vinyl chloride.	Uncertain. Requires 100-ft-deep trench in bedrock.	Very high	No
Ex- situ ground water treatment	GAC sorption—aqueous phase	Applicable for VOCs and HE compounds.	Effective for most VOCs, HE, but not nitrates. Most appropriate for low flow rates and low concentrations.	Implementable. Potentially high (operation and maintenance) O&M due to chemical precipitation and vessel clogging. RDX levels require monitoring not to exceed 10% concentration, which then qualifies as an explosive. Used carbon requires regeneration or disposal. RDX must be desorbed using innovative methods such as base-hydrolysis. Off-site GAC regeneration for sorbed VOCs.	Medium	Yes
	Air stripping/air sparging	Applicable for VOCs. Air permit required. Vapor-phase GAC required.	Effective when combined with vapor-phase GAC. Possible reduced efficiency due to chemical precipitation.	Implementable. Potentially high O&M due to chemical precipitation and reduced efficiency. Need to design to prevent scaling.	Medium	Yes

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	UV/oxidation—aqueous phase	Applicable for VOCs and RDX.	Effective, destroys VOCs. Possible reduced efficiency due to chemical precipitation, turbidity.	Implementable. High energy consumption due to high concentration of nitrates and sulfates that "quench" the process. May require GAC polishing unit to achieve discharge requirements. High O&M costs.	High	Yes
	Ozone/H_2O_2 peroxidation	Applicable for RDX and VOCs.	Effective	Implementable	Medium	Yes
	Biological treatment	Applicable for treatment of base-hydrolysis solution generated during RDX desorption from GAC. Innovative technology	Effective	Implementable	High	Yes
	Constructed wetlands/natural degradation ponds	Applicable. Innovative technology.	Effective	Implementable. May need subsurface flow to avoid mosquitoes. High sulfate concentrations may cause nuisance odors, algae growth, or hydrogen sulfide.	Medium	Yes

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Photolysis in evaporation ponds	Applicable for RDX when VOCs are first removed.	Effectiveness unlikely due to low concentrations.	Requires large surface impoundments. Flow rates and residence times require large, shallow ponds.	NCF	No
	Ion exchange	Applicable for nitrates.	Effective when designed for Site 300 high sulfate water. Commercially available resins will preferentially select sulfate over nitrate.	May be implementable with nitrate-selective resins. Resin regeneration required. Disposal costs for brine are high.	High	No
	Reverse osmosis	Applicable	Effective. 97.7% nitrate-removal rate.	Implementable. Brine disposal costs are high.	Very high	No
Disposal of treated ground water	On-site surface discharge	Applicable	Effective	Additional investigation required to identify discharge areas.	Low	Yes
	Reinjection	Applicable. May also act to mitigate plume migration when combined with ground water extraction.	Effective. May also be used to hydraulically displace contaminants toward extraction wells/trenches.	Must ensure that recharge does not adversely affect subsurface (e.g., migration of contaminants). Permitting required. Scaling may clog system, requiring regular maintenance.	Medium–high	Yes

Table B-1. (Continued)

Remediation technology type	Technology (process options)	Screening comments	Effectiveness	Implementability	Cost	Retained
	Air misting	Applicable	Only effective for low flows.	Implementable	Low	Yes

a Discussed in Chapter 2 with regard to Tps remediation.

NCF = Not considered further.

Table B-2. Retained remedial technologies.

Remediation technology type	Effectiveness	Cost	Selected for use in Chapter 2 Alternatives
Access and use restrictions			
Fencing and signs	Effective	Low	Yes
Security guards/patrols	Effective	High	Yes
Ground water containment/control			
Hydraulic barrier (via injection)	Effective for on-site plume control of RDX.	Medium	Yes
Hydraulic control (via extraction)	Effective	Medium	Yes
Ground water extraction			
Extraction from wells (vertical)	Effective when combined with treatment. Provides hydraulic control of contaminant plume.	Medium	Yes
Ex-situ ground water treatment			
GAC sorption—aqueous phase	Effective for most VOCs, HE, but not nitrates. Most appropriate for low flow rates and low concentrations.	Medium	Yes
Air stripping/air sparging	Effective when combined with vapor-phase GAC. Possible reduced efficiency due to chemical precipitation.	Medium	No
UV/oxidation—aqueous phase	Effective, destroys VOCs. Possible reduced efficiency due to chemical precipitation, turbidity.	High	No
Ozone/H_2O_2 peroxidation	Effective	Medium	No
Biological treatment	Effective	High	Yes
Constructed wetlands/natural degradation ponds	Effective	Medium	Yes
Disposal of treated ground water			
On-site surface discharge	Effective	Low	Yes
Reinjection	Effective. May also be used to hydraulically displace contaminants toward extraction wells/trenches.	Medium–high	Yes
Air misting	Only effective for low flows.	Low	No

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Appendix C

Proposed Innovative Technologies

Appendix C

Proposed Innovative Technologies

C-1. Combined GAC, Base Hydrolysis, and Biological Treatment Method

Aqueous phase GAC will be used to treat extracted ground water prior to injection or discharge to a constructed wetland or pond system. The cost of regenerating GAC laden with the high explosive compound RDX is very expensive because few facilities will accept it. The base hydrolysis and biological treatment method can regenerate GAC contaminated with RDX. The byproducts of this method include treated ground water, a small quantity of process effluent, and regenerated GAC containing residual TCE contamination. The regenerated GAC would be sent off site for thermal TCE regeneration; the other byproducts can be disposed of or recycled.

The first step of this three-step process is to remove RDX from the ground water, using traditional aqueous-phase GAC. TCE present in the ground water will also be adsorbed onto the GAC. The next step is to regenerate the GAC using a base hydrolysis method. This process occurs in a batch mode using a 0.1-molar solution of sodium hydroxide, which removes RDX and leaves most of the TCE on the GAC. As the hydrolysis solution is heated to 80°C, a small fraction of the TCE may be desorbed. Empirical data needs to be obtained concerning the amount of TCE desorption that would occur. This process generates a hydrolysate, which is an alkaline solution that contains primarily nitrite and formate. This solution is then neutralized with hydrochloric acid. The final step removes nitrate and formate from the neutralized hydrolysate, using biological treatment in a bioreactor. The bioreactor is a column of plastic saddles inoculated with a denitrifying consortium of microorganisms that are optimized to degrade RDX and its byproducts. The biomass is allowed to develop on the saddles for approximately 1 month prior to treatment of the hydrolysate. During this period the biomass is fed a mixture of nutrients and ethanol as a carbon source. Hydrolysate treatment is accomplished by pumping the diluted solution through the column at a low flow rate. Completion of the biological treatment is expected to take a few days to a few weeks, depending on the volume of carbon regenerated and the dilution rate required (Knezovich, 1995).

C-2. Constructed Wetlands

We propose using a constructed wetland or pond system to reduce nitrate concentrations in extracted ground water prior to surface discharge. While use of constructed wetlands for treating municipal waste water is an established method, this technology has not been widely implemented for treatment of industrial or remediation waste water.

We propose this technology because conventional methods (e.g., ion exchange and reverse osmosis) may not effectively achieve the low nitrate concentrations required for surface discharge. Such methods required lengthy retention times and are susceptible to interference from other inorganics (such as sulfates) in the ground water. Our proposed option is also more cost effective than the alternative technologies previously discussed, and it provides a means for destroying contaminants as opposed to transferring contaminants from one medium to another.

Wetland and pond systems use the interaction of rhyzomous vegetation and anaerobic bacteria to denitrify water. Although a variety of designs may be employed, we have chosen a subsurface flow wetland system for preliminary design and cost analysis. Limited data on denitrification rates indicate that subsurface flow systems are significantly more effective than surface flow systems (Hammer, 1989). Additionally, a subsurface flow system would virtually eliminate any need for mosquito abatement or odor control.

As shown in Figure F-1, three primary components are required in a subsurface flow wetland, in ascending order: an impermeable layer (generally clay), a gravel layer that provides a substrate for the vegetation root zone, and an above-surface vegetation zone. The impermeable layer prevents infiltration of the waste water. The gravel layer and associated root zone is where waste water flows and the denitrification process occurs. The above-surface vegetative zone contains the green, photosynthetic portion of the plant that provides the initial carbon fixation and ultimate carbon supply to the denitrification process. In addition, this top zone lends an aesthetic appeal to the system.

Water containing elevated concentrations of nitrates is pumped or gravity drained into one end of the wetland through a piping manifold to evenly distribute the water and prevent channeling. Water then gradually flows about 1 ft below the surface through the gravel layer, contacting the root zone and discharging from the distal end of the wetland. Wetland dimensions (width, depth, and length) are specified based on retention time necessary for sufficient denitrification to occur. Frequently, wetland systems are designed with multiple cells to provide flexible flow rates to achieve adequate retention time and ensure sufficient water to sustain the vegetation. The capacity of a wetland can be affected by precipitation and evapotranspiration rates, the root depth of the chosen vegetation, and areal extent. Areal extent can be limited by local topography or cultural features.

Although many reactions occur in the root and gravel zone, the primary process of interest is anaerobic denitrification. This process is a form of cellular respiration that occurs in the anoxic portions of the root zone. The rhyzomatous roots provide a substrate for bacterial attachment. They also help create adjacent aerobic and anoxic zones, which are important for the cycling of nitrogen and carbon in the system. Such cycling includes the initial breakdown of root matter or root exudate. Once the carbon is released in the aerobic zone directly adjacent to the root, it can be used in the more distal anoxic areas where denitrification occurs. The following formula describes this biological process for denitrification:

$$5\,CH_2O + 4H^+ + 4\,NO_3^- \text{------>} 2\,N_2 + 5\,CO_2 + 7\,H_2O.$$

Nitrification also takes place, which conflicts with denitrification. This process is controlled by the supply of organic carbon produced by decaying plants. The choice of plants with a favorable carbon-nitrogen ratio can minimize this process.

C-3. References

Hammer, D. A., Ed. (1989), *Constructed Wetlands for Waste Water Treatment: Municipal, Industrial, and Agricultural* (Lewis Publishers: Chelsea, Michigan).

Knezovich, J. P. (1995), *Regeneration of RDX-Laden Activated Carbon Used to Treat Ground Water at Site 300*, Internal technical memo, October 1995, Lawrence Livermore National Laboratory, Livermore, Calif.

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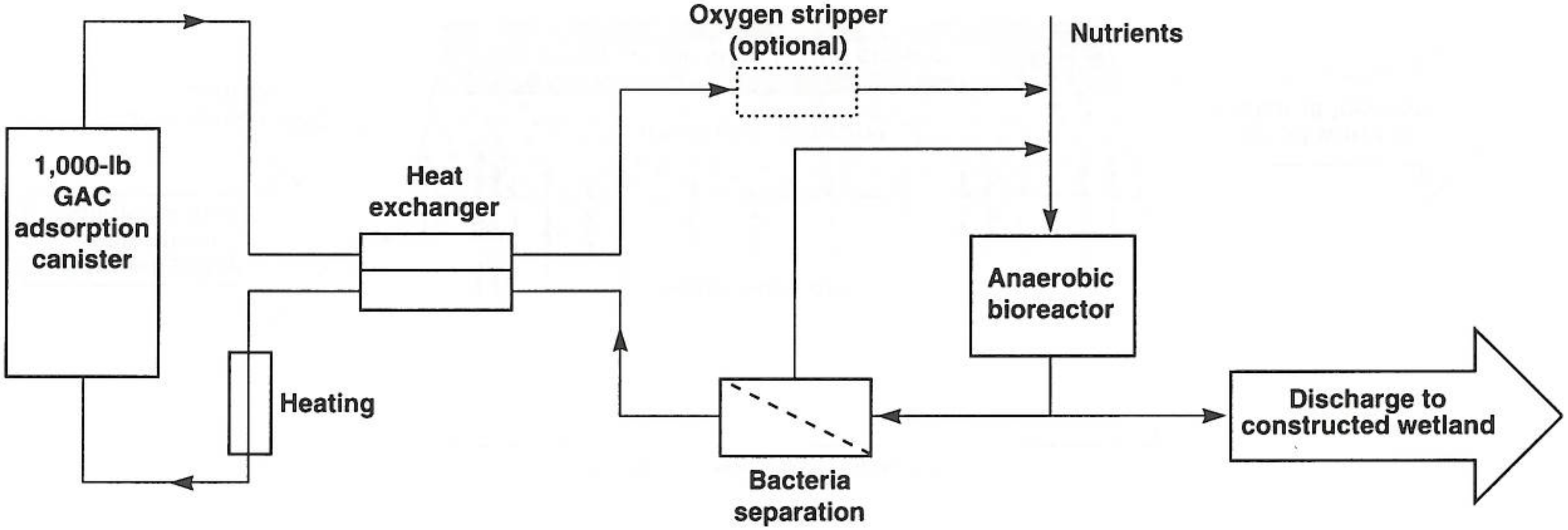

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Figure C-1. Schematic of biological treatment system to regenerate granular activated carbon with high-explosives.

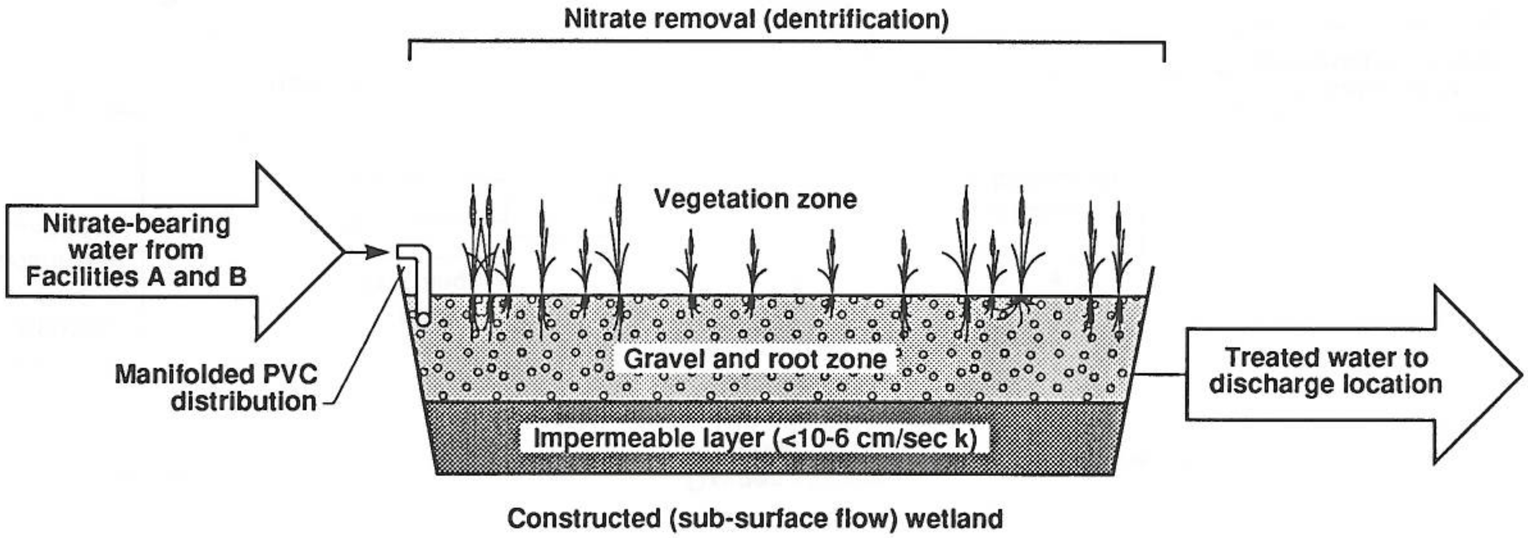

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Figure C-2. Proposed nitrate treatment system—Alternative B.

Appendix D

Estimates of Area, Volume, and Mass of Contamination

Appendix D

Estimates of Area, Volume, and Mass of Contamination

D-1. Estimates of Area, Volume, and Mass

This appendix presents estimates of area, volume, and mass of subsurface contamination (TCE, nitrates, and RDX) in the Building 815 OU, showing how these estimates were derived.

As discussed in Chapter 1, TCE is the primary indicator chemical for VOCs; therefore, we used TCE to delineate the extent, volume, and mass of VOCs in the Building 815 OU. Although we do not address other VOCs of potential concern in this appendix, we considered them in the design of alternatives discussed in Chapter 2.

D-1.1. Estimates of Area, Volume, and Mass in the $Tnbs_2$ Aquifer

In calculating estimates of area, volume, and mass of TCE, nitrates, and RDX in the $Tnbs_2$ aquifer, we used a porosity value of 0.25 (dimensionless). This value is from the conservative end of the porosity range for sandstone (5–30%) presented by Freeze and Cherry (1979). We use a density of 1.46 grams per cubic centimeter (g/cc) for TCE (Windholz, 1983), and 1.82 g/cc for RDX (Layton, 1987). For the estimates, we derived the concentration data from our most recent (fourth quarter 1994) and/or complete sampling data set. To define the affected areas, we used isoconcentration contours for contaminants in ground water in the Building 815 OU $Tnbs_2$ aquifer (Figs. 1-9, 1-11, and 1-13). These contours represent the site hydrogeologist's best professional judgment based on available data and experience. We assumed complete vertical mixing of contaminants in ground water, and we used water level measurements and well logs to determine the saturated thickness of the aquifer. To calculate the total volume of a contaminant in ground water, we used the geometric mean concentration to represent the bulk concentration of the contaminated volume between adjacent contours. For example, the volume of contaminated ground water between the 10 µg/L and 1.0 µg/L TCE isoconcentration contours was assigned a geometric mean TCE concentration value of 3.16 µg/L. We calculated the volume of contaminated ground water, the mass of contaminant, and the volume of contaminant for each of the contour intervals shown in Figures 1-9, 1-11, and 1-13. The corresponding masses/volumes calculated for each interval were summed to estimate the total quantity of contaminated ground water and the corresponding volume/mass of contaminant contained within the $Tnbs_2$ ground water plumes.

We used the following equation to calculate the total volume (in gallons) of ground water contaminated with TCE ($V_{C\text{-}GW}$):

$$V_{C\text{-}GW} = A \times b \times n \times 7.48 \qquad \text{(D-1)}$$

where

A = area between TCE contour intervals (ft^2),

b = contaminated saturated thickness (ft),

n = porosity (dimensionless), and

7.48 = conversion factor (gal/ft^3).

We applied the same method to calculate the total volume of ground water contaminants with nitrate and RDX.

We used the following equation to calculate mass of TCE (M_{TCE}) dissolved in ground water:

$$M_{TCE} = A \times b \times n \times (C_{TCE}/10^6) \times 28.32 \tag{D-2}$$

where

A = area between contour intervals (ft^2),

b = contaminated saturated thickness (ft),

n = porosity (dimensionless),

C_{TCE} = geometric-mean TCE ground water concentrations (µg/L), and

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}):

$$V_{TCE} = M_{TCE} / (1.46 \times 1{,}000 \times 3.785) \tag{D-3}$$

where

M_{TCE} = mass of TCE (g) from equation D-2, and

$(1.46 \times 1{,}000 \times 3.785)$ = conversion factors for the density of TCE (ml/L and L/gal, respectively).

We applied the same method as discussed above to RDX in ground water. Table D-1 shows the results of our calculations for all three contaminants.

D-1.2. Estimates of Area, Volume, and Mass in the Tps Water-Bearing Unit

We also estimated the area, volume, and mass of TCE for the Tps perched water-bearing zone in the Building 815 area, using the same parameter and methods as described in Section D-1.1. Table D-2 shows the resulting estimations.

D-2. Sensitivity Analysis for Estimates of TCE, Nitrates, and RDX in the $Tnbs_2$ Aquifer and the Tps Water-Bearing Zone

For the $Tnbs_2$ aquifer, four variables were used for each of our mass and volume estimates of contaminants in ground water: area, saturated thickness, porosity, and contaminant concentration. By inspecting equations D-1 and D-2, we see a linear relationship between all four parameters and the resulting mass or volume estimates. Therefore, if one of these parameters is adjusted, the result will be adjusted by the same factor. For example, if the saturated thicknesses were decreased by 50%, the resulting mass and volume would also decrease by 50%.

D-3. References

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

Layton, D., B. Mallon, W. Mitchell, L. Hall, R. Fish, L. Perry, G. Snyder, K. Bogen, W. Malloch, C. Ham, and P. Dowd (1987), *Conventional Weapons Demilitarization: A Health and Environmental Effects Data Base Assessment—Explosives and Their Co-Contaminants Final Report, Phase II*, Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-21109).

Windholz, M., Ed. (1983), *The Merck Index*, 10th Edition (Merck & Co., Rahway, NJ).

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Table D-1. Estimated ground water contaminants in Building 815 OU Tnbs$_2$ aquifer.

Contaminant plume	Total affected area (ft^2)	Average contaminated saturated thickness (ft)	Volume of contaminated water (ft^3)	Contaminant volume (gal)	Contaminant mass (kg)
TCE	2,000,000	45	31,000,000	2.52	14
Nitrate	2,700,000	45	8,000,000	–	–
RDX	630,000	22	3,500,000	0.39	2.7

Note: – indicates not applicable.

Table D-2. Estimated TCE in the Tps water-bearing zone at the Building 815 area.

Contaminant plume	Total affected area (ft^2)	Average contaminated saturated thickness (ft)	Volume of contaminated water (ft^3)	Contaminant volume (gal)	Contaminant mass (kg)
TCE	420,000	8	830,000	6.7×10^{-2}	0.37

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Appendix E

Modeling of Capture and Injection Zones, Contaminant Mass Removal, and Contaminant Fate and Transport

Appendix E

Modeling of Capture and Injection Zones, Contaminant Mass Removal, and Contaminant Fate and Transport

E.1. Estimates of Capture and Injection Zones for Ground Water Extraction and Reinjection

E-1.1. Objective

The objective of the procedure described below was to estimate capture and injection zones for ground water extraction and reinjection. These estimates were calculated to develop Alternatives A and B discussed in Chapter 2.

E-1.2. Calculation

We used the following calculations to estimate capture and injection zone configurations (Strack, 1989):

$$Q = wq \tag{E-1}$$

where

$Q =$ flow rate through cross-sectional area, which is also equal to the pumping/injection rate $[L^3 \cdot T^{-1}]$,

$w =$ maximum width [L] of capture/injection zone, and

$q =$ discharge potential $[L^2 \cdot T^{-1}]$, which is also

$$= K\,i\,b, \text{ for a confined aquifer, and} \tag{E-2}$$

$$= K\left(\frac{h_2^{\,2} - h_1^{\,2}}{2D}\right), \text{ for an unconfined aquifer,} \tag{E-3}$$

where

$K =$ hydraulic conductivity $[L \cdot T^{-1}]$,

$i =$ hydraulic gradient $[L \cdot L^{-1}]$, also

$$= \frac{h_2 - h_1}{D}, \tag{E-4}$$

$h_2 =$ hydraulic head at upgradient location 2 (two) [L],

$h_1 =$ hydraulic head at downgradient location 1 (one) [L], D = horizontal distance between locations 1 and 2 [L], and

b = average saturated thickness [L].

The stagnation point is defined as

$$S = \frac{w}{2\pi} \tag{E-5}$$

where

S = distance directly downstream from the well point where ground water velocity is 0 (zero) [L], and

π = 3.14 [dimensionless].

Although the zones of capture and injection are calculated the same way, Q is either negative or positive, respectively. As such, the resulting streamlines are drawn either approaching or leaving the well point, respectively.

E-1.3. Parameter Discussion

This two-dimensional (2-D) approach assumes a homogeneous, isotropic aquifer of constant thickness, uniform gradient, horizontal flow, and constant rate of extraction/injection. This approach also includes the conservative assumption that the $Tnbs_2$ aquifer is of infinite extent. We obtain Q and K from well tests; i, h_2, and h_1 from potentiometric surface maps developed from fourth quarter 1994 water level data; and b from the same water level data and well logs.

E-1.4. Results

Tables E-1 and E-2 show the values used for, and the results of, the above calculations. Figures E-1 through E-5 show the plotted capture/injection zones, which are oriented with the regional gradient approximately northwest–southeast. These capture/injection zones are plotted conservatively for each individual well. The figures do not account for interference between wells. In reality, these zones would not overlap and, as a group, would have a wider total width of capture/injection.

E-1.5. Sensitivity Analysis

As shown by the above equations, the influences of most parameters on capture widths are either proportional or inversely proportional, depending on whether the parameter is in the numerator or the denominator. For example, if the pumping rate were to increase by 50%, the maximum width of capture or injection would also increase by 50%; and if K were to increase by 100%, the maximum width of capture or injection would decrease by 50%. The exception is the case of an unconfined aquifer, where h_2 and h_1 are squared then subtracted for the calculation of discharge.

E-2. Estimates of Contaminant Mass Removal

E-2.1. Objective

Our objective was to estimate contaminant mass removal by ground water extraction wells, calculating concentration declines through time for the chemicals TCE, RDX, and nitrates. As discussed in Chapter 1, TCE is the predominant VOC, and RDX is the predominant HE compound; therefore, both compounds were used as indicator chemicals. The contaminant mass removal estimates were calculated to develop Alternatives A and B discussed in Chapter 2.

E-2.2. Calculation Description

The following mixed-tank model was used to estimate mass removal rates (Isherwood et al., 1990/1991).

$$C = C_0\, e^{kt};\ k = -\frac{Q}{V\,n\,R} - \frac{\lambda}{R} \qquad \text{(E-6)}$$

where

$C =$ contaminant concentration in ground water $[M \cdot L^{-3}]$,

$C_0 =$ contaminant concentration in ground water at time $t = 0$ $[M \cdot L^{-3}]$,

$e =$ 2.72 [dimensionless],

$k =$ exponential decline constant $[T^{-1}]$,

$t =$ time [T],

$Q =$ combined flow rate from wells $[L^3 \cdot T^{-1}]$,

$V =$ volume being flushed $[L^3]$,

$n =$ porosity [dimensionless],

$R =$ retardation coefficient [dimensionless], and

$\lambda =$ first-order transformation rate $[T^{-1}]$.

E-2.3. Parameter Discussion

This non-dimensional (0-D) approach assumes a well-mixed domain, an initial uniform concentration, and constant flow, Q, through volume V. We obtain an initial concentration from an area-weighted geometric mean using contoured fourth-quarter 1994 ground water analyses; Q from well tests; V from capture zone estimates discussed in section E-1; and, n, R, and λ from previous modeling (Webster-Scholten, 1994).

E-2.4. Results

Tables E-3 and E-4 show the values used for, and the results of, the above calculations. Figures E-6 through E-9 show the estimated concentration decrease through time for all three contaminants.

E-2.5. Sensitivity Analysis

As shown by the above equations, the exponents t and k are inversely proportional to one another for a given C_0 and C. For example, if a parameter is changed in a way that doubles k (e.g., doubling Q), the half-life is shortened by a factor of 2 (two): a given C would be achieved in half the time. Furthermore, C_0 has a linear relation to C; if we double C_0, we double C.

E-3. Estimates of Contaminant Fate and Transport in the Unsaturated Zone of the $Tnbs_2$ Aquifer

E-3.1. Objective

The objective for modeling is to estimate the potential impact of TCE, presently in the Tps hydrologic unit, on the underlying $Tnbs_2$ aquifer. We calculated this potential impact by simulating TCE transport through the unsaturated portion of the $Tnbs_2$ aquifer, using the numerical code VLEACH.

E-3.2. Conceptual Model

In the Building 815 area, the Tps perched water-bearing zone overlays the $Tnsc_2$ confining unit, which overlays an unconfined portion of the $Tnbs_2$ aquifer. Although data indicate that the predominant mode for ground water flow in the Tps is horizontal and south toward Spring 5, we conservatively assume transport to occur vertically downward into the $Tnbs_2$, ignoring the low permeability confining capacities of the $Tnsc_2$. Furthermore, we conservatively assumed that this TCE mass is dissolved in water at the top of the $Tnbs_2$ unsaturated zone. At a time $t = 0$ we assume that the TCE is instantaneously released and begins to migrate.

E-3.3. Code Description

VLEACH (U.S. EPA, 1990) is a simplified, one-dimensional (1-D) numerical model that simulates the vertical migration of contaminants in the vadose zone (partially saturated zone). VLEACH models the following processes:

- Aqueous-phase advection.
- Vapor-phase diffusion.
- Solid-phase sorption.

The VLEACH model is based on the following assumptions:

- Solid-liquid partitioning coefficient (K_d) and the liquid-vapor partitioning coefficient (H) are constants, i.e., the partitioning relationships between phases are linear.
- Liquid, vapor, and sorbed phases are in a state of equilibrium in each cell.
- Moisture content profile is constant, i.e., the volumetric water content is constant with depth.
- Contaminant dispersion in the liquid phase is negligible.
- No free product is present in the simulation column.

- Soil within a simulated column is completely homogeneous, and behaves as a uniform porous medium with no preferential flow pathways.
- Volatilization from the top of the soil column may be either completely restricted or totally unimpeded.

Contaminant transport is assumed to occur in the liquid and gas phases. Equations E-7 and E-8 define 1-D contaminant transport in the liquid and gas phases, respectively. The processes include liquid-phase advection resulting from downward seepage, vapor-phase diffusion, partitioning (sorption) described by a linear equilibrium isotherm, and contaminant degradation in the liquid phase with first-order kinetics. Sorption slows the rate of solute transport relative to ground water flow, and is represented by the retardation coefficient (R) in the transport equation.

$$R\frac{dC_l}{dt} = v\frac{\partial C_l}{\partial z} - \lambda R C_l\text{, and} \tag{E-7}$$

$$R\frac{dC_g}{dt} = D_{eff}\frac{\partial^2 C_g}{\partial z^2} \tag{E-8}$$

where

C_l = Contaminant concentration in the aqueous phase $[M \cdot L^{-3}]$,

C_g = Contaminant concentration in the gas phase $[M \cdot L^{-3}]$,

D_{eff} = Effective diffusion coefficient $[L^2 \cdot T^{-1}]$,

R = Retardation factor [dimensionless],

v = Vertical seepage velocity $[L \cdot T^{-1}]$,

z = Vertical depth variable [L], and

λ = Degradation rate constant $[T^{-1}]$.

Equation E-9 describes the vapor diffusion coefficient as a function of the total and water-filled porosity, and the free-air diffusion coefficient. Equation E-10 describes the effective diffusion coefficient in terms of the vapor-diffusion coefficient; it incorporates retardation due to linear, equilibrium partitioning.

$$D_v = D_{air}\frac{[(n - \theta)^{10/3}]}{n^2}\text{, and} \tag{E-9}$$

$$D_{eff} = \frac{HD_v}{[\rho b K_d + \theta + (n - \theta)H]} \tag{E-10}$$

where

D_{air} = Vapor diffusion coefficient for air $[L^2 \bullet T^{-1}]$,

D_v = Vapor diffusion coefficient for porous media $[L^2 \bullet T^{-1}]$,

D_{eff} = Effective diffusion coefficient $[L^2 \bullet T^{-1}]$,

K_d = Liquid/solid partitioning coefficient $[L^3 \bullet M^{-1}]$,

H = Henry's law constant [dimensionless],

n = Total porosity [dimensionless],

θ = Water-filled porosity [dimensionless], and

ρb = Bulk density $[M \bullet L^{-3}]$.

In each column, the soil is assumed to be completely homogeneous, with no preferential flow pathways. Each column is divided into cells of uniform thickness. An initial depth-concentration profile can be assumed by specifying the initial aqueous-phase concentration for each cell along a simulated column. The boundaries at the upper and lower ends of the simulated column may be specified as either being impermeable to contaminant flux out of the system (zero-flux boundary), or as each having a constant contaminant concentration (constant-concentration boundary). A contaminant, present in infiltrating water, may enter the soil column at a specified initial concentration and a constant recharge or infiltration rate.

The model source code was modified to include aqueous-phase contaminant degradation. The model assumes equilibrium between the solid, liquid, and gas phases, and redistributes the contaminant mass in each phase after every time step. At the end of the simulation, the model predicts a flux of contaminant to ground water, and generates a profile of contaminant concentration versus depth for each of the three phases. VLEACH is conservative to the extent that it considers the shortest possible transport path. Details on the model, the initial and boundary conditions, and the input parameters are included in the VLEACH manual (U.S. EPA, 1990).

We modified the original version of VLEACH to account for possible aqueous-phase degradation. To do this, we assumed that the rate of contaminant mass loss due to chemical transformation was proportional to the contaminant mass present. Accordingly,

$$\frac{dC}{dt} = kC \qquad \text{(E-11)}$$

where

C = Contaminant concentrations at time t $[M \bullet L^{-3}]$ and

k = First-order rate constant $[T^{-1}]$.

By integrating equation E-11, we obtain an exponential loss rate,

$$C = C_0 \exp(-kt) \qquad \text{(E-12)}$$

where

$C_0 =$ Contaminant concentrations at time $t = 0$ $[M \cdot L^{-3}]$.

The constant k is related to the contaminant degradation half-life $T_{1/2}$ by

$$T_{1/2} = \frac{0.693}{k}. \tag{E-13}$$

The modification requires the addition of an assumed contaminant degradation half-life $T_{1/2}$ to the VLEACH input file.

E-3.4. Parameter Discussion

Tables E-5 through E-7 present the soil properties, chemical properties, and input parameters we used, respectively. Soil and chemical properties are consistent with previous modeling done for the SWRI, the HE Burn Pit Closure report (Lamarre et al., 1993), and the present mass, area, and volume estimations presented in Appendix D. Other input parameters, such as temporal and spatial discretization, were chosen to optimize the accuracy of the numerical code. We applied the present total mass of TCE in the Tps ground water, 370 g (Appendix D), to an area defined by the Tps extent of saturation. Allowing for equilibration in all three phases, a total mass (aqueous, vapor, and sorbed phases) of 880 g was placed in the top cell of the $Tnbs_2$ unsaturated zone, with 370 g in the aqueous phase at time $t = 0$. The 30-ft thickness of the $Tnbs_2$ unsaturated zone was estimated using hydrogeologic cross-section B-B' (Fig. F-1).

E-3.5. Results

The predicted 300-year average TCE concentration in percolate to reach the $Tnbs_2$ saturated zone is 0.34 µg/L. VLEACH predicts 300 years to reduce the total TCE mass in the model domain ($Tnbs_2$ unsaturated zone) to 0.1% of the original mass. The peak concentration of 0.78 µg/L reaches the $Tnbs_2$ saturated zone in 90 years. Figure E-11 displays our results. Upon reaching the 10-ft-thick $Tnbs_2$ saturated zone, the percolate concentrations will be further reduced by dilution.

E-3.6. Sensitivity Analysis

We examined the sensitivity of predicted maximum TCE concentrations reaching the $Tnbs_2$ saturated zone to the following parameters: original aqueous phase TCE mass, degradation rate, infiltration rate, and volumetric water content.

E-3.6.1. Original Aqueous Phase TCE Mass

This model has a linear relationship between original aqueous phase TCE mass and the predicted maximum concentration to reach the $Tnbs_2$ saturated zone. The predicted maximum TCE concentrations are 0.39, 0.78, and 1.6 µg/L for an original aqueous phase mass of 190, 370, and 740 g, respectively. The predicted time (90 years) that the maximum concentration reaches the saturated zone is not affected by a change in the original mass.

C_0 = Contaminant concentrations at time t = 0 $[M \bullet L^{-3}]$.

The constant k is related to the contaminant degradation half-life $T_{1/2}$ by

$$T_{1/2} = \frac{0.693}{k}. \qquad \text{(E-13)}$$

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E-3.6.2. Degradation Rate

This model is not very sensitive to the degradation rate. The predicted maximum concentrations to reach the Tnbs$_2$ saturated zone are 0.78, 1.0, and 1.4 µg/L for degradation rates of 50, 100, and ∞ (infinity, which is equal to zero degradation), respectively. The time required for the predicted maximum concentrations to reach the Tnbs$_2$ saturated zone are 90, 100, and 100 years, respectively.

E-3.6.3. Infiltration Rate

This model is very sensitive to the infiltration rate. The predicted maximum concentrations to reach the Tnbs$_2$ saturated zone are 0.047, 0.78, and 9.6 µg/L, for infiltration rates of 0.0091, 0.091, and 0.91 ft/year, respectively. The time required for the predicted maximum concentrations to reach the Tnbs$_2$ saturated zone are 170, 90, and 13 years, respectively.

E-3.6.4. Volumetric Water Content

This model is also very sensitive to the volumetric water content. The predicted maximum concentrations to reach the Tnbs$_2$ saturated zone are 0.24, 0.78, and 5.7 µg/L for volumetric water contents of 0.13, 0.17, and 0.21, respectively. The time required for the predicted maximum concentrations to reach the Tnbs$_2$ saturated zone are 40, 90, and 130 years, respectively.

E-3.7. Conclusions

Our modeling predicts that average TCE concentrations reaching the Tnbs$_2$ saturated zone (resulting from Tps leachate) are likely to be below the limit of detection, 0.5 µg/L. Based on these results, it is unlikely the TCE presently residing in the Tps perched water-bearing zone will have a detectable impact on the Tnbs$_2$ aquifer. Our results are based on highly conservative assumptions; actual concentrations are likely to be lower than estimated.

E-4. References

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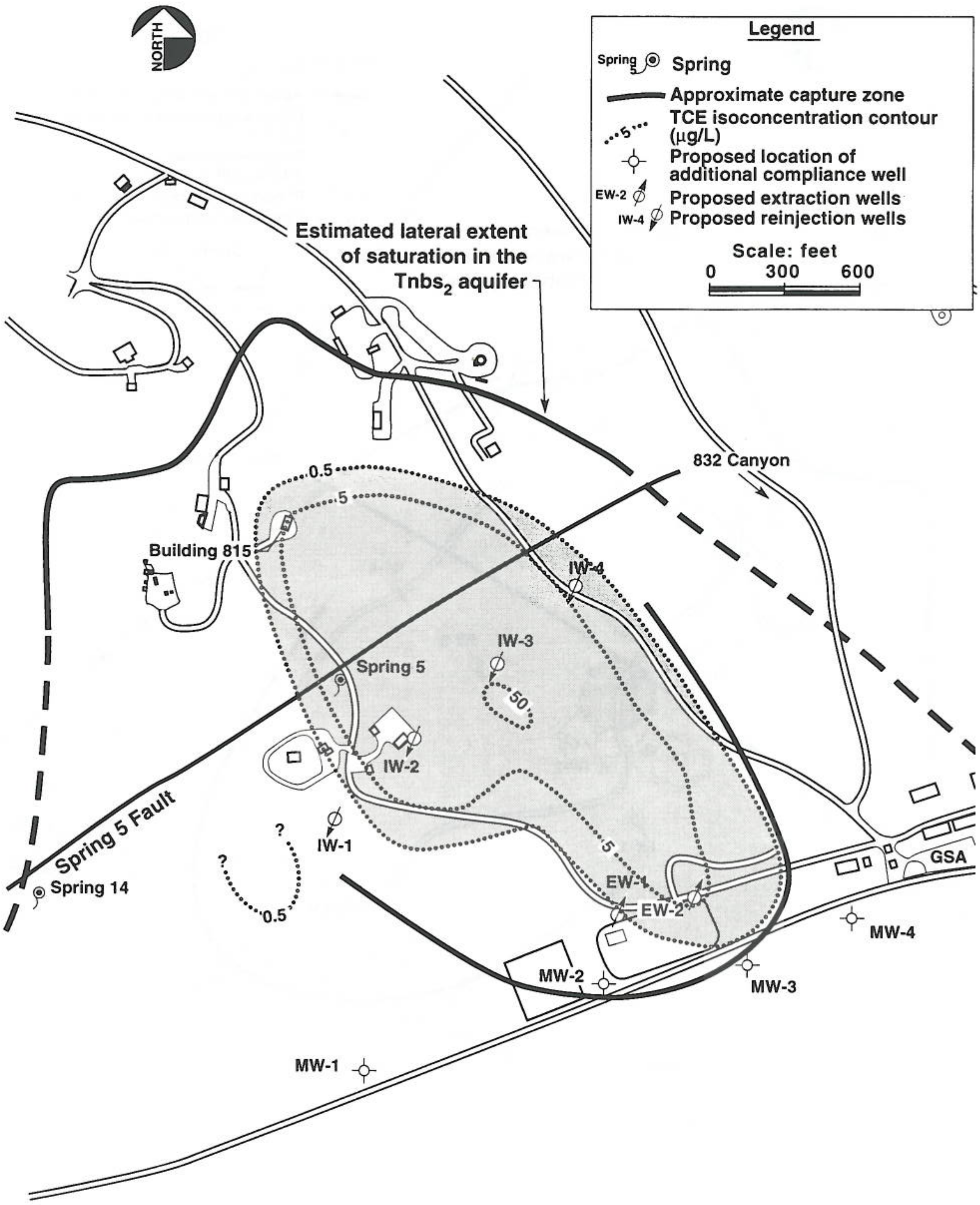
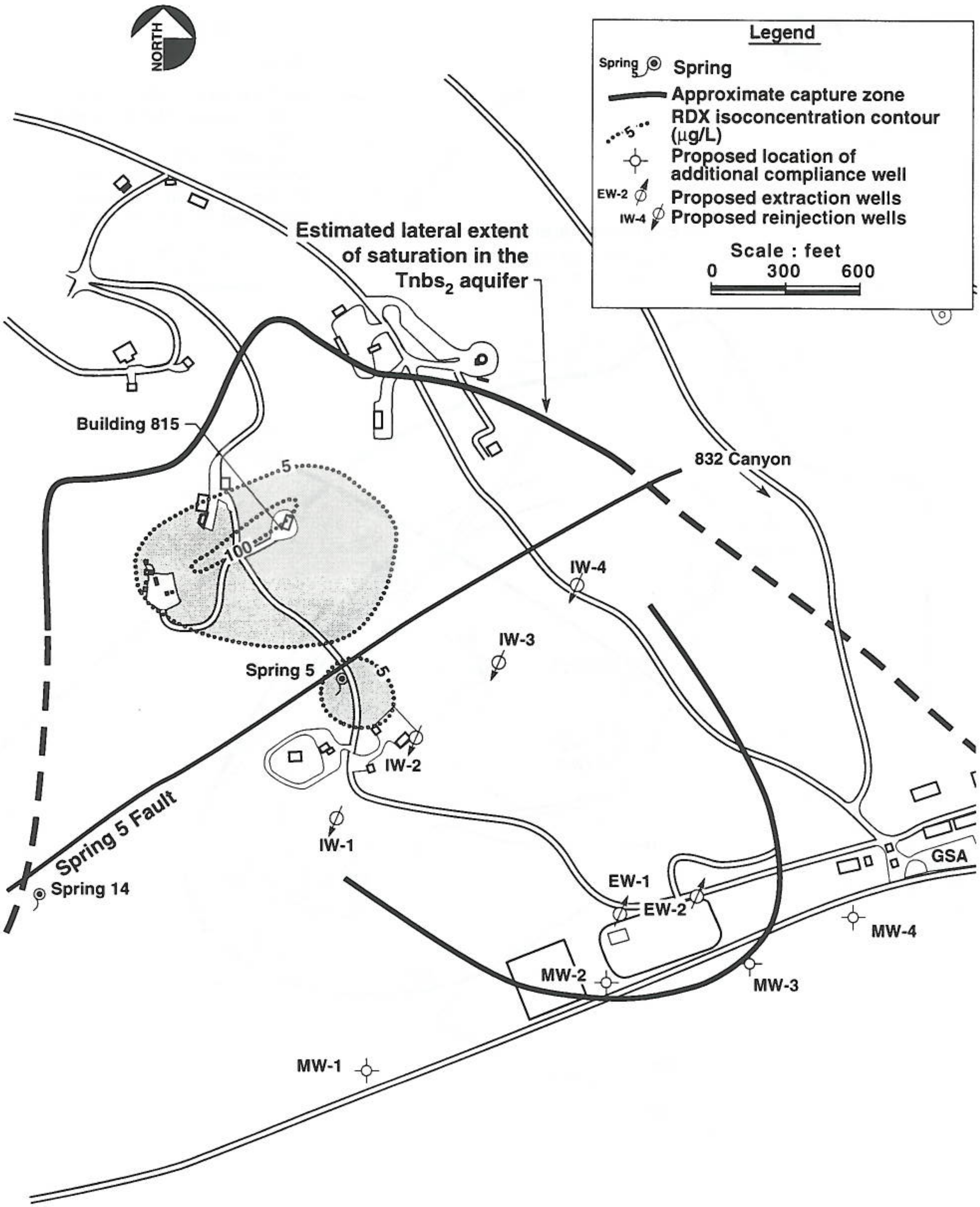


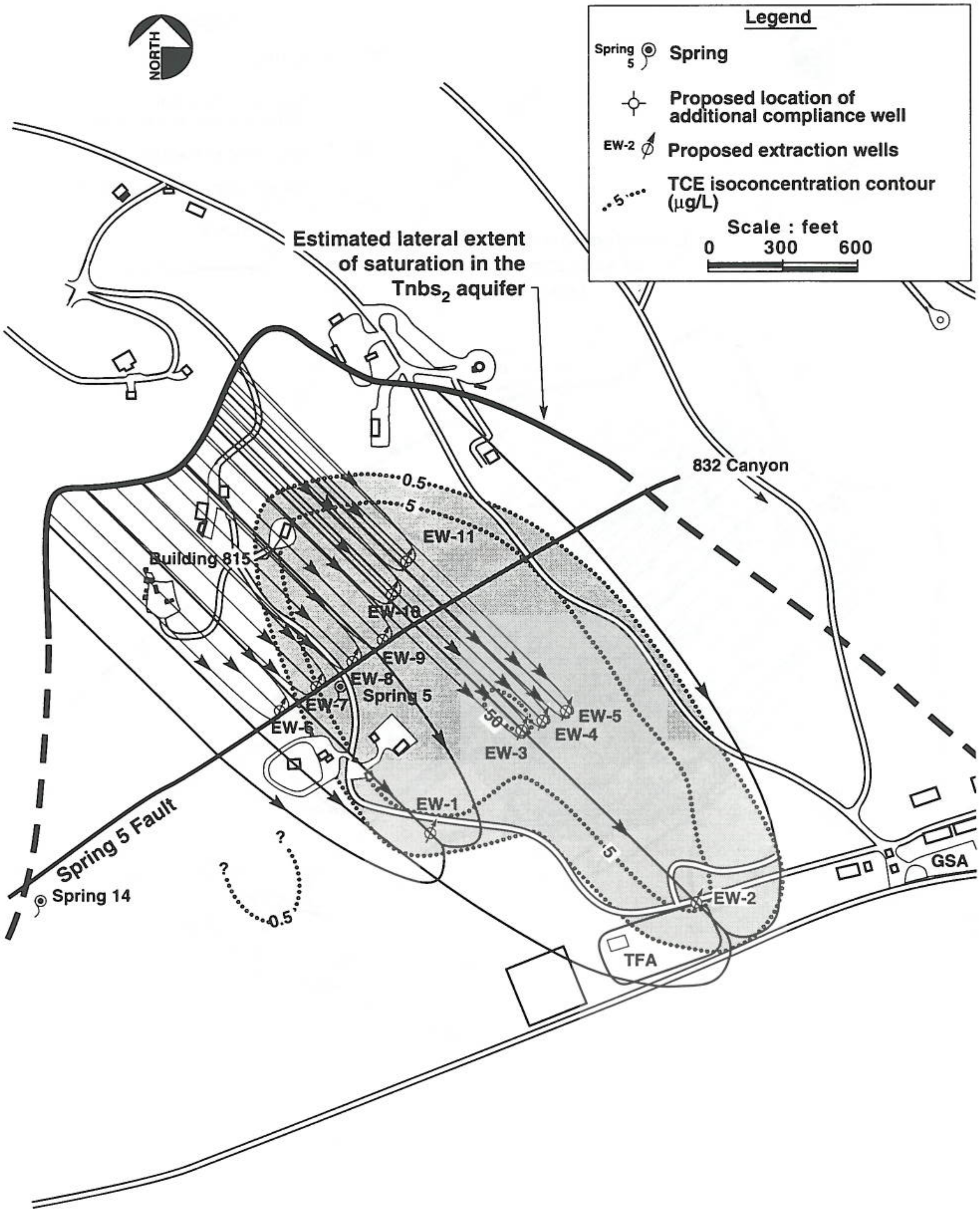
ERD-ERA-815-0030

Figure E-1. Alternative A extraction and injection wells and TCE plume. Approximate capture zone does not account for interference between wells.



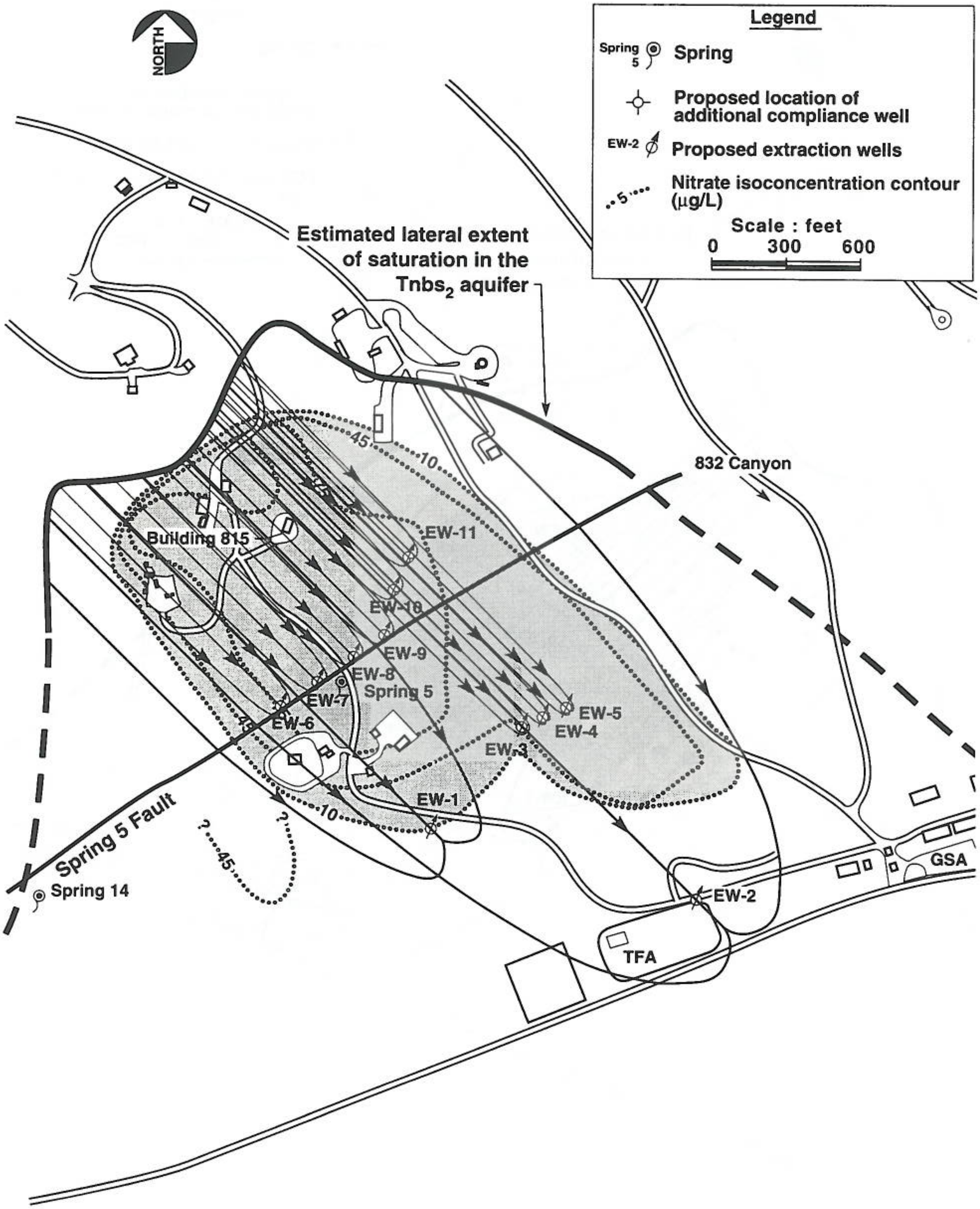
ERD-ERA-815-0031

Figure E-2. Alternative A extraction and injection wells and RDX plume. Approximate capture zone does not account for interference between wells.



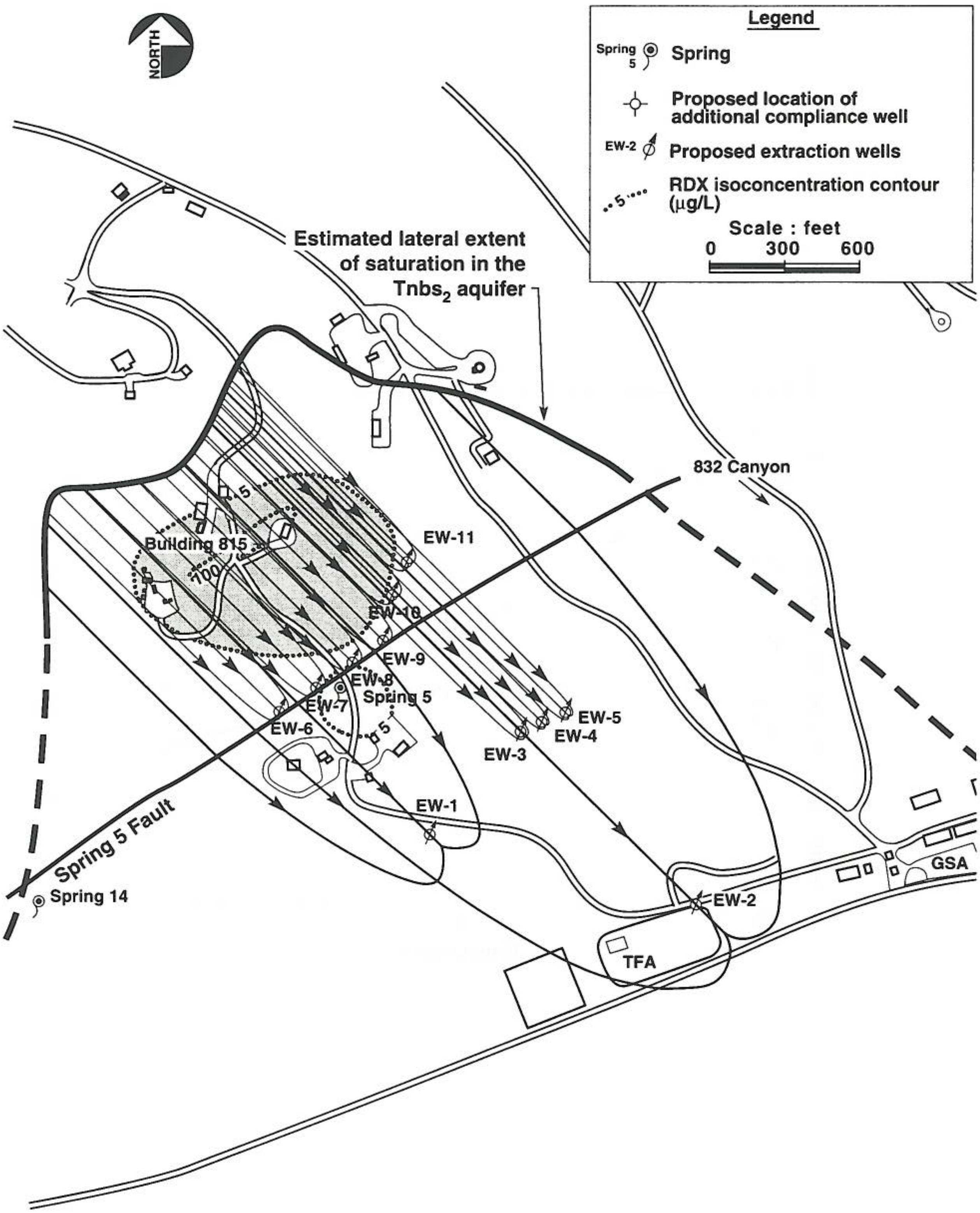
ERD-ERA-815-0032

Figure E-3. Alternative B capture and injection zones and TCE plume. Zones represent individual well influences; interference between wells is not accounted for.



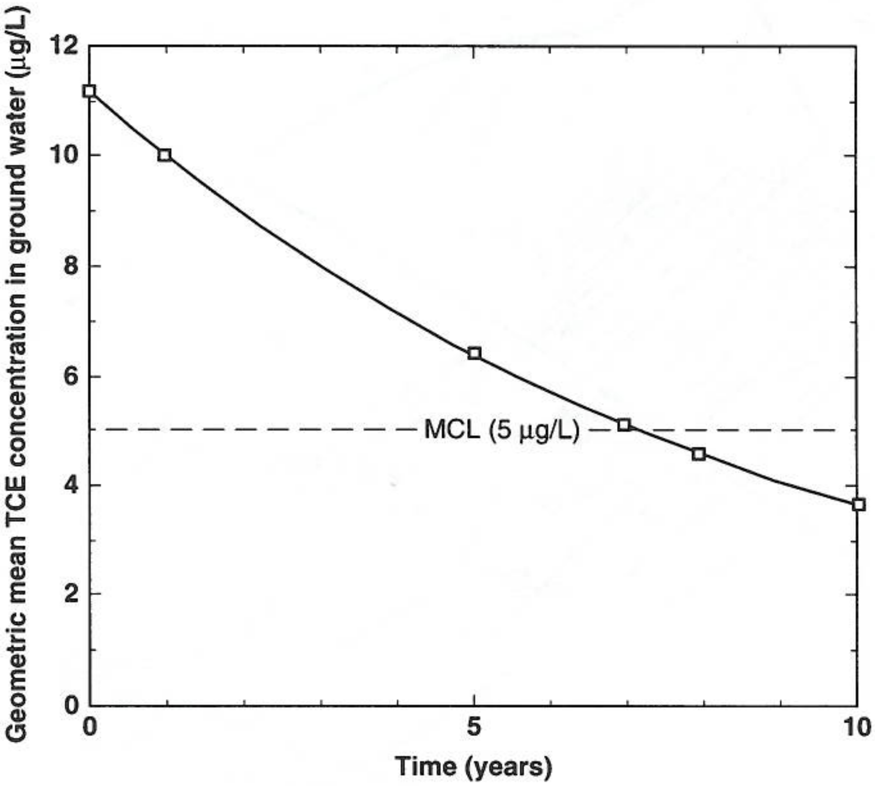
ERD-ERA-815-0033

Figure E-4. Alternative B capture and injection zones and nitrate plume. Zones represent individual well influences; interference between wells is not accounted for.



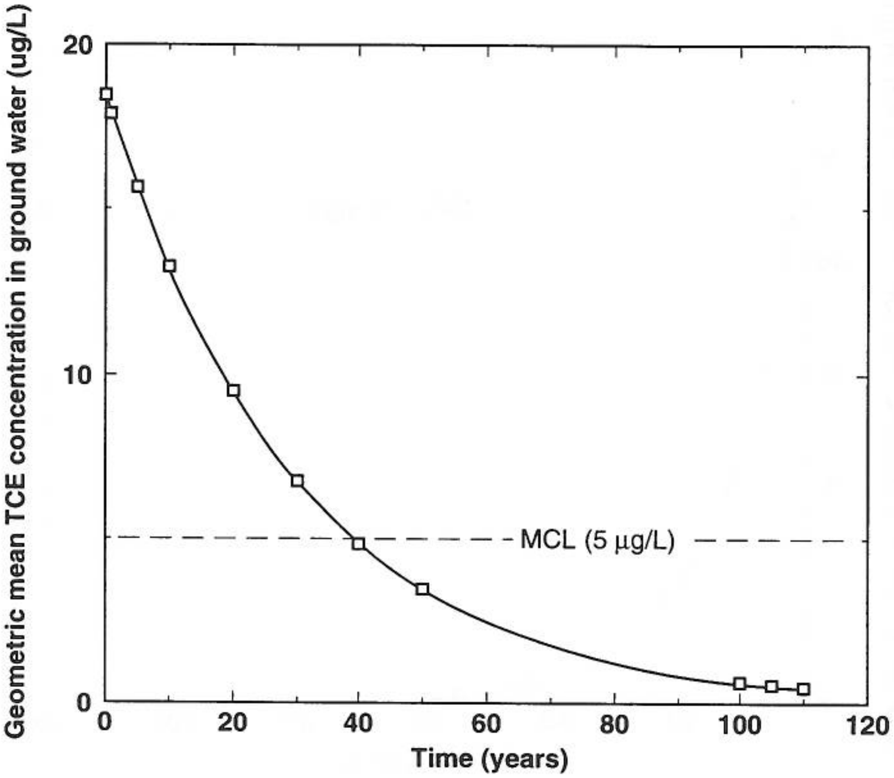
ERD-ERA-815-0034

Figure E-5. Alternative B capture and injection zones and RDX plume. Zones represent individual well influences; interference between wells is not accounted for.



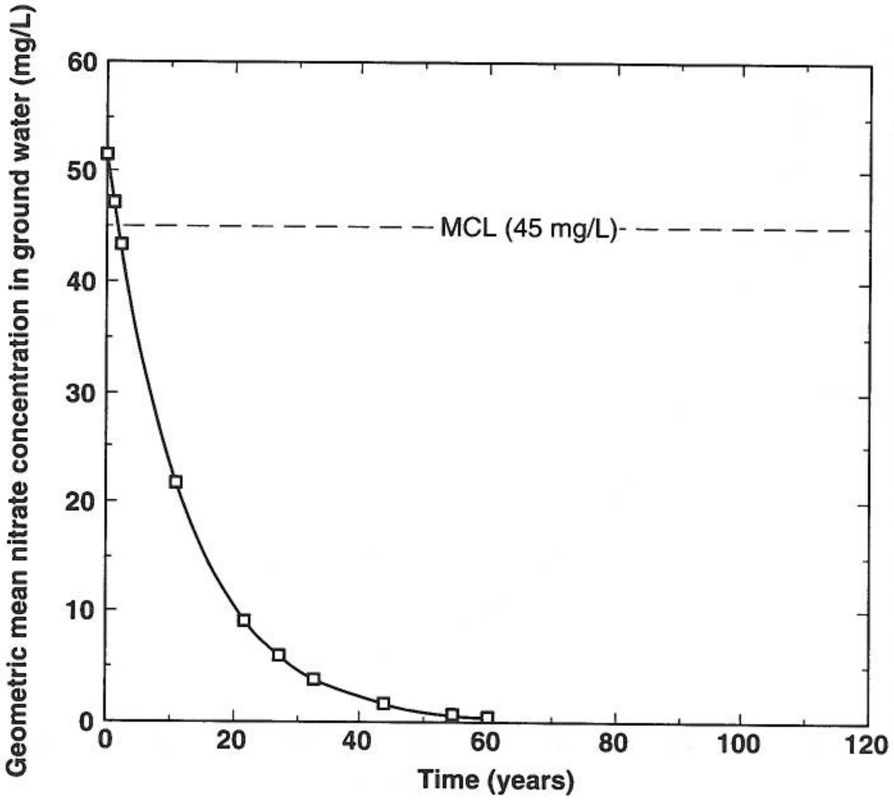
ERD-ERA-815-0035

Figure E-6. Estimated geometric mean of TCE concentrations in the ground water plume for the southern portion of the Tnbs$_2$ aquifer during Alternative A extraction program.



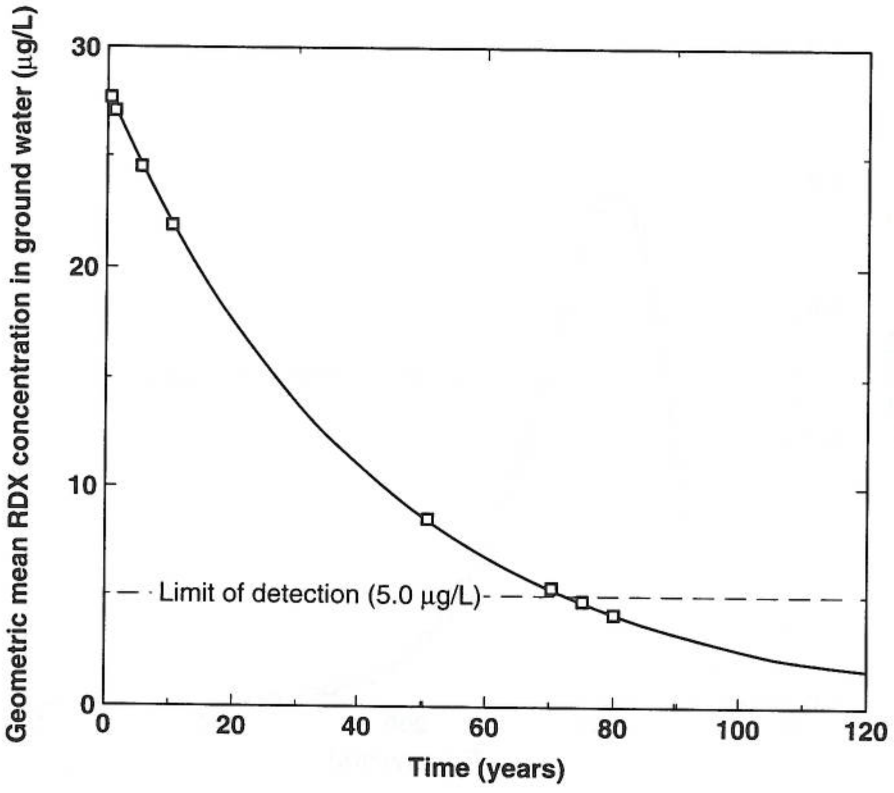
ERD-ERA-815-0041

Figure E-7. Estimated geometric mean of TCE concentrations in the ground water plume for the $Tnbs_2$ aquifer during Alternative B extraction program.



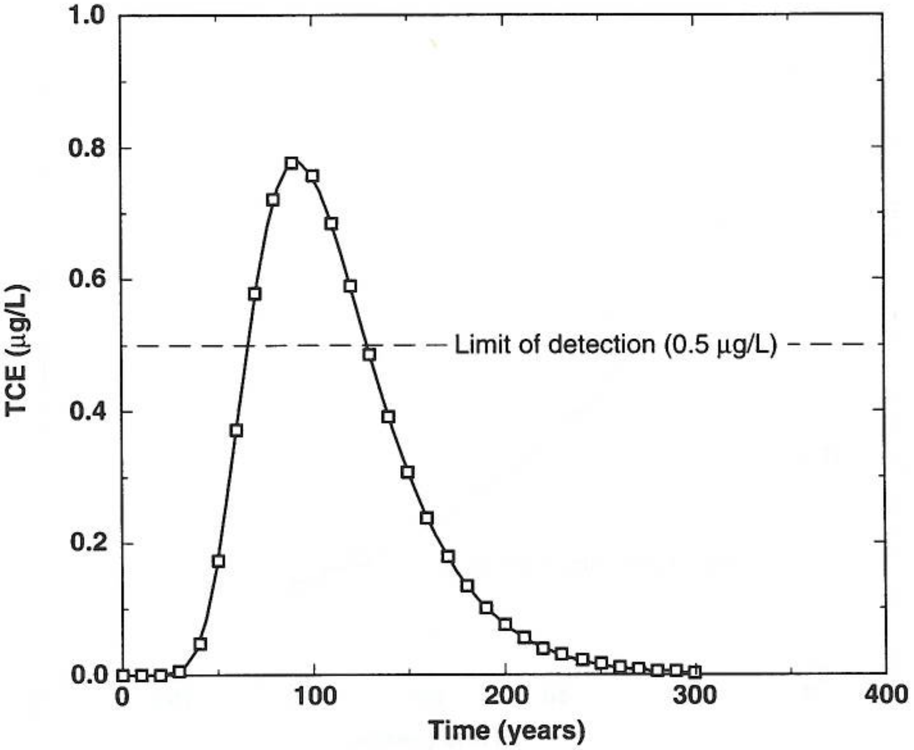
ERD-ERA-815-0038

Figure E-8. Estimated geometric mean of nitrate concentrations in the ground water plume for the $Tnbs_2$ aquifer during Alternative B extraction program.



ERD-ERA-815-0039

Figure E-9. Estimated geometric mean of RDX concentrations in the ground water plume for the $Tnbs_2$ aquifer during Alternative B extraction program.



ERD-ERA-815-0040

Figure E-10. Aqueous phase TCE concentrations in Tps percolate reaching the saturated portion of the $Tnbs_2$ aquifer.

Table E-1. Capture/injection zone parameters and results for Alternative A.

Well name(s)	Extraction/ injection rate [gpm]	Hydraulic head at locations 1 and 2 [ft] or hydraulic gradient [ft/ft]	Horizontal distance between locations 1 and 2 [ft]	Hydraulic conductivity [gal/day•ft^2]	Saturated thickness [ft]	Maximum capture/ injection width [ft]	Stagnation point [ft]
EW-1, EW-2	20	0.036	–	9.2	50	1750	280
IW-1, IW-2, IW-3, IW-4	10	14, 42	450	9.2	–	900	140

Table E-2. Capture zone parameters and results for Alternative B.

Well name(s)	Extraction rate [gpm]	Hydraulic head at locations 1 and 2 [ft] or hydraulic gradient [ft/ft]	Horizontal distance between locations 1 and 2 [ft]	Hydraulic conductivity [gal/day•ft^2]	Saturated thickness [ft]	Maximum capture width [ft]	Stagnation point [ft]
EW-2	20	0.036	–	9.2	50	1750	280
EW-1	10	0.036	–	9.2	50	870	140
EW-3, EW-4, EW-5	2	39, 67	450	9.2	–	95	15
EW-6, EW-7, EW-8, EW-9, EW-10, EW-11	1	19, 24	130	9.2	–	180	28

Table E-3. Mass removal calculation parameters and results for Alternative A.

Plume	Extraction rate [gpm]	Volume to be flushed $[ft^3]$	Retardation coefficient (dimensionless)	First-order transformation rate [1/years]	Contaminant geometric mean	Time to MCLs [years]	Time to background [years]
TCE	40	1.50×10^7	1.8	0.014	11.2 ppb	8 (5[a])	30 (0.5[b])
Nitrate	40	9.16×10^7	1	0	45.5 ppm	0 (45[a])	5 (12[b])

[a] MCL; units are μg/L except nitrates, which are mg/L.

[b] Background concentration level; units are μg/L except nitrates, which are mg/L.

Table E-4. Mass removal calculation parameters and results for Alternative B.

Plume	Extraction rate [gpm]	Volume to be flushed $[ft^3]$	Retardation coefficient (dimensionless)	First-order transformation rate [1/years]	Contaminant geometric mean	Time to MCLs [years]	Time to background [years]
TCE	41	6.35×10^7	1.8	0.014	18.5 ppb	40 (5[a])	110 (0.5[b])
Nitrate	41	3.42×10^7	1	0	51.5 ppm	2 (45[a])	55 (12[b])
RDX	15	3.48×10^6	13.8	0	27.7 ppb	-	75 (5[b])

[a] MCL; units are μg/L except nitrates, which are mg/L.

[b] Background concentration level; units are μg/L except nitrates, which are mg/L.

Table E-5. Soil properties for VLEACH modeling.

Property	Value
Porosity (dimensionless)	0.25
Bulk density (g/cc)	2.0
Volumetric water content (dimensionless)	0.17
Organic carbon content (dimensionless)	0.001

Table E-6. Chemical properties for VLEACH modeling.

Property	Value
Organic partitioning coefficient (ml/g)	98
Henry's law constant	0.44
Aqueous solubility (dimensionless)	1,100
Free-air diffusion coefficient (mg/L)	0.43
Degradation half-life (years)	50

Table E-7. Input parameters for VLEACH modeling.

Parameter	Value
Number of polygons	1
Polygon area (ft^2)	150,000
Polygon thickness (ft)	30
Number of cells	120
Cell thickness (ft)	0.25
Calculation time step (year)	0.1
Infiltration rate (ft/year)	0.091
Infiltrating concentration (mg/L)	0.0
Atmospheric concentration (mg/L)	0.0
Ground water concentration—first cell only (g/ft^3)	0.057 (equivalent to 370 g of TCE in the ground water of the first cell)
Ground water concentration—all other cells (g/ft^3)	0.0
Partition coefficient (ml/g)	0.098
Retardation factor (dimensionless)	1.8
Degradation coefficient (1/year)	0.014 (equivalent to a 50-year half-life)

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Appendix F

Evaluation of Tps Perched Water-Bearing Zone

Appendix F

Evaluation of Perched Tps Water-Bearing Zone

F-1. Introduction

In this appendix we evaluate information relevant to the Tps perched water-bearing zone to address the following concerns:

- The potential for dissolved contaminants in the Tps perched water-bearing zone to degrade the beneficial uses of the $Tnbs_2$ aquifer.
- The potential for the Tps perched water-bearing zone to be a source of public drinking water under SWRCB Resolution No. 88-63.
- The potential for human exposure to contaminants in the Tps perched water-bearing zone.
- The capital costs associated with remediating the Tps perched water-bearing zone.

Table F-1 summarizes relevant physical and geochemical properties of the Tps perched water-bearing zone, including saturated thickness, TDS, and estimated yield.

F-2. Evaluation of Potential for Dissolved Contaminants in the Perched Water-Bearing Zone Tps to Degrade Beneficial Uses of the $Tnbs_2$ Aquifer.

This section presents an evaluation of observed Tps perched water-bearing zone and $Tnbs_2$ aquifer contaminant concentration trends and unsaturated flow modeling using VLEACH to simulate potential downward migration of contaminants in the Tps perched water-bearing zone. The unsaturated flow modeling is based on the conceptual hydrogeologic model presented in Chapter 13 of the SWRI report (Webster-Scholten, 1994).

Based on the Tps hydrogeologic model presented in the SWRI report, dissolved contaminants within the Tps hydrogeologic unit are contained within a low-yielding, laterally heterogeneous, and discontinuous perched water-bearing zone that is, in effect, vertically and laterally hydraulically isolated from the underlying $Tnbs_2$ aquifer. Information to support this model is presented in hydrogeologic cross-section B-B' (Fig. F-1) and geophysical log correlation section A-A' (Fig. F-2). As shown by the geophysical log responses, a contrast exists between the variable and generally fine-grained material exhibited by the Tps unit and the laterally continuous underlying $Tnbs_2$ aquifer.

To evaluate the potential for downward migration of dissolved VOCs in the Tps perched water-bearing zone we simulated unsaturated flow using the numerical code VLEACH. VLEACH modeling is presented in Appendix E. Simulation results indicate that concentrations of TCE potentially percolating from the Tps water-bearing zone would likely be below the detection limit (0.5 µg/L) when reaching the upper unsaturated portion of the $Tnbs_2$ hydrologic unit.

Conclusions reached using VLEACH are supported by data illustrated on time-series concentration maps of the Tps and $Tnbs_2$ TCE plumes (Figs. F-3 and F-4). As shown by these time-series maps, TCE concentrations along the ground water plume margin generally exhibit a stable or decreasing trend, whereas concentrations in the plume interior have clearly decreased. This trend is consistent with a ground water plume that is undergoing natural attenuation and, in effect, is hydraulically isolated from its contaminant source or the contaminant source is depleted. The observed decreasing concentrations in the Tps TCE ground water plume, combined with the observed decreasing interior concentrations of the $Tnbs_2$ TCE ground water plume and the VLEACH modeling results, suggest that the source of TCE in the Tps perched water-bearing zone is depleted and is no longer a threat to underlying ground water.

F-3. Evaluation of Tps Perched Water-bearing Zone as Suitable Public Water Supply

This section evaluates the suitability of Tps perched water-bearing zone as a potential source of public water supply based on criteria listed in SWRCB Resolution No. 88-63. According to this resolution, all surface and ground waters of the State are considered to be suitable for municipal or domestic water supply except:

a. Water containing TDS exceeding 3,000 mg/L that is not reasonably expected by Regional Boards to supply a public water system.

b. Water contaminated by natural processes or human activity (unrelated to a specific pollution incident), that cannot be treated reasonably for domestic use applying best management practices or best economically achievable treatment practices.

c. Water sources that cannot provide sufficient water to supply a single well capable of producing an average, sustained yield of 200 gal/day.

Although the Tps perched water-bearing zone meets the TDS requirement specified in criterion "a" (above), field hydraulic data indicate that it does not meet the minimum sustained yield requirement specified in criterion "c." Criterion "b" is evaluated in Section F-4. The estimation of a low yield is based primarily on drawdown in Tps monitor wells during well development and sampling. Tps wells are routinely pumped "dry" at relatively low flow rates ranging from 0.2–0.8 gpm prior to extracting three casing volumes during ground water sampling events. This low sustained yield precludes conducting long-term aquifer tests. Low-yield water-bearing zones are commonly tested using the slug/bail test method. Such a test was performed on well W-809-01, resulting in a transmissivity (T) of 2.5 gpd/ft (Fig. F-5). Assuming order of magnitude accuracy (i.e., T ranges from 0.25–25 gpd/ft) and a saturated thickness of 5 ft, the maximum yield from this well would be 125 gpd. Given the limited size of the Tps perched water-bearing zone and lack of ground water recharge, it is highly unlikely that this well could actually sustain a yield of 125 gpd. This result is below the 200 gpd minimum sustained yield criteria specified in SWRCB Resolution No. 88-63.

F-4. Evaluation of Potential for Human Exposure to Tps Ground Water Contaminants at Concentrations Exceeding Health-Based Levels

The Tps ground water plume is contained in a perched water bearing zone that is approximately 500 ft wide by 1,000 ft long. As shown in Figure 1-6, the areal extent of perched water-bearing zone saturation is limited based on observations made during the drilling of nearby monitor well boreholes. In addition, it is unlikely that the areal extent of perched Tps ground water will increase significantly in the future, because all artificial recharge mechanisms have been eliminated or rerouted.

There are no existing or planned water-supply wells to extract ground water from the Tps perched water-bearing zone. As discussed in Section F-2, the Tps water-bearing zone exhibits such low sustainable yields (likely to be <1.25 gpd) that it is not suitable for public or private water supply. Additional measures, such as restricting access, can be implemented to prevent ingestion of contaminated Tps ground water discharged at Spring 5.

F-5. Evaluation of Tps Ground Water Remediation

In this section, we evaluate Tps ground water remediation using ground water extraction and treatment. This is the only technology potentially applicable to remediating Tps ground water, although we screen out this approach based on concerns for effectiveness, implementability, and cost. Effectiveness of *in-situ* methods such as bioremediation are limited. The Tps water-bearing zone is heterogeneous and relatively impermeable; therefore, delivery of a bio-reagent to this zone would be ineffective. Soil vapor extraction (SVE) was excluded because TCE soil concentrations are too low to be effectively remediated using SVE.

For this evaluation, we assume that extracted Tps ground water could be treated with the same Alternative B treatment system. Three methods of ground water extraction are possible:

1. Vertical ground water extraction wells.
2. Horizontal ground water extraction wells.
3. Ground water interceptor trench.

Pumping from vertical extraction wells is the conventional method for extracting ground water. To be effective, an array of vertical ground water extraction wells must adequately capture the ground water contaminant plume. Additionally, ground water extraction wells must have sufficient sustained yield to achieve full capture. As discussed in Section 1.3.1. and Section F.2., the Tps perched water-bearing zone consists of a series of small, partially saturated lenses of unknown connectivity. Short-term yield from existing monitor wells is typically less than 0.5 gpm, and many Tps ground water monitor wells are easily pumped dry during sampling events. For these reasons, we consider this approach to be impractical and we evaluate two possible alternatives: horizontal wells and trenching.

F-4.1. Horizontal Wells for Ground Water Extraction

An alternative method for extracting ground water from the Tps hydrologic unit is to install a horizontal well perpendicular to the direction of ground water flow. To estimate costs, we assume that one horizontal well is installed approximately half way between Tps ground water monitor wells W-815-01 and W-815-03, and five exploratory borings are drilled to confirm the presence and depth of ground water at this location. We also assume the length of the borehole is about 600 ft, and length of the screen is about 320 ft.

We also assume that sufficient ground water is encountered, and no drilling-related delays occur. Because the horizontal drilling method generates a large volume of cuttings, disposal of drilling spoils may present a problem. For waste characterization purposes, we assume that one sample is collected per 100 yards^3 of drilling spoils, and all drilling spoils are disposed of on site.

F-4.2. Interceptor Trench for Ground Water Extraction

An alternative method to installing horizontal wells is to install a screen with standpipes or caissons in an interceptor trench for ground water extraction. To estimate costs, we assume the trench is in the same location as the horizontal well, and five exploratory borings are drilled to confirm the presence and depth of ground water. We assume that the trench is 275 ft long and installed in unconsolidated soil; a 6-in. screen is installed along the base of the trench and backfilled with gravel to 3 ft below surface; and 3 ft of excavated material is used to backfill to the surface.

We also assume that sufficient ground water is encountered and no excavation or installation-related delays occur. Because trenching generates excess soil, disposal of materials may present a problem. For waste characterization purposes, we assume that one sample is collected per 100 yards^3 of soil, and all excess soil is disposed of on site.

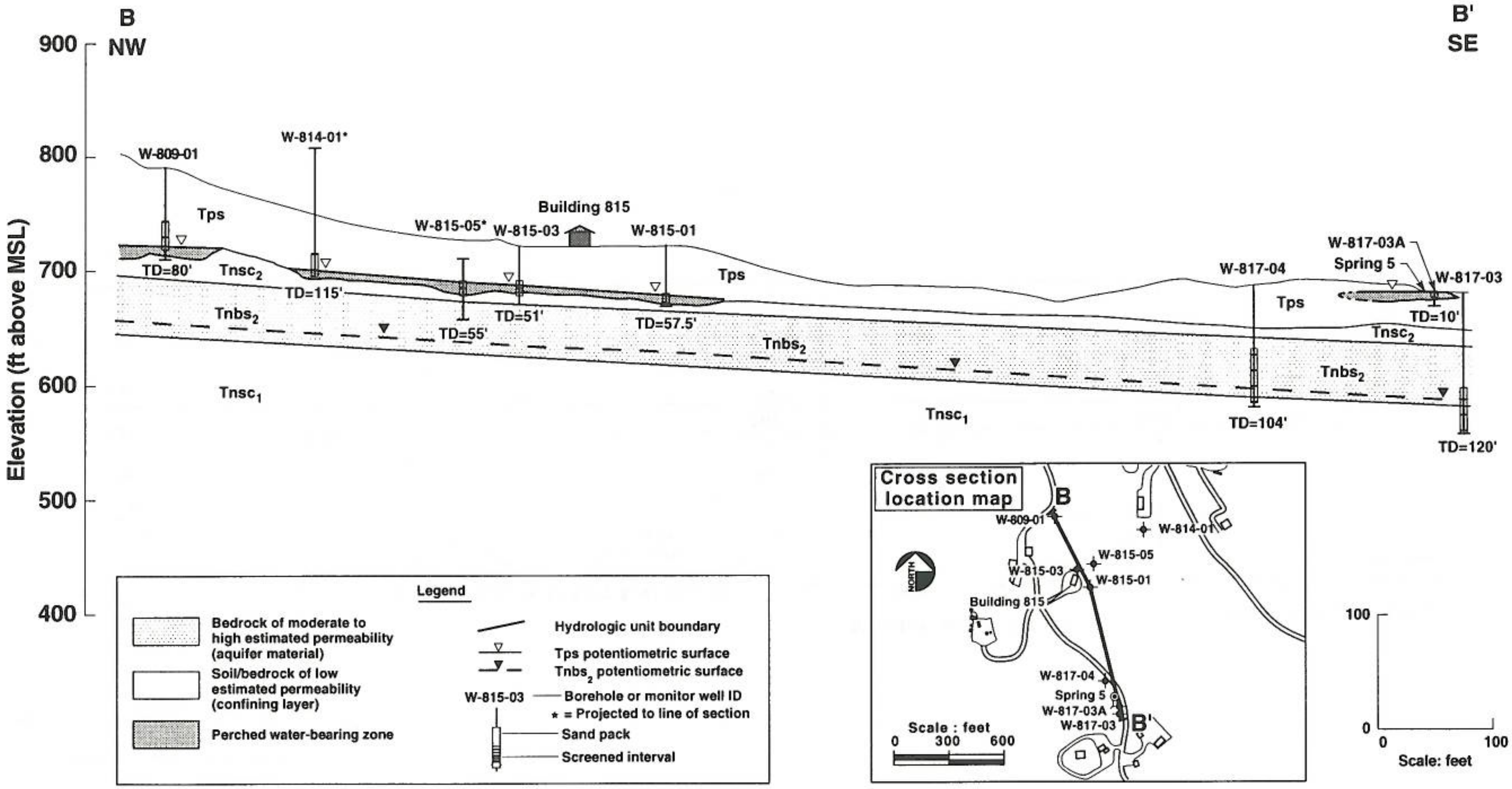
F-4.3. Cost Evaluation

We evaluated the capital costs for the two alternative approaches to remediate ground water in the Tps perched water-bearing zone, a horizontal well and an interceptor trench. These capital cost estimates (Tables F-2 and F-3) are very conservative and do not include the following: O&M, long-term monitoring, analytical and data analyses, and administration. We estimate the capital cost for one horizontal well and one interceptor trench are at $475,000 and $870,000, respectively. The effectiveness of either approach is uncertain because of the lateral heterogeneity and lack of interconnectivity within the Tps perched water-bearing zone. To successfully implement either approach, multiple horizontal wells or interceptor trenches may be required.

F-6. References

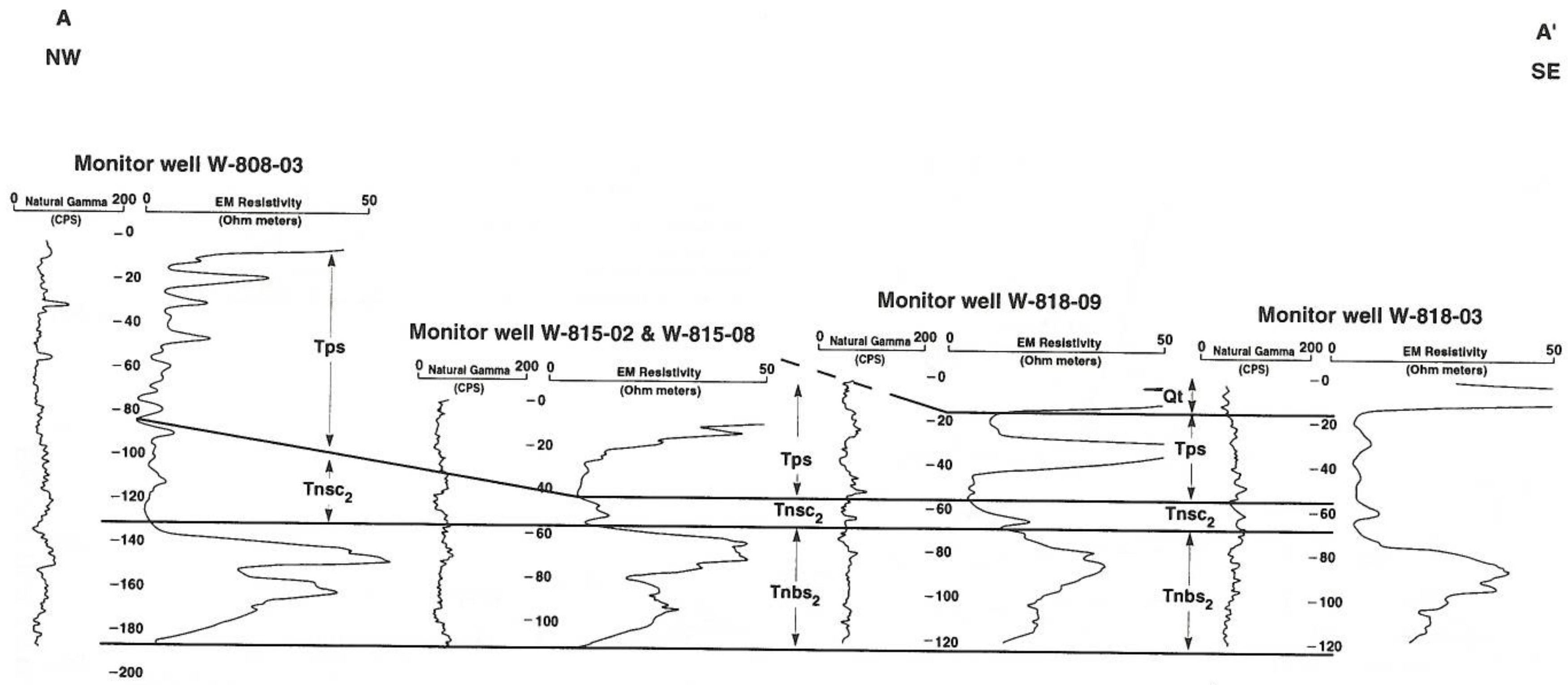
Papadopulos, I. S., J. D. Bredehoeft, and H. H. Cooper, Jr. (1973), "On the Analysis of 'Slug Test' data," *Water Resources Research 9*, pp. 1087–89.

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-21010).



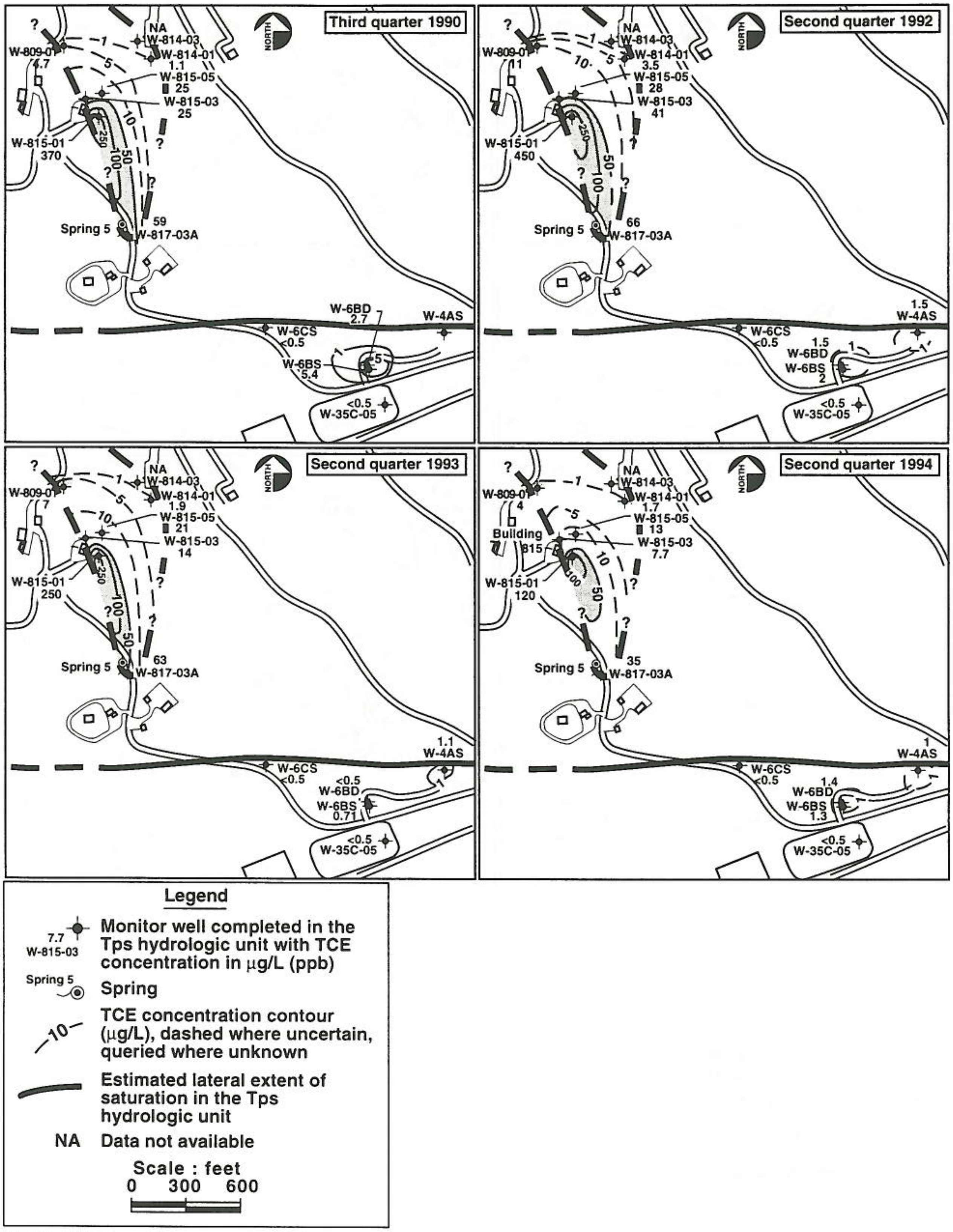
ERD-ERA-815-0019

Figure F-1. Cross section B-B' showing Tps perched water-bearing zone.



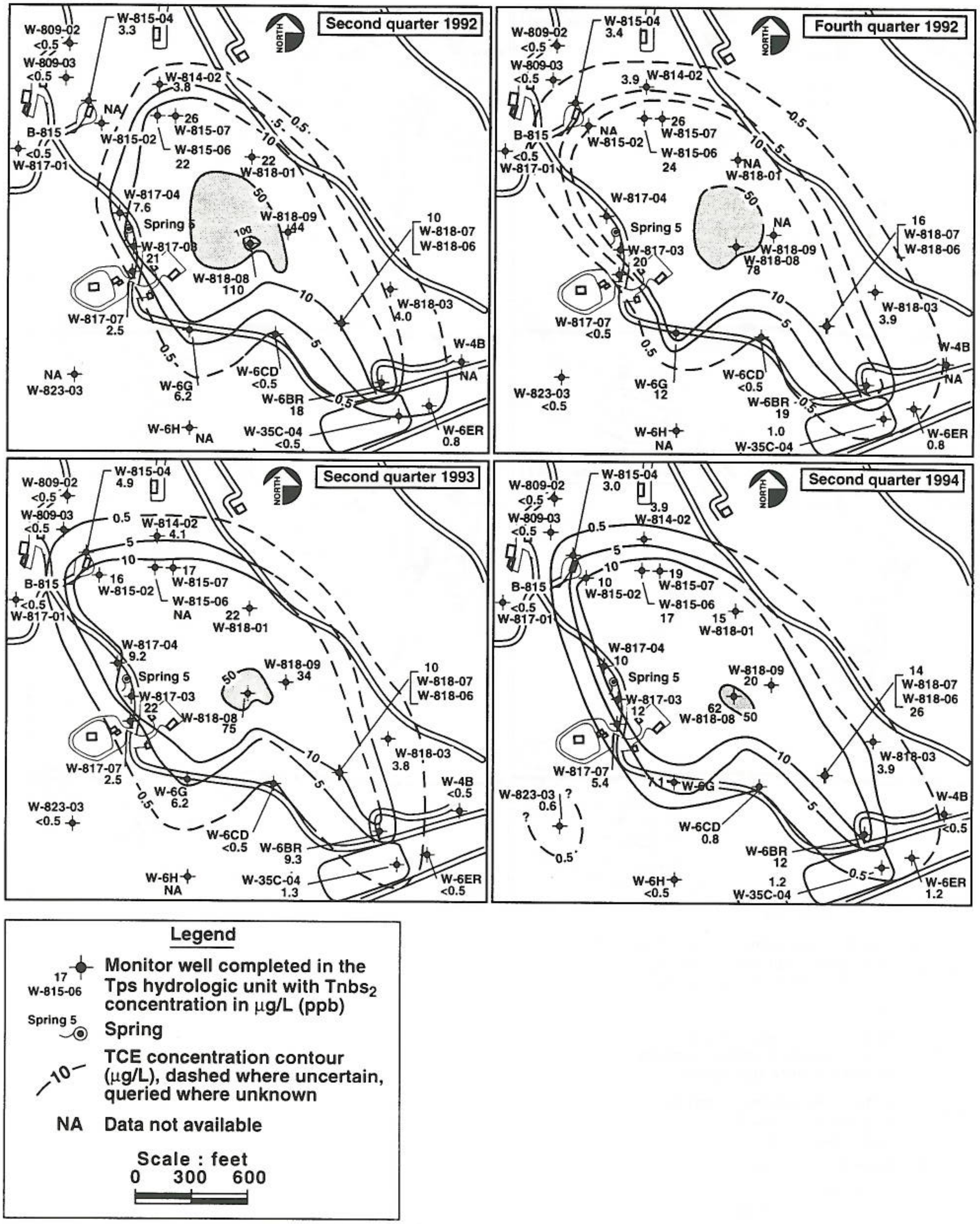
ERD-ERA-815-0020

Figure F-2. Geophysical log correlation section A-A' showing Tps hydrologic unit and $Tnbs_2$ aquifer.



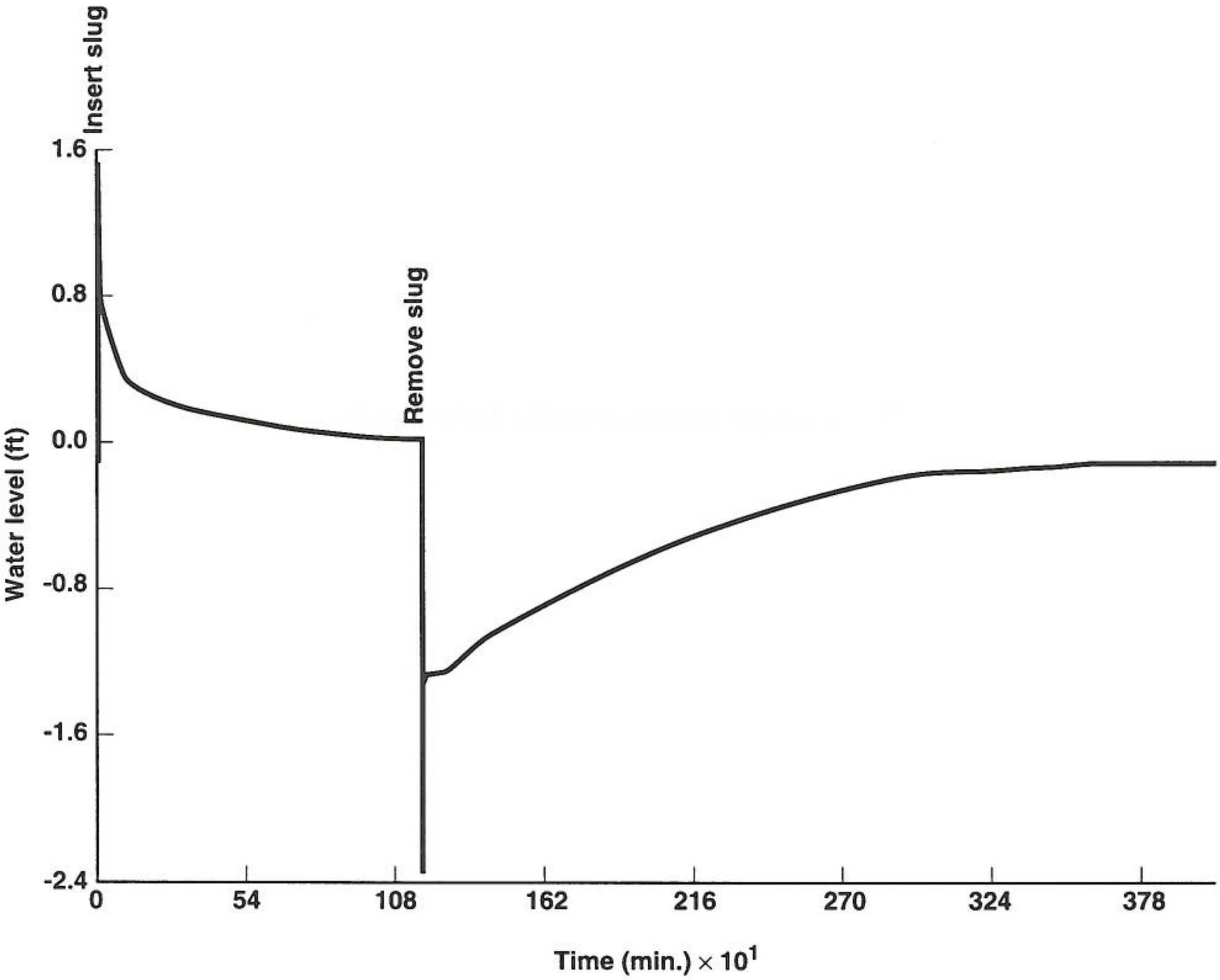
ERD-ERA-815-0017

Figure F-3. Time-series TCE plume maps for the Tps perched water-bearing zone between Third quarter 1990 and Second quarter 1994.



ERD-ERA-815-0018

Figure F-4. Time-series TCE plume maps for the $Tnbs_2$ aquifer between Third quarter 1990 and Second quarter 1994.



ERD-ERA-815-0021

Figure F-5. Slug/bail test of Tps well W-809-01.

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Table F-1. Summary of Tps perched water-bearing zone saturated thickness, ground water salinity, and yield.

Well	Saturated thickness (ft)	Total dissolved solids (mg/L)	Well test	Analysis	T (gpd/ft)	Pump type	Yield during sampling
W-809-01	5.0	980	a. slug b. bail	M. Pap. M. Pap.	a. 1.5 b. 2.5	ww –	<0.2 gpm*
W-814-01	1.5	570	NA	NA	NA	ww	<0.8 gpm*
W-814-03	(dry)	NA	NA	NA	NA	(dry)	(dry)
W-815-01	1.5	780–920	NA	NA	NA	bailer	NA
W-815-03	1.0	740–860	NA	NA	NA	ww	<0.3 gpm*
W-815-05	3.7	800	slug	Pap.	NA	ww	<0.6 gpm*
W-817-03A Spring 5	7.5	1,000–1,100	NA	NA	NA	bailer	NA

Notes:

M. Pap. = Modified Papadopulos method.

Pap. = Papadopulos method.

ww = Well wizard.

NA = Not available.

T = Transmissivity.

– = Not applicable.

* = pumped "dry" during sampling at indicated flow rate.

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Table F-2. Cost estimate for Tps source removal using a horizontal well.

Capital cost items	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Site Preparation				
Grade access roads				60,000
Total site preparation cost				**60,000**
Surface and overburden characterization				
Exploratory boreholes (equipment and labor)	5	Boreholes	5,200	26,000
Analyze samples (121 soil samples, 6 liquid samples including 10% QA/QC samples)	127	Samples	155	19,685
Total characterization costs				**45,685**
Installation of horizontal well				
Well installation	605	Feet	100	60,500
Dedicated pump	2	Each	2,000	4,000
Analysis of cuttings for disposal	2	Sample suite	1,000	2,000
Total horizontal well installation costs				**62,500**
Site Restoration				
Regrade site/restore road				100,000
Total site restoration costs				**100,000**
Subtotal Horizonal Well costs				**268,185**
Contractor overhead and profit (15% of subtotal field costs)				40,228
Subtotal contractor field costs				**308,413**
LLNL material procurement charge (MPC) (9.7% of contractor field costs)				29,916
Total field costs				**338,329**

Table F-2. Cost estimate for Tps source removal using a horizontal well.

Capital cost items	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Professional environmental services				
Work Plan, Site Safety Plan	40	Hours	75	3,000
Assist with project management	40	Hours	75	3,000
Assist with contractor negotiation	40	Hours	75	3,000
Subtotal professional environmental services				**9,000**
LLNL MPC (9.7% of professional environmental services)				873
Total professional environmental services				**9,873**
Total capital costs				**348,202**
LLNL General & Administration Tax (7.5%)				26,115
Subtotal				**374,317**
LLNL Lab-Directed Research & Development Tax (6.0%)				22,459
Subtotal				**396,776**
Contingency (20%)				79,355
Total Cost for Excavation				**476,131**

Table F-3. Cost estimate for Tps source removal using an interceptor trench.

Capital cost items	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Site Preparation				
Grade access roads				60,000
Total site preparation cost				**60,000**
Surface and overburden characterization				
Exploratory boreholes (equipment and labor)	5	Boreholes	5,200	26,000
Analyze samples (121 soil samples, 6 liquid samples including 10% QA/QC samples)	127	Samples	155	19,685
Total characterization costs				**45,685**
Installation of horizontal drains				
Excavation of soil and installation of 6 inch screen with several risers	275	Feet	1,000	275,000
Dedicated pump	2	Each	2,000	4,000
Total horizontal drain installation costs				**279,000**
Waste disposal				
Analytical (one sample/100 yd3)	9	Sample suite	1,000	9,000
Set up of aeration pile	40	Hours	30	1,200
Aeration of soil	72	Hours	30	2,160
Total waste disposal costs				**12,360**
Site Restoration				
Regrade site/restore road				100,000
Total site restoration costs				**100,000**
Subtotal Trenching Scenario costs				**497,045**
Contractor overhead and profit (15% of subtotal field costs)				74,557

Table F-3. Cost estimate for Tps source removal using an interceptor trench.

Capital cost items	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Subtotal contractor field costs				**571,602**
LLNL material procurement charge (MPC) (9.7% of contractor field costs)				55,445
Total field costs				**627,047**
Professional environmental services				
Work Plan, Site Safety Plan	40	Hours	75	3,000
Assist with project management	40	Hours	75	3,000
Assist with contractor negotiation	40	Hours	75	3,000
Subtotal professional environmental services				**9,000**
LLNL MPC (9.7% of professional environmental services)				873
Total professional environmental services				**9,873**
Total capital costs				**636,920**
LLNL General & Administration Tax (7.5%)				47,769
Subtotal				**684,689**
LLNL Lab-Directed Research & Development Tax (6.0%)				41,081
Subtotal				**725,770**
Contingency (20%)				145,154
Total Cost for Excavation Scenario				**870,925**

Appendix G

Cost Estimates and Design Assumptions for Remedial Alternatives A and B

Appendix G

G-1. Cost Estimates and Design Assumptions for Remedial Alternatives A and B

This appendix presents the cost estimates and the assumptions for remedial Alternatives A and B described in Chapter 2. The assumptions made in this appendix are based on the conceptual remedial designs presented in Chapter 2.

These comparative cost estimates were prepared to evaluate and select the preferred remedial action alternative. These cost estimates were developed in accordance with U.S. EPA guidelines (U.S. EPA, 1987 and 1988a), and are intended for evaluation of relative costs of remedial alternatives. However, 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.
- Changes in applicable LLNL taxes such as General and Administrative (G&A) taxes, Lab-Directed Research and Development (LDRD) tax, and applicable LLNL charges such as Material Procurement Charge (MPC), etc.
- 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%.

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 (RD) report, following selection of the preferred remedial alternative.

Present-worth cost estimates assume that the entire funding for a project occurs as a lump sum investment at the beginning of the project life, that funds are initially invested, and that the return on the investment exceeds inflation. Therefore, a discount rate is applied to account for the projected net interest income generated over time. The discount rate is based on the anticipated difference in investment return (i.e., net interest income) and inflation. For this document, we have assumed an interest rate of 6.5% and an inflation rate of 3%, resulting in a discount rate of 3.5%.

Project funding is more likely to occur incrementally (i.e., annually) as the project proceeds rather than as a lump sum investment at the beginning of the project. Therefore, we also present total costs for each alternative with no discount rate (0.0%) and with inflation only (assuming 3.0% inflation).

G-2. Assumptions Used to Develop Remedial Alternative Cost Estimates

Cost estimates with brief descriptions of assumptions for Alternatives A and B are presented in Tables G-1 and G-2, respectively. We present these cost assumptions chronologically under the headings of capital costs, operation and maintenance costs, monitoring costs, and overhead and contingency costs.

As discussed in Chapter 2, Alternative A establishes criteria under ground water monitoring and contingency plans to evaluate changes in plume concentrations. It also establishes criteria to implement, if necessary, active remedial measures to prevent off-site migration of contaminants at concentrations exceeding MCLs. Table G-1 presents: 1) monitoring costs for Alternative A without implementation of the contingent remedial actions; additional monitoring costs associated with implementation of the contingency plan; and 3) capital operation and maintenance costs for the contingency remediation system.

Alternative B includes the installation of two treatment facilities and a constructed wetland or pond denitrification system. Table G-2 presents capital costs, followed by operation, maintenance, and monitoring costs.

G-2.1. Capital Cost Assumptions and Design Considerations

The following assumptions apply to capital cost estimates for both 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. Water discharged from the two GAC facilities proposed in Alternative B would be pumped or gravity-drained to a constructed wetland or pond denitrification system located in the southwestern part of the Building 815 OU (Fig. 2-7). Nitrate concentrations in extracted ground water would be reduced to background concentrations in a subsurface-flow, constructed wetland via anaerobic denitrification prior to surface discharge as presented in Appendix C.

   The estimated total installation cost for a sub-surface flow, constructed wetland is \$200,000. Costs are based on:

   - Influent stream flow rate of 42 gpm,
   - Influent nitrate (NO_3^-) concentration of 52 mg/L,
   - Effluent concentration of 12 mg/L,
   - Denitrification rate of 2.2 g NO_3^-/m^2/day, and
   - Cost of \$49.50/m^2.

   Because data for sub-surface flow systems are scarce, the assumed denitrification rate is conservatively based on data for a surface flow, constructed wetland, which typically has a lower denitrification rate (Hammer, 1989). The construction costs are extrapolated from actual costs for a 24-gpm pilot, subsurface flow wetland (EPA, 1988b).

3. Installation costs for the remediation systems are estimated by applying a percentage, or factor, to the capital cost of major equipment items. This technique is commonly used in industry to develop conceptual cost estimates. These factors are used to determine the cost of labor and material for installation (58% of major equipment costs) and the cost of instrumentation and electrical components (20% of major equipment costs). Our experience with the construction of similar remediation facilities is used to develop these factors. This procedure was applied equally to both alternatives. For Alternative B, the constructed wetland cost estimates include installation and electrical components, so these installation factors are not applied separately.

4. Full-time LLNL employees (FTEs) are included as required at a rate of $173,500/year to cover potential additional work (such as extra reporting, system evaluation, modeling, etc.) during start-up and initial operation of each alternative. The FTE rate is based on FY 1995 LLNL resource estimates and all applicable taxes (G&A, LDRD, etc.). For start-up and initial operation cost estimates, we assume:

   - Alternative A = 1 FTE.
   - Alternative B = 1.5 FTE.

5. 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. Included in these charges are the G&A tax (56%) and the LDRD tax (6.38%). Costs are expressed in FTEs at a rate of $173,500/FTE based on these assumptions. We estimate:

   - Alternative A = 2.25 FTE.
   - Alternative B = 4 FTE.

6. We assume LLNL taxes on material and outside services to be 11%. This cost includes the MPC on major equipment and professional contract services (estimated to be 7%), with G&A taxes applied to the procurement cost (56% of MPC).

7. Drill cuttings produced from ground water well installation are assumed to be clean or to contain low VOC concentrations that can be aerated on site. Although it is not anticipated, we have included the cost for cuttings disposed at a Class III landfill at an estimated cost of $20/yd^3 (including transportation). We assume that 7.5 yd^3 of cuttings will be generated per well.

8. The estimated cost to prepare the RD report is:

   - Alternative A = $150,000.
   - Alternative B = $300,000.

   The 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 close-out requirements. Costs for treatability studies and reports are also included.

9. Because access to the Building 815 OU is restricted, LLNL Protective Service escorts are required for all construction workers. LLNL protective service provides an escort at $40/hr. We assume two escorts will be required during the construction phase for the following periods:
   - Alternative A = 4 weeks.
   - Alternative B = 12 weeks.

G-2.1.1. Ground Water Extraction Wells

1. The cost to install a ground water well (extraction, injection, or monitoring) up to 150 ft deep is estimated to be $50,000. The cost to install a piezometer up to 150 ft deep is estimated to be $20,000. These estimates include labor and materials for borehole drilling, well construction, and well development. Disposal costs for drill cuttings are presented as a separate line item.
2. An additional $1,500 is estimated for borehole (soil and rock) and initial ground water samples to be analyzed for VOCs.
3. Each new ground water extraction 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 with an average pump cost of $2,000 and average pump size of 2 hp. For all new monitor wells, we assume an average pump cost of $800 per well and average pump size of 1/2 hp. Each new extraction and injection well will be fitted with a well-head vault, valves, sampling ports, and gauges at an estimated total cost of $1,500, including wiring, controller, and installation. Piezometers will not be outfitted with pumps.
4. Hydraulic tests are estimated to cost $3,000 for each ground water extraction well. A cost of $5,000 is estimated for hydraulic testing of the proposed injection wells. A cost of $1,500 is estimated for hydraulic testing of piezometers.

G-2.1.2. Structures

1. The ground water extraction and treatment systems planned as part of Alternatives A and B will each be housed in 1-story buildings approximately 20 ft by 15 ft. The estimated cost for construction of each building is $200,000. Approximately half of this cost estimate is to provide required utilities such as electrical, HVAC, water, etc.
2. The estimated cost for geotechnical studies required prior to the construction of each building is $20,000.

G-2.1.3. Ground Water Extraction and Treatment System

1. We assume that locations for extraction and injection wells and the treatment systems will be as shown in Figures 2-1 and 2-4. Two extraction wells are planned as part of Alternative A, and 11 are planned as part of Alternative B. Four injection wells are planned as part of Alternative A.

2. Ground water treatment systems consist of a particulate filter assembly, three 1000-lb aqueous-phase GAC canisters connected in series, storage tank, and discharge pump with associated piping and instrumentation. Treatment Facility B for Alternative B would gravity feed directly to the constructed wetland or pond denitrification system. Therefore, no storage tank or discharge pump is included in the costing of Treatment Facility B.
3. We assume that the electrical power-supply line is included in the cost of the buildings for the two ground water treatment facilities. Additional electrical supply lines will be run above ground to each ground water extraction well in conduit supported with unistrut; the lines will be placed adjacent to the ground water extraction system piping.
4. To convey extracted ground water, we have specified 2-in.-diam, Schedule 80, polyvinyl chloride (PVC) piping. The piping will be run above ground, supported with unistrut, from the extraction wells to the appropriate treatment facility. Similar piping will be used to convey treated water discharged from the treatment facility to the proposed injection wells in Alternative A and to the constructed wetland or pond system in Alternative B.
5. Costs include piping, fittings, valves, totalizing flow meters, gauges, and hardware for installation.

G-2.1.4. Professional Environmental Services

For each alternative, LLNL sub-contractors are included as required at a rate of $79.65/hour to cover professional environmental services (e.g., assistance with facility design, permitting, performance evaluation, etc.). The FTE rate is based on FY 1995 LLNL resource estimates and all applicable taxes (G&A, LDRD, etc.). Costs for these services are listed below for each alternative.

1. Consultant design and plan review:
    - Alternative A = $28,000 (2 mo).
    - Alternative B = $55,000 (4 mo).
2. Total permitting:
    - Alternative A = $19,000 (1 mo to obtain a Substantive Requirement discharge agreement and re-injection permit).
    - Alternative B = $24,000 (1 mo to obtain an NPDES permit and conduct seismic safety inspections, electrical inspections, etc.).
3. System start-up, including coordination, field work, sampling and analyses, etc.:
    - Alternative A = $28,000 (2 mo).
    - Alternatives B = $63,000 (4.5 mo).
4. In Alternative A, we assume that 0.25 FTE is required at a cost of $21,000 to coordinate and evaluate data during the 6-mo sampling period following confirmation of the "initial exceedance."

5. In Alternatives A and B, we assume that 0.5 FTE is required for 3 mo at a cost of $22,000 to analyze data and evaluate system performance.

G-2.2. Operation and Maintenance Cost Assumptions

Operation and maintenance (O&M) costs cover annual maintenance of the ground water extraction and treatment systems; monitoring costs cover maintenance of the ground water monitor wells/pumps.

A 3.5% discount rate was applied to calculate present-worth costs. This discount rate is based on the Office of Management and Budget (OMB) estimate of federal long-term opportunity costs (OMB, 1992). Operating cost estimates are discounted to 1995 present-worth costs following procedures described by U.S. EPA (1987).

Because project funding is more likely to occur incrementally (i.e., annually), we also present total costs for each alternative with no discount rate (0.0%) and with inflation only (assuming 3.0% inflation).

G-2.2.1. Ground Water Extraction and Treatment

1. An operating factor of 90% is assumed for the ground water extraction and treatment system in Alternatives A and B.
2. The cost for electricity is estimated at the rate of $0.07/kW•h, plus an annual connection fee of $36/kW. Power consumption for each treatment system is based on the horsepower rating for treatment system components and ground water extraction well pumps.
3. Annual labor estimates and FTE rates are based on LLNL FY 1995 resource estimates and all applicable taxes to operate the proposed ground water extraction and treatment system(s). These values are listed below for each alternative.

   Alternative A:

   - Project management = 0.1 FTE at $238,500/year to manage the ground water extraction/treatment/re-injection system.
   - Engineering = 0.1 FTE at $173,500/year to optimize the ground water extraction/treatment/re-injection system.
   - Hydrogeologist = 0.25 FTE at $173,500/year to optimize the ground water extraction/re-injection well-field.
   - Operations = 0.15 FTE at $129,800/year to operate the ground water extraction/treatment/re-injection system.
   - Administrative personnel = 0.1 FTE at $92,600/year.

   Alternative B:

   - Project management = 0.2 FTE at $238,500/year to manage the ground water extraction/treatment systems.

- Engineering = 0.25 FTE at $173,500/year to optimize the ground water extraction/treatment system.
- Hydrogeologist (for well-field system optimization) = 0.25 FTE at $173,500/year to optimize the ground water extraction well-field.
- Operations = 0.3 FTE at $129,800/year to operate the ground water extraction/treatment system.
- Administrative personnel = 0.1 FTE at $92,600/year.

4. We assume that discharge permits will require monthly collection of water samples at ground water treatment system influent, carbon midpoint, and effluent ports, and at the wetland or pond denitrification system effluent. During each sampling event, an additional sample will be collected for QA/QC. We assume that samples will be analyzed for VOCs at $50/sample and HE compounds at $108/sample. Monthly analytical costs are estimated to be:
   - Alternative A (4 VOC samples) = $200.
   - Alternative B (5 VOC samples and 3 HE samples) = $574.
5. About 10% of the major equipment installed cost (MEIC) is included in the annual operating cost to cover materials and replacement parts for equipment maintenance for the ground water extraction and treatment systems. About 15% of the total installation cost (58% of MEIC) is included for routine equipment maintenance labor. We estimate the total MEIC for each alternative to be:
   - Alternative A = $146,494.
   - Alternative B = $183,468.
6. Costs for ground water extraction and treatment O&M are included for:
   - Alternative A during years 11 through 20.
   - Alternative B during years 1 through 110.
7. In both alternatives, aqueous-phase GAC canisters are used to treat ground water containing VOCs. The cost for replacing of spent GAC loaded with VOCs is $2.30/lb of GAC. This cost estimate includes removal of the spent carbon, off-site thermal regeneration, replacement with fresh GAC, and all freight and outside labor costs. Costs are based on the assumption that the first carbon bed will be regenerated a minimum of once every 5 years (200 lb/year) to account for the possibility of carbon canister clogging due to biofouling, etc.

   We assume that only treatment facility B of Alternative B is required to treat HE compounds in addition to VOCs. The cost for replacing spent GAC loaded with VOCs and HE is based on the base hydrolysis method described in Appendix C. It is assumed that 6 weeks of technician time at 0.5 FTE, and chemical reagents at $300 will be required for each regeneration of a 1,000-lb GAC canister. The regenerated GAC will then be shipped off site for thermal regeneration to remove VOCs at a total cost of $10/lb of GAC.

Aqueous-phase GAC consumption rates for ground water treatment are based on conservative estimates of ground water extraction rates and concentrations. Assumed concentrations of TCE and RDX used to model GAC consumption are presented in Appendix E. Consumption rates are based on a 0.5% adsorption capacity for TCE, due to the reduced efficiency of carbon adsorption for low influent VOC concentrations, and a 10% adsorption capacity for the RDX. For each alternative, we propose the following flow rates for influent to the ground water treatment system:

- Alternative A = 40 gpm.
- Alternative B = 42 gpm total.
  - Treatment Facility A = 26 gpm.
  - Treatment Facility B = 16 gpm.

G-2.3. Cost Assumptions for Baseline Monitoring Program

Both Alternatives A and B include a ground water monitoring program. The program is different for each alternative because of variance in a number of new wells and the assumed schedule for implementation of ground water extraction. The monitoring program for each alternative is presented in Chapter 2. Details of the program for Alternative A are presented in Tables 2-1 and 2-2; for Alternative B, they are described in Tables 2-1 and 2-6.

A 3.5% discount rate was applied to calculate present-worth costs. The discount rate is based on the OMB estimate of government's long-term opportunity costs (OMB, 1992). Monitoring cost estimates are discounted to 1995 present-worth costs following procedures described by U.S. EPA (1987).

Because project funding is more likely to occur incrementally (i.e., annually) as the project proceeds, we also present total costs for each alternative with no discount rate (0.0%) and with inflation only (assuming 3.0% inflation).

G-2.3.1. Ground Water Monitoring

The ground water monitoring program for each alternative includes water level measurements, sample collection and analysis, maintenance of well and sampling pumps, reporting, and project management. Analytical methods and sampling frequency for each monitor well are presented in Tables 2-1, 2-2, and 2-6 . Other assumptions include:

1. Water level measurements will generally be made quarterly in all wells and piezometers in the Building 815 OU. The estimated labor cost for these measurements is 0.5 hr/well/quarter at $62.50/hr (2 hr/well/year).
2. Ground water samples will be collected using dedicated pumps installed in each monitor and extraction well. The labor cost for sample collection is estimated to be 2 hr/sample at $62.50/hr (8 hr/well/year). Ground water monitoring costs also include labor for sample collection, purge water disposal, and QA/QC. Monitoring system maintenance includes labor for pump repair and pump replacement. We assume that ground water samples will not be collected from proposed piezometers.

3. The Alternative A cost estimate assumes that the trigger criteria are met after 10 years of monitoring. We assume that two additional samples will be collected from the compliance monitor well, exceeding the trigger criteria, followed by six monthly samples collected from the six compliance monitor wells. One engineer or geologist will be required at 0.5 FTE during the 6-mo sampling period.
4. Analytic costs per sample are based on 1995 rates in LLNL contracts with commercial analytical laboratories:

Analyte	EPA method	Cost ($)
VOCs	601	50
BTEX	602	75
TPH (gas and diesel)	8015 (Modified)	100
HE compounds (HMX & RDX)	8330	108
Nitrates (as NO_3)	353.2	75
Oil and grease	418.1	35
PCBs	608	180

6. Samples of on-site spring water will be collected quarterly from Spring 5. The labor cost for sample collection is estimated to be 2 hr/suite of samples at $62.50/hr. Analytic costs, at $477/suite of samples, are based on rates in current 1995 LLNL contracts with commercial analytical laboratories:

Analyte	EPA Method	Cost ($)
VOCs	601	50
Metals	DDWM	120
General minerals	GENMIN	100
HE compounds (HMX & RDX)	8330	108
Tritium	RAD:H3	57
Gross alpha/gross beta	RAD:Gross A & B	42

7. To account for QA/QC (e.g., field blanks and duplicate samples), 10% is added to the total analytical cost per alternative.
8. We assume that quarterly monitoring reports will be submitted to regulatory agencies until MCLs are met for Alternatives A and B and annually thereafter. We estimate a cost of $10,000 per report. Costs include analytic and water level data entry, interpretation, reporting, and all applicable LLNL taxes.
9. Well and pump maintenance is estimated at $430/year, including labor, periodic pump replacement, and all applicable LLNL taxes. Injection well maintenance is estimated at $1,000/year, including periodic maintenance and well redevelopment.

10. Project management with 0.25 FTE is allotted at $238,500/year for additional interpretation, meetings, and other tasks. When all sampling is reduced to annual frequency, we allot 0.10 FTE for project management.

G-2.4. Contingency Cost Assumptions

A contingency of 20% is applied to the total cost estimate for each alternative.

G-3. Cost Summary

Costs for each Alternative A and B are summarized below and presented in detail in Tables G-1 and G-2, respectively. Additional cost information and assumptions are presented in Chapter 2.

G-3.1. Alternative A: Monitoring with Contingency Plume Containment

The estimated costs for Alternative A are presented in Table G-1 and Figure G-1. The capital requirement is $2,093,353, which is assumed to be incurred 10 years after the project begins, for a present-worth cost of $1,484,187. The present-worth cost of O&M is $925,047, and the present-worth monitoring cost is $2,948,873. Assuming the trigger criteria are met under Alternative A, the total present-worth cost for an estimated 45-year project life is $6,429,727. The total non-discounted cost is $10,862,546.

G-3.2. Alternative B: Aquifer Remediation

The estimated costs for Alternative B are presented in Table G-2 and Figure G-2. The capital requirement is $3,691,304, and the present-worth cost of O&M is $1,845,155. The present-worth monitoring cost is $5,789,447. Under Alternative B, the total present-worth cost for an estimated 115-year project life is $20,509,551. The total non-discounted cost of Alternative B is $65,558,133.

G-4. References

Hammer, D. A., Ed. (1989), *Constructed Wetlands for Waste Water Treatment: Municipal, Industrial, and Agricultural* (Lewis Publishers: Chelsea, Michigan).

Office of Management and Budget (OMB) (1992), *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs,* Office of Management and Budget, Washington, D.C. (OMB Circular A-94).

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

U.S. EPA (1988b), *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Waste water Treatment,* U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. (EPA/625/1-88/022).

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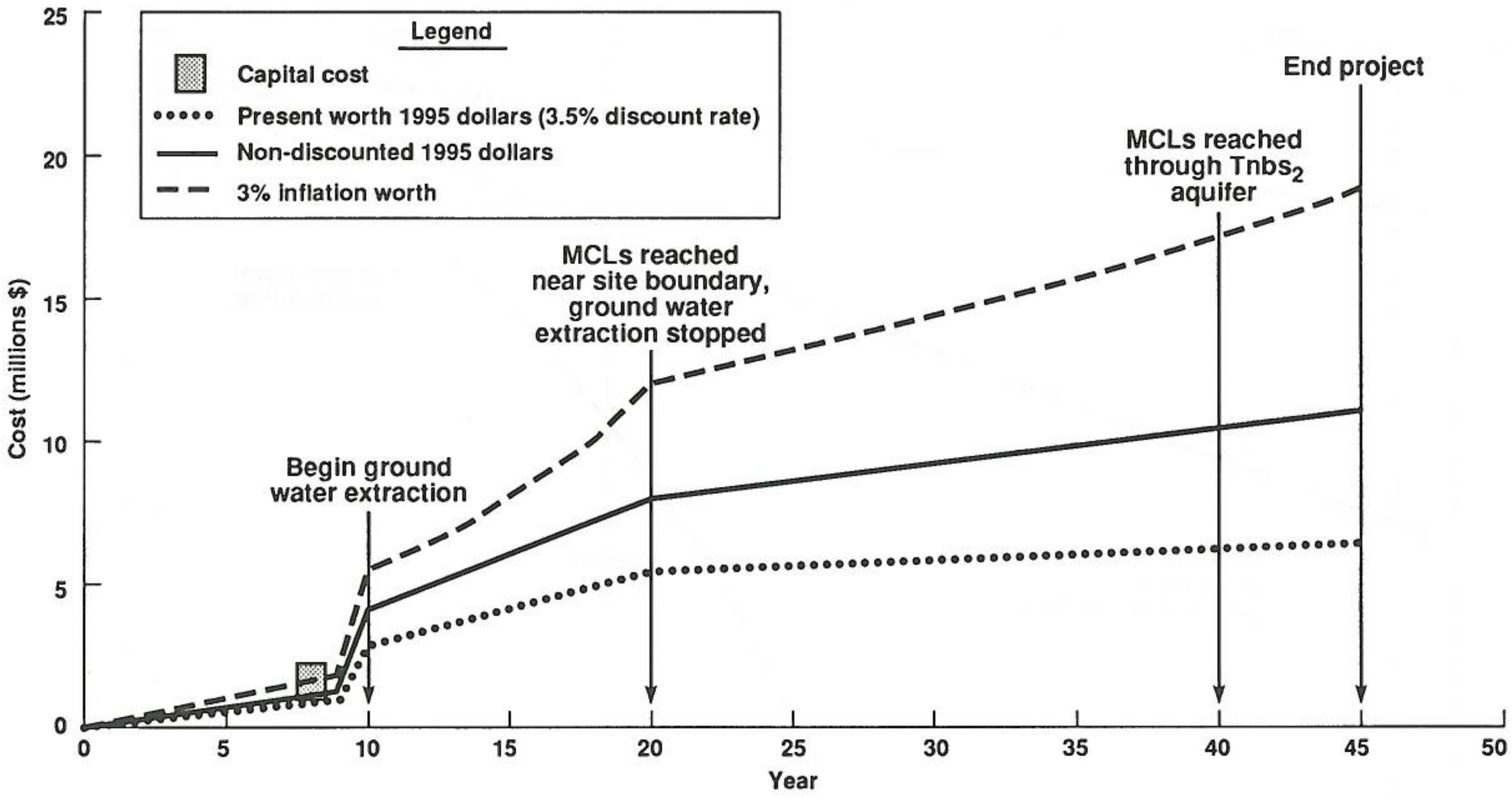

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Figure G-1. Comparison of cumulative cost at three discount rates – Alternative A.

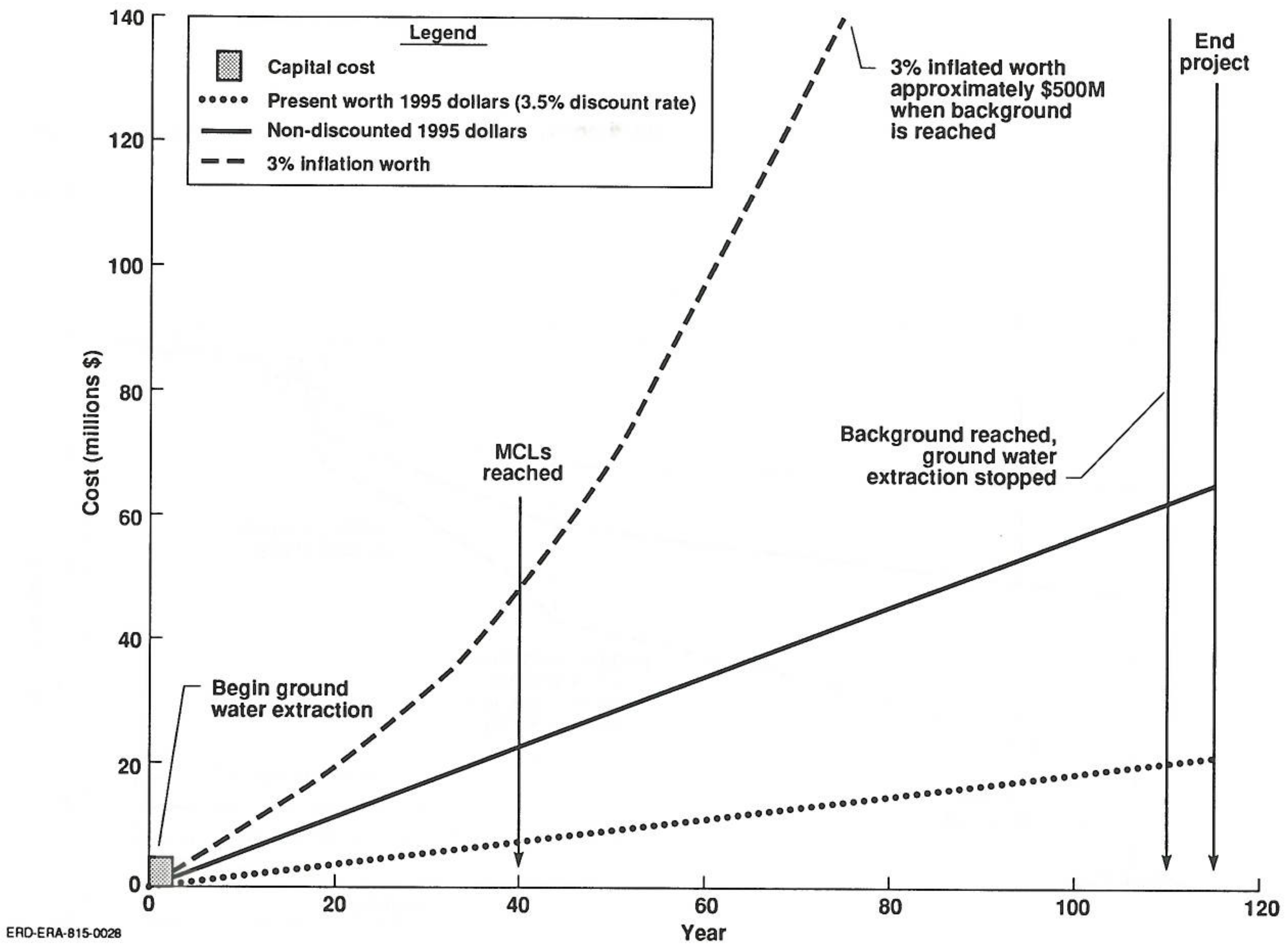

Figure G-2. Comparison of cumulative cost at three discount rates – Alternative B.

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Baseline ground water monitoring				
Annual costs, years 1–20				
VOC analysis (EPA Method 601)	46	each	50	2,300
Nitrates analysis (as NO3)	30	each	75	2,250
HE analysis (HMX & RDX)	39	each	108	4,212
BTEX compounds analysis (EPA Method 602)	8	each	75	600
Oil and grease analysis (EPA Method 418.1)	1	each	50	50
TPH: gas and diesel analysis (modified EPA Method 8015)	1	each	100	100
PCB analysis (EPA Method 608)	1	each	180	180
Quarterly spring water sample analysis	4	suite	477	1,908
QA/QC analysis (10% of analytic costs)				1,160
Quarterly monitoring reports	4	report	10,000	40,000
LLNL tax (11% of outside charges)				5,804
Quarterly water-level measurements (B815 OU wells)	23	well	125	2,875
Quarterly ground water sample collection	6	well	500	3,000
Semi-annual ground water sample collection	5	well	250	1,250
Annual ground water sample collection	12	well	125	1,500
Quarterly spring water sample collection	1	spring	500	500
Maintenance of ground water sampling system	23	well	430	9,890
Project management	0.25	FTE	238,500	59,625
Total annual costs, years 1–20				**137,204**
Total present-worth cost, years 1–20 years (factor = 14.212)				**1,949,938**
Annual costs, years 21–45				
VOC analysis (EPA Method 601)	23	each	50	1,150
Nitrates analysis (as NO3)	12	each	75	900
HE analysis (HMX & RDX)	16	each	108	1,728
BTEX compounds analysis (EPA Method 602)	3	each	75	225
Oil and grease analysis (EPA Method 418.1)	1	each	50	50
TPH: gas and diesel analysis (modified EPA Method 8015)	1	each	100	100

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
PCB analysis (EPA Method 608)	1	each	180	180
Annual spring water sample analysis	1	suite	477	477
QA/QC analysis (10% of analytic costs)				481
Annual monitoring reports	1	report	10,000	10,000
LLNL tax (11% of outside charges)				1,682
Quarterly water-level measurements (B815 OU wells)	23	well	62.50	1,438
Annual ground water sample collection	23	well	125	2,875
Annual spring water sample collection	1	spring	125	125
Maintenance of ground water sampling system	23	well	430	9,890
Project management	0.10	FTE	238,500	23,850
Total annual costs, years 21–45				**55,151**
Total present worth, years 21–45 years (factor = 8.283)				**456,812**

Additional contingency plan ground water monitoring

6-month trigger verification monitoring (year 10)

VOC analysis (EPA Method 601)	38	each	50	1,900
Nitrates analysis (as NO3)	32	each	75	2,400
HE analysis (HMX & RDX)	31	each	108	3,348
BTEX compounds analysis (EPA Method 602)	12	each	75	900
Oil and grease analysis (EPA Method 418.1)	6	each	50	300
TPH: gas and diesel analysis (modified EPA Method 8015)	6	each	100	600
PCB analysis (EPA Method 608)	6	each	180	1,080
Monthly spring water sample analysis	6	suite	477	2,862
QA/QC analysis (10% of analytic costs)				1,339
LLNL tax (11% of outside charges)				1,620
Additional confirmatory ground water sample collection	1	well	250	250
Monthly ground water sample collection	6	well	750	4,500
Monthly spring water sample collection	1	spring	750	750
Statistical data analysis	0.10	FTE	173,500	17,350
Total 6-month cost				**39,199**
Total present-worth cost, year 10 (factor = 0.709)				**27,792**

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Additional annual costs, years 11–20				
VOC analysis (EPA Method 601)	24	each	50	1,200
Nitrates analysis (as NO3)	24	each	75	1,800
HE analysis (HMX & RDX)	24	each	108	2,592
QA/QC analysis (10% of analytic costs)				559
LLNL tax (11% of outside charges)				677
Quarterly water-level measurements (piezometers)	11	well	125	1,375
Quarterly ground water sample collection (2 extraction, 4 monitoring)	6	well	500	3,000
Additional maintenance of ground water sampling system	6	well	430	2,580
Additional maintenance of injection well system	4	well	1,000	4,000
Additional project management	0.10	FTE	238,500	23,850
Total annual costs, years 11–20				**41,633**
Total present-worth cost, years 11–20 years (factor = 5.896)				**245,467**
Additional annual costs, years 21–45				
VOC analysis (EPA Method 601)	6	each	50	300
Nitrates analysis (as NO3)	6	each	75	450
HE analysis (HMX & RDX)	6	each	108	648
Ground water treatment system analysis (water only)	12	event	150	1,800
QA/QC analysis (10% of analytic costs)				320
LLNL tax (11% of outside charges)				387
Quarterly water-level measurements (piezometers)	11	well	125	1,375
Annual ground water sample collection	6	well	125	750
Additional maintenance of ground water sampling system	6	well	430	2,580
Additional project management	0.10	FTE	238,500	23,850
Total annual costs, years 21–45				**32,460**
Total present-worth cost of additional monitoring, years 21–45 years (factor = 8.283)				**268,864**
Total present-worth cost of ground water monitoring for 45 years (25 years after ceasation of ground water extraction)				**2,948,873**

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Capital costs				
Ground water extraction system major equipment costs (MEC)				
Extraction wellhead vaults, valves, sampling ports, gauges	2	each	1,500	3,000
Re-injection wellhead vaults, valves, sampling ports, gauges	4	each	1,500	6,000
Electrical line and conduit	400	foot	1.75	700
2-in. PVC piping	2,800	foot	1.50	4,200
Extraction well electric submersible pumps (2 hp)	2	each	2,000	4,000
Monitor well electric submersible pumps (1/2 hp)	4	each	800	3,200
PVC pipe fittings, unistrut	1	lot	10,000	10,000
Ground water treatment MEC				
Particulate filter assembly	1	each	3,700	3,700
Aqueous-phase carbon canisters (1,000 lb)	3	each	6,000	18,000
Treated water discharge storage tank (2,500 gal.)	1	each	2,500	2,500
Manifold, piping, valves, gauges, sampling ports, totalizer, controllers	1	lot	15,000	15,000
Treated water discharge pump (15 hp)	1	each	2,000	2,000
Treated water discharge piping and fittings	1	each	10,000	10,000
Total MEC for ground water extraction and treatment				**82,300**
Electrical components (20% of MEC)				16,460
Installation cost (58% of MEC)				47,734
Major equipment installed cost (MEIC)				**146,494**
Other capital costs				
Wells/borings				
Ground water extraction well installation and development	2	well	50,000	100,000
Ground water monitor well installation and development	4	well	50,000	200,000
Treated water reinjection well installation and development	4	well	50,000	200,000
Piezometer installation and development	11	well	20,000	220,000

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Soil boring and initial water sample analysis	21	well	1,500	31,500
Soil disposal (Class III)	158	cu yard	20	3,150
Hydraulic test for ground water extraction wells	2	well	3,000	6,000
Hydraulic test for reinjection wells	4	well	5,000	20,000
Hydraulic test for piezometers	11	well	1,500	16,500
Structures				
Equipment building for ground water treatment system	1	each	200,000	200,000
Geotechnical testing	1	each	20,000	20,000
LLNL Protective Services				
Escort service (2 guards for 4 weeks)	20	day	640	12,800
Total field costs (TFC)				**1,176,444**
LLNL tax (11% of total field costs)				129,409
Professional environmental services				
Statistical analysis of trigger criteria data				21,000
Design/assist with project management				28,000
Permitting				19,000
Start-up labor and analyses				28,000
Plume capture performance evaluation				21,000
Total professional environmental services				**117,000**
LLNL ERD team				
Full-time employee	1	FTE	173,500	173,500
Remedial Design Report				150,000
Total LLNL ERD team				**323,500**
LLNL technical support services				
LLNL Plant Engineering planning and Title I, II, and III services	2	FTE	173,500	347,000

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Total LLNL support services				**347,000**
Total capital costs				**2,093,353**
Total present-worth cost of capital costs in year 10 (factor = 0.709)				**1,484,187**

Operation and maintenance costs

Fixed O&M costs for ground water extraction and treatment

Fixed annual ground water extraction and treatment O&M

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Electricity	112,000	kw•h	0.07	7,840
Electrical capacity charge	14.2	kw	36	511
Ground water treatment system analysis (water only)	12	event	200	2,400
Maintenance materials (10% of MEC)				8,230
LLNL tax (11% of outside charges)				2,088
Project management	0.10	FTE	238,500	23,850
System optimization, engineer	0.10	FTE	173,500	17,350
Well field optimization, hydrogeologist	0.25	FTE	173,500	43,375
Operating labor	0.15	FTE	129,800	19,470
Administrative personnel	0.10	FTE	92,600	9,260
Maintenance labor (15% of total installation cost)				21,974
Total fixed annual ground water extraction and Treatment O&M				**156,348**
Total present-worth cost of annual ground water treatment O&M, years 11–20 (factor = 5.896)				**921,831**

Variable operating costs for ground water extraction and treatment

Annual costs, year 11

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Ground water treatment system replacement of aqueous phase GAC	335	lb	2.30	771
Total annual costs, year 11				**771**
Total present-worth cost, year 11 (factor = 0.685)				**528**

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Annual costs, year 12				
Ground water treatment system replacement of aqueous phase GAC	300	lb	2.30	690
Total annual costs, year 12				690
Total present-worth cost, year 12 (factor = 0.662)				**457**
Annual costs, year 13				
Ground water treatment system replacement of aqueous phase GAC	270	lb	2.30	621
Total annual costs, year 13				621
Total present-worth cost, year 13 (factor = 0.639)				**397**
Annual costs, year 14				
Ground water treatment system replacement of aqueous phase GAC	240	lb	2.30	552
Total annual costs, year 14				552
Total present-worth cost, year 14 (factor = 0.618)				**341**
Annual costs, year 15				
Ground water treatment system replacement of aqueous phase GAC	215	lb	2.30	495
Total annual costs, year 15				495
Total present-worth cost, year 15 (factor = 0.597)				**295**
Annual costs, years 16–20				
Ground water treatment system replacement of aqueous phase GAC	200	lb	2.30	460
Total annual costs, years 16–20				460
Total present-worth cost, years 16–20 (factor = 2.604)				**1,198**
Total present-worth cost of variable operating costs for ground water extraction and treatment				**3,216**

Table G-1. Alternative A: monitoring with contingency plume containment.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Contingency costs and totals				
Subtotal present-worth cost of Alternative A				**5,358,106**
Contingency (20%)				1,071,621
Total present-worth cost of Alternative A				**6,429,727**
Total non-discounted worth of Alternative A				***10,862,546***

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Capital costs				
Facility A				
Ground water extraction system major equipment costs (MEC)				
Extraction wellhead vaults, valves, sampling ports, gauges	4	each	1,500	6,000
Electrical line and conduit	1,400	foot	1.75	2,450
2-in. PVC piping	2,400	foot	1.50	3,600
Extraction well electric submersible pumps (2 hp)	4	each	2,000	8,000
Monitor well electric submersible pumps (1/2 hp)	4	each	800	3,200
PVC pipe fittings, unistrut	1	lot	10,000	10,000
Ground water treatment MEC				
Particulate filter assembly	1	each	3,700	3,700
Aqueous-phase carbon canisters (1,000 lb)	3	each	6,000	18,000
Treated water discharge storage tank (2,500 gal)	1	each	2,500	2,500
Manifold, piping, valves, gauges, sampling ports, totalizer, controllers	1	lot	15,000	15,000
Treated water discharge pump (15 hp)	1	each	2,000	2,000
Treated water discharge piping and fittings	1	each	10,000	10,000
Total MEC for Facility A ground water treatment system				**84,450**
Facility B				
Ground water extraction system major equipment costs (MEC)				
Extraction wellhead vaults, valves, sampling ports, gauges	7	each	1,499	10,493
Electrical line and conduit	1,900	foot	1.75	3,325
2-in. PVC piping	3,400	foot	1.50	5,100
Extraction well electric submersible pumps (2 hp)	7	each	2,000	14,000
Monitor well electric submersible pumps (1/2 hp)	4	each	800	3,200
PVC pipe fittings, unistrut	1	lot	10,000	10,000

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Ground water treatment MEC				
Particulate filter assembly	1	each	3,700	3,700
Aqueous-phase carbon canisters (1,000 lb)	3	each	6,000	18,000
HE aqueous-phase carbon regeneration equipment	1	each	4,500	4,500
HE biological treatment system	1	each	7,500	7,500
Manifold, piping, valves, gauges, sampling ports, totalizer, controllers	1	lot	15,000	15,000
Treated water discharge piping and fittings	1	each	10,000	10,000
Total MEC for Facility B ground water treatment system				**104,818**
Total MEC for Building 815 OU ground water extraction and treatment systems				**189,268**
Electrical components (20% of MEC)				37,854
Installation cost (58% of MEC)				109,775
Denitrification system				
Constructed wetland or pond denitrification system MEC				
2-in. PVC piping	500	foot	1.50	750
Manifold, piping, valves, gauges, sampling ports, totalizer, controllers	1	lot	5,000	5,000
Denitrification system installation (constructed wetland or pond system)	1	system	160,000	185,000
Treated water discharge piping and fittings	1	each	10,000	10,000
Total major equipment installed cost for constructed wetland or pond denitrification system				**200,750**
Major equipment installed cost (MEIC)				**537,647**
Other capital costs				
Wells/borings				
Ground water extraction well installation and development	11	well	50,000	550,000

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Ground water monitor well installation and development	4	well	50,000	200,000
Piezometer installation and development	10	well	20,000	200,000
Soil boring and initial water sample analysis	21	well	1,500	31,500
Soil disposal (Class III)	158	cu yard	20	3,150
Hydraulic test for ground water extraction wells	11	well	3,000	33,000
Hydraulic test for piezometers	10	well	1,500	15,000
Structures				
Equipment building for ground water treatment system	2	each	200,000	400,000
Geotechnical testing	2	each	20,000	40,000
LLNL Protective Services				
Escort Service (2 guards for 12 weeks)	60	day	640	38,400
Total field costs (TFC)				**2,048,697**
LLNL tax (11% of total field costs)				225,357
Professional environmental services				
Design/assist with project management				55,000
Permitting				24,000
Start-up labor and analyses				63,000
Plume capture performance evaluation				21,000
Total professional environmental services				**163,000**
LLNL ERD team				
Full-time employee	1.5	FTE	173,500	260,250
Remedial Design Report				300,000
Total LLNL ERD team				**560,250**
LLNL technical support services				
LLNL Plant Engineering planning and Title I, II, and III services	4	FTE	173,500	694,000

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Total LLNL support services				694,000
Total capital costs				**3,691,304**

Operation and maintenance costs

Fixed O&M costs for ground water extraction and treatment

Fixed annual ground water extraction and treatment O&M

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Electricity	206,000	kw•h	0.07	14,420
Electrical capacity charge	26.1	kw	36	941
Ground water treatment system analysis (water only)	12	event	574	6,888
Maintenance materials (10% of total installed MEC)				31,632
LLNL tax (11% of outside charges)				5,927
Project management	0.20	FTE	238,500	47,700
System optimization, engineer	0.25	FTE	173,500	43,375
Well field optimization, hydrogeologist	0.25	FTE	173,500	43,375
Operating labor	0.30	FTE	129,800	38,940
Clerical	0.10	FTE	92,600	9,260
Maintenance labor (15% of total installed cost)				27,520
Total fixed annual ground water extraction and treatment O&M				**269,978**
Total present-worth cost of annual ground water treatment O&M, years 1–40 (factor = 21.355)				**5,765,387**
Total present-worth cost of annual ground water treatment O&M, years 41–110 (factor = 6.567)				**1,772,948**

Variable operating costs for ground water extraction and treatment

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Annual costs, years 1-5				
Facility A replacement of aqueous phase GAC	350	lb	2.30	805
Facility B replacement and regeneration of aqueous phase GAC	215	lb	10.00	2,150

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Total annual costs, years 1–5				**2,955**
Total present-worth cost, years 1–5 (factor = 4.515)				**13,342**
Annual costs, years 6–10				
Facility A replacement of aqueous phase GAC	300	lb	2.30	690
Facility B replacement and regeneration of aqueous phase GAC	200	lb	10.00	2,000
Total annual costs, years 6–10				**2,690**
Total present-worth cost, years 6–10 (factor = 3.802)				**10,227**
Annual costs, years 11–20				
Facility A replacement of aqueous phase GAC	230	lb	2.30	529
Facility B replacement and regeneration of aqueous phase GAC	200	lb	10.00	2,000
Total annual costs, years 11–20				**2,529**
Total present-worth cost, years 11–20 (factor = 5.896)				**14,911**
Annual costs, years 21–110				
Facility A replacement of aqueous phase GAC	200	lb	2.30	460
Facility B replacement and regeneration of aqueous phase GAC	200	lb	10.00	2,000
Total annual costs, years 21–110				**2,460**
Total present-worth cost, years 21–40 (factor = 7.143)				**17,572**
Total present-worth cost, years 41–110 (factor = 6.567)				**16,155**
Total present-worth cost of variable operating costs for ground water extraction and treatment				**72,207**

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Baseline ground water monitoring				
Annual costs, years 1–40				
VOC analysis (EPA Method 601)	106	each	50	5,300
Nitrates analysis (as NO3)	90	each	75	6,750
HE analysis (HMX & RDX)	99	each	108	10,692
BTEX compounds analysis (EPA Method 602)	8	each	75	600
Oil and grease analysis (EPA Method 418.1)	1	each	50	50
TPH: gas and diesel analysis (modified EPA Method 8015)	1	each	100	100
PCB analysis (EPA Method 608)	1	each	180	180
Quarterly spring water sample analysis	4	suite	477	1,908
QA/QC analysis (10% of analytic costs)				2,558
Quarterly monitoring reports	4	report	15,000	60,000
LLNL tax (11% of outside charges)				9,695
Quarterly water-level measurements (piezometers)	25	well	125.00	3,125
Quarterly water-level measurements (B815 OU wells)	38	well	125.00	4,750
Quarterly ground water sample collection (11 extraction, 10 monitoring)	21	well	500	10,500
Semiannual ground water sample collection	5	well	250	1,250
Annual ground water sample collection	12	well	125	1,500
Quarterly spring water sample collection	1	spring	500	500
Maintenance of ground water sampling system	38	well	430	16,340
Project management	0.35	FTE	238,500	83,475
Total annual costs, years 1–40				**219,273**
Total present-worth cost, years 1–40 years (factor = 21.355)				**4,682,579**
Annual costs, years 41–110				
VOC analysis (EPA Method 601)	106	each	50	5,300
Nitrates analysis (as NO3)	90	each	75	6,750
HE analysis (HMX & RDX)	99	each	108	10,692
BTEX compounds analysis (EPA Method 602)	8	each	75	600
Oil and grease analysis (EPA Method 418.1)	1	each	50	50

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
TPH: gas and diesel analysis (modified EPA Method 8015)	1	each	100	100
PCB analysis (EPA Method 608)	1	each	180	180
Quarterly spring water sample analysis	4	suite	477	1,908
QA/QC analysis (10% of analytic costs)				2,558
Annual monitoring reports	1	report	15,000	15,000
LLNL tax (11% of outside charges)				4,745
Quarterly water-level measurements (piezometers)	25	well	125.00	3,125
Quarterly water-level measurements (B815 OU wells)	38	well	62.50	2,375
Quarterly ground water sample collection	21	well	500	10,500
Semiannual ground water sample collection	5	well	250	1,250
Annual ground water sample collection	12	well	125	1,500
Quarterly spring water sample collection	1	spring	500	500
Maintenance of ground water sampling system	38	well	430	16,340
Project management	0.35	FTE	238,500	83,475
Total annual costs, years 41–110				**166,948**
Total present-worth cost, years 41–110 years (factor = 6.567)				**1,096,349**
Annual costs, years 111–115				
VOC analysis (EPA Method 601)	38	each	50	1,900
Nitrates analysis (as NO3)	27	each	75	2,025
HE analysis (HMX & RDX)	38	each	108	4,104
BTEX compounds analysis (EPA Method 602)	3	each	75	225
Oil and grease analysis (EPA Method 418.1)	1	each	50	50
TPH: gas and diesel analysis (modified EPA Method 8015)	1	each	100	100
PCB analysis (EPA Method 608)	1	each	180	180
Annual spring water sample analysis	1	suite	477	477
QA/QC analysis (10% of analytic costs)				906
Annual monitoring reports	1	report	15,000	15,000
LLNL tax (11% of outside charges)				2,746
Quarterly water-level measurements (piezometers)	25	well	125.00	3,125
Quarterly water-level measurements (B815 OU wells)	38	well	62.50	2,375
Annual ground water sample collection	38	well	125	4,750
Annual spring water sample collection	1	spring	125	125

Table G-2. Alternative B: aquifer remediation.

	Quantity	Unit type	Unit price (1995 $)	Total (1995 $)
Maintenance of ground water sampling system	38	well	430	16,340
Project management	0.20	FTE	238,500	47,700
Total annual costs, years 111–115				**102,128**
Total present-worth cost, years 111–115 years (factor = 0.103)				**10,519**
Total present worth of ground water monitoring for 115 years (5 years after reaching background)				**5,789,447**
Contingency costs and totals				
Subtotal present-worth cost of Alternative B				**17,091,292**
Contingency (20%)				3,418,258
Total present-worth cost of Alternative B				**20,509,551**
Total non-discounted worth cost of Alternative B				***65,558,133***

Acronyms and Abbreviations

Acronyms and Abbreviations

AOS	Adult on site
ARARs	Applicable or Relevant and Appropriate Requirements
AVI	Active vacuum induced
BTEX	Benzene, toluene, ethylbenzene, xylene(s)
C	Carbon
Cal-EPA	California Environmental Protection Agency
CCR	Code of California Regulations
CFR	Code of Federal Regulations
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CH_2O	Carbohydrate or simple sugar
COC	Chemical of concern
CO_2	Carbon dioxide
1,1-DCA	1,2-dichloroethane
1,1-DCE	1,1-dichloroethylene, also 1,1-dichloroethene
DOE	Department of Energy
EPA	Environmental Protection Agency
exp	Exponential
ft	Feet
FTE	Full-time employee
g	Gram(s)
G&A	General and Administrative
g/cc	Grams per cubic centimeter
GAC	Granular activated carbon
gal	Gallon(s)
g/L	Gram(s) per liter(s)
gpd	Gallons per day
gpm	Gallons per minute
H_2O	Water
H_2O_2	Hydrogen peroxide

H	Hydrogen
HE	High explosives or high-explosives compounds such as HMX, RDX, or TNT.
HI	Hazard index (indices)
HMX	A high explosive, known also as octogen or homocyclonite.
hp	Horse power
HVAC	Heating, ventilation, and air conditioning (systems)
kWh	Kilowatt hours
in.	Inch(es)
kg	Kilogram
lb	Pound(s)
LDRD	Lab-directed research and development
L/gal	Liter(s) per gallon
LLNL	Lawrence Livermore National Laboratory
m^2	Meters squared
MCL	Maximum contaminant level. A drinking-water standard.
mg/L	Milligrams per liter
µg/L	Micrograms per liter
MEIC	Major equipment installed cost
min	Minute(s)
ml/g	Milliliters per gram
ml/L	Milliliters per liter
mo	month(s)
MPC	Material Procurement Charge
NA	Not available
N_2	Hydrogen gas
NEPA	National Environmental Policy Act
NO_2	Nitrite
NO_3	Nitrate
NPDES	National Pollutant Discharge Elimination System
O&M	Operations and Maintenance
OU	Operable Unit
PCB	Polychlorinated biphenyl compound

ppb	Parts per billion. Equals µg/kg, and, approximately, µg/L.
ppm	Parts per million. Equals mg/kg, and, approximately, mg/L.
QA/QC	Quality assurance/Quality control
RAR	Relevant and appropriate requirement
RD	Remedial Design
RDX	A high explosive, also known as cyclonite or hexogen.
RES	Residential exposure
RWQCB	Regional Water Quality Control Board
SVE	Soil vapor extraction
SVS	Soil vapor survey
SWRCB	State Water Resources Control Board (California)
SWRI	Site-Wide Remedial Investigation report for LLNL Site 300
t	Time
TBC	To be considered
TCE	Trichloroethylene
TDS	Total dissolved solids
$Tnbs_2$	Miocene Neroly Formation Upper Blue Sandstone
TPH	Total petroleum hydrocarbons
Tps	Pliocene nonmarine unit
TQs	Toxicity Quotients
U.S. EPA	United States Environmental Protection Agency
UV	Ultraviolet
VOCs	Volatile Organic Compound(s)
WDR	Waste discharge requirement
yd	Yard

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