U.S. Department of Energy

Livermore Site Office, Livermore, California 94551

Lawrence Livermore National Laboratory

Lawrence Livermore National Security, LLC, Livermore, California 94551

LLNL-AR-470073

Five-Year Review Report for the Building 832 Canyon Operable Unit at Lawrence Livermore National Laboratory Site 300

Authors:

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August 2011

*Weiss Associates, Emeryville, California

Environmental Restoration Department

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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.

Aug 24, 2011

Victor Madrid Date
California Registered Geologist
No. 5051
License expires: April 30, 2012
California Certified Hydrogeologist
No. 378
License expires: April 30, 2012

Approval and Concurrence for the Five-Year Review for the Building 832 Canyon Operable Unit at Lawrence Livermore National Laboratory Site 300

Prepared by:

The United States Department of Energy
Livermore Site Office
Livermore, California

Approved:

6/24/11

for **Claire S. Holtzapple** **Date**
Site 300 Remedial Project Manager
U.S. Department of Energy
National Nuclear Security Administration
Livermore Site Office

Five-Year Review Summary Form

Site Identification		
Site name: Lawrence Livermore National Laboratory Site 300, Building 832 Canyon Operable Unit (OU)		
EPA ID: CA 2890090002		
Region: IX	State: California	City/County: San Joaquin/Alameda
Site Status		
NPL status: Final		
Remediation status: Operating		
Multiple OUs: Yes	Construction completion date: September 2007	
Has the site been put into reuse: No		
REVIEW STATUS		
Reviewing agency: United States (U.S.) Department of Energy (DOE)		
Author name: Anne Helmig		
Author title: Site 300 Hydrogeologist	Author affiliation: Weiss Associates Emeryville, California	
Review period: February 2006 to June 2010		
Date(s) of site inspection: February 5, 2008		
Type of review: Statutory		
Review number: 1		
Triggering action: Interim Remedial Design for the Building 832 Canyon OU		
Triggering action date: February 2006		
Due date: August 12, 2011		

Five-Year Review Summary Form (continued)

Deficiencies

No deficiencies in the remedy were identified during this evaluation.

Recommendations and Follow-Up Actions

The following recommendations to be carried out by the U.S. Department of Energy (DOE) were developed during the review process:

1. Drill and install one new extraction well (W-830-2701) to increase hydraulic capture and prevent migration of contaminants of concern (COCs) in the $Tnsc_{1a}$ hydrostratigraphic unit (HSU). This new extraction well would be connected to the 830-Source (SRC) facility where extracted ground water would be treated.
2. Drill and install one new dual-phase extraction well (W-832-2702) to increase hydraulic capture of COCs in the $Tnsc_{1b}$ HSU and contaminant mass removal in the Building 832 source area, and prevent contaminant migration in this HSU. This new extraction well would be connected to the 832-SRC facility where extracted ground water and soil vapor would be treated.
3. Drill and install two $Tnsc_{1a}$ HSU monitor wells (W-832-3102 and W-830-2803) to better delineate the volatile organic compound (VOC) plume in the $Tnsc_{1a}$ HSU west and southwest of the Building 830 source area, respectively.
4. Drill and install one $Tnsc_{1a}$ HSU monitor well (W-832-3001) to better delineate the extent of VOC contamination in this HSU downgradient of the Building 832 source area. This proposed monitor well W-832-3001 may be converted to an extraction well if ground water yields and total VOC concentrations are sufficient.
5. Drill and install one monitor well (W-832-2901 in the Upper $Tnbs_1$ ($UTnbs_1$) HSU downgradient of the Building 832 source area (Figure 12). This well will be used as an $UTnbs_1$ HSU guard well to verify that no contaminants from the Building 832 source area have reached this HSU.
6. Due to contamination by storm water runoff, abandon $Tnsc_{1b}$ HSU monitor well W-832-05. Monitor well W-832-06, which is screened across the $Tnsc_{1b}$ and $Tnsc_{1a}$ HSUs, should also be abandoned because data collected from this well may not be fully representative of VOC concentrations in the $Tnsc_{1a}$ HSU near the Building 832 source area, and the well could act as a conduit by allowing the downward migration of contaminants from the $Tnsc_{1b}$ HSU into the underlying $Tnsc_{1a}$ HSU. After abandonment, replace wells with new monitor wells in the $Tnsc_{1b}$ and $Tnsc_{1a}$ HSUs. The locations of

the replacement wells are to be determined, but will likely be located near the 832-SRC or 830-SRC treatment facilities.

No other follow-up actions were identified related to this Five-Year Review. As discussed below, these recommendations do not affect the protectiveness of the remedy.

DOE will: (1) estimate costs and the timeframe necessary to accomplish the new work scope; (2) prioritize new work scope and present these priorities to the regulatory agencies; (3) incorporate the new work scope into upcoming fiscal year budget requests; and (4) develop a schedule for implementing the work.

Protectiveness Statement

The remedy at the Building 832 Canyon OU is protective of human health and the environment for the site's industrial land use. The remedy protects human health because exposure pathways that could result in unacceptable risk to onsite workers are being controlled by the implementation of institutional controls, the Health and Safety Plan, and the Contingency Plan.

The cleanup standards for Building 832 Canyon OU ground water are drinking water standards. Because drinking water standards do not differentiate between industrial and residential use, the ground water cleanup remedy will be protective under any land use scenario.

The cleanup standards for VOCs in subsurface soil are to reduce concentrations to mitigate risk to onsite workers and prevent further impacts to ground water to the extent technically and economically feasible. Because some VOCs may remain in subsurface soil following the achievement of these cleanup standards, a land use control prohibits the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition is included in the Site-Wide ROD. This prohibition will remain in place until and unless a risk assessment is performed in accordance with current U.S. EPA risk assessment guidance and is agreed by the DOE, the EPA, the DTSC, and RWQCB as adequately showing no unacceptable risk for residential or unrestricted land use.

Table of Contents

List of Figures

List of Tables

Appendices

1. Introduction

The United States (U.S.) Department of Energy (DOE) has conducted a Five-Year Review of the remedial actions implemented at the Building 832 Canyon operable unit (OU) at Lawrence Livermore National Laboratory (LLNL) Site 300. Environmental cleanup is conducted under the oversight of the U.S. Environmental Protection Agency (U.S. EPA), the California Department of Toxic Substances Control (DTSC), and the California Regional Water Quality Control Board (RWQCB). DOE is the lead agency for environmental restoration at LLNL. The review documented in this report was conducted from February 2006 through June 2010. Parties providing analyses in support of the review include:

- U.S. DOE, Livermore Site Office.
- LLNL, Environmental Restoration Department.
- Weiss Associates.

The purpose of a Five-Year Review is to evaluate the implementation and performance of a remedy to determine whether the remedy will continue to be protective of human health and the environment. The Five-Year Review report presents the methods, findings, and conclusions of the review. In addition, the Five-Year Review identifies issues or deficiencies in the selected remedy, if any, and presents recommendations to address them. The format and content of this document is consistent with guidance issued by DOE (U.S. DOE, 2002) and the U.S. EPA (U.S. EPA, 2001a).

Section 121 of the Comprehensive Response, Compensation, and Liability Act (CERCLA), as amended by the Superfund Amendment Reauthorization Act (SARA), requires that remedial actions that result in any hazardous substances, pollutants, or contaminants remaining at the site be subject to a five-year review. The National Contingency Plan further provides that remedial actions which result in any hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure be reviewed every five years to ensure protection of human health and the environment. Consistent with Executive Order 12580, Federal agencies are responsible for ensuring that five-year reviews are conducted at sites where five-year reviews are required or appropriate.

This is the first Five-Year Review for the Building 832 Canyon OU (OU 7). This review is considered a statutory review because: (1) contamination will remain onsite upon completion of the remedial action, (2) the Record of Decision (ROD) was signed after October 17, 1986 (the effective date of the SARA), and (3) the remedial action was selected under CERCLA. The triggering action for the first Building 832 Canyon review was the February 2006 submittal date of the Interim Remedial Design for the Building 832 Canyon Operable Unit at Lawrence Livermore National Laboratory Site 300 (Madrid et al., 2006).

Five-year reviews are conducted individually for each OU at Site 300. The Remedial Action Completion Report (Holtzapple, 2008) and Site-Wide ROD (U.S DOE, 2008) are the triggers for the five-year reviews for OUs 3 and 8, respectively, in accordance with EPA guidance. At the other OUs where construction began prior to the Site-Wide ROD as treatability studies and/or

removal actions, DOE and the regulatory agencies agreed to use the completion of the OU-specific Remedial Design report as the trigger for the first five-year review.

The background and description of the Building 832 Canyon OU are presented in Section 3. The following sections include the descriptions and status of the other OUs and areas where environmental restoration activities are occurring at Site 300.

1.1. General Services Area (GSA) OU (OU 1)

The GSA OU has been separated into the Central GSA and the Eastern GSA based on differences in hydrogeology and the distribution of environmental contaminants. DOE has performed two Five-Year Reviews for the GSA OU (Ferry et al., 2001a and Dibley et al, 2006a).

1.1.1. Central GSA

Chlorinated solvents, mainly trichloroethene (TCE), were used as degreasing agents in craft shops in the Central GSA. Rinse water from these degreasing operations was disposed of in dry wells that were gravel-filled holes about 3 to 4 feet (ft) deep and two ft in diameter. As a result, subsurface soil and ground water was contaminated with volatile organic compounds (VOCs). There are no contaminants of concern (COCs) in surface soil in the central GSA. The Central GSA dry wells were used until 1982. In 1983 and 1984, these dry wells were decommissioned and excavated.

Ground water cleanup began in the Central GSA in 1992 and soil vapor extraction started in 1994 as removal actions. In 1997, a Final ROD for the GSA OU (U.S. DOE, 1997) was signed and ground water and soil vapor extraction and treatment continued as a remedial action. The selected remedy for the Central GSA includes monitoring, risk and hazard management, and ground water and soil vapor extraction and treatment. The remedial design was completed in 1998 and construction completion for the OU was achieved in September 2005.

Operation of the ground water and soil vapor extraction and treatment systems to remove VOCs from the subsurface is ongoing. Remediation has reduced maximum VOC concentrations in ground water from 272,000 micrograms per liter (µg/L) to 2,000 µg/L (June 2010) and has mitigated the risk to onsite workers from inhalation of VOCs inside Building 875.

1.1.2. Eastern GSA

The source of contamination in the Eastern GSA is an abandoned debris burial trench that received craft shop debris. Leaching of solvents from the debris resulted in the release of VOCs to ground water.

Ground water cleanup began in the Eastern GSA in 1991 as a removal action. In 1995, a Final ROD for the GSA OU was signed and ground water extraction and treatment continued as a remedial action. The remedial design was completed in 1998 and construction completion for the OU was achieved in September 2005. A ground water extraction and treatment system operated from 1991 to 2007 to remove VOCs from ground water.

As of February 2007, remediation had reduced VOC concentrations in on- and offsite ground water to meet cleanup standards. The treatment system was shut off and placed on standby. Post-shutdown monitoring is being conducted to determine if VOC concentrations rebound

above cleanup standards. If VOC concentrations remain below cleanup standards for five years, the treatment system and associated wellfield will be decommissioned.

1.2. Building 834 (OU 2)

From 1962 to 1978, intermittent spills and piping leaks resulted in contamination of the subsurface soil and rock and ground water with VOCs and silicone oils (tetrabutyl orthosilicate/tetrakis (2-ethylbutyl) silane [TBOS/TKEBs]). Nitrate in ground water results from septic system effluent but may also have natural sources. There are no COCs in surface soil.

Completed remedial activities include excavating VOC-contaminated soil (1983) and installing a surface water drainage diversion system to prevent rainwater infiltration in the contaminant source area (1998). Ground water and soil vapor extraction and treatment began in 1986 as treatability studies. An area-specific Interim ROD for the Building 834 OU (U.S. DOE, 1995) was superseded by the Interim ROD and subsequent 2008 Site-Wide ROD. The Building 834 OU remedy includes monitoring, risk and hazard management, and ground water and soil vapor extraction and treatment. Significant *in situ* bioremediation is occurring in Building 834 ground water and a treatability study focusing on understanding and enhancing this process is currently underway. The remedial design was completed in 2002 and construction completion for the OU was achieved in September 2005.

Remediation has reduced VOC concentrations in ground water from a historical maximum of 1,060,000 µg/L to a maximum of 180,000 µg/L in January 2010. TBOS/TKEBs in ground water has also been reduced from a historic maximum concentration of 7,300,000 µg/L in 1995 to 140,000 µg/L (January 2010). While nitrate concentrations have decreased from a historic maximum of 749 milligrams per liter (mg/L) in 2000 to 290 mg/L (January 2010), the continued elevated nitrate concentrations indicate an ongoing source of ground water nitrate. It is likely that there are multiple sources of nitrate at Building 834. One possible anthropogenic source is the septic system leach field located in the vicinity of wells W-834-S1. A second probable source is natural soil nitrate. Additional sources could be nitrogenous compounds, like nitric acid or barium nitrate, that might have inadvertently been discharged into the septic system via a test cell floor drain or to the ground during accidental spills and/or pipeline leaks that released TCE to the environment. Anaerobic bacteria in the Building 834 Core and T2 areas reduce nitrate locally by denitrification.

DOE has performed two Five-Year Reviews for the Building 834 OU (Ferry et al., 2002a and Dibley et al., 2007a).

1.3. Pit 6 Landfill (OU 3)

From 1964 to 1973, approximately 1,900 cubic yards (yd^3) of waste from LLNL Livermore Site and Lawrence Berkeley Laboratory was buried in nine unlined trenches and animal pits at the Pit 6 Landfill. Infiltrating rainwater leached contaminants from pit waste resulting in tritium, VOC, and perchlorate contamination in ground water. Nitrate contamination in ground water results from septic system effluent. No COCs were identified in surface or subsurface soil.

In 1971, DOE excavated portions of the waste contaminated with depleted uranium. In 1997, a landfill cap was installed as a CERCLA removal action to prevent infiltrating precipitation

from further leaching contaminants from the waste. Because of decreasing VOC concentrations in ground water, the presence of TCE degradation products, and the short half-life of tritium (12.3 years), the selected remedy for VOCs and tritium at the Pit 6 Landfill is monitored natural attenuation (MNA). Because ground water monitoring data for perchlorate and nitrate are limited, DOE will continue to monitor ground water to determine if and when an active remedy for these contaminants might be necessary. The remedy also includes risk and hazard management. Construction completion was achieved in October 2002. No Remedial Design document was required for this area.

The extent of contamination at the Pit 6 Landfill is limited and continues to decrease with concentrations/activities near and below cleanup standards. Natural attenuation has reduced VOCs in ground water from a historic maximum of 250 µg/L in 1988 to a maximum concentration of 8 µg/L (March 2010). Tritium activities are well below the cleanup standard and continue to decrease towards background levels. Perchlorate is not currently detected in any wells above the cleanup standard. The extent of nitrate at concentrations exceeding the cleanup standard continues to be limited to one well. Installation of the landfill cap mitigated the onsite worker inhalation risk.

A Five-Year Review for this OU is scheduled for 2012.

1.4. High Explosives (HE) Process Area (OU 4)

From 1958 to 1986, surface spills at the drum storage and dispensing area for the former Building 815 steam plant resulted in the release of VOCs to ground water, subsurface soil, and bedrock. HE compounds, nitrate, and perchlorate detected in ground water are attributed to wastewater discharges to former unlined rinsewater lagoons that occurred from the 1950s to 1985. VOCs, nitrate, and perchlorate have also been identified as COCs in ground water near the former HE Burn Pits. HE compounds are COCs in surface soil. HE compounds and VOCs are COCs in subsurface soil. VOCs are COCs at Spring 5.

The HE Open Burn Facility was capped under the Resource Conservation and Recovery Act (RCRA) in 1998. In 1999, DOE implemented a CERCLA removal action to extract ground water at the site boundary and prevent offsite TCE migration. The HE Process Area remedy includes: (1) ground water extraction and treatment for VOCs, HE compounds, and perchlorate, and (2) MNA for nitrate (except at Building 829 where nitrate is extracted and treated), (3) monitoring, and (4) risk and hazard management. The remedial design was completed in 2002. Construction completion for the OU was achieved in September 2007. Six ground water extraction and treatment systems currently operate in the OU.

Ground water remediation efforts have reduced VOC concentrations from a historic maximum of 450 µg/L in 1992 to a maximum of 61 µg/L in March 2010. Research Department Explosive (RDX) in ground water has also been reduced from a maximum historic concentration of 350 µg/L to a maximum concentration of 110 µg/L in February 2010. Natural denitrification processes are reducing nitrate concentrations in ground water to background levels. Perchlorate concentrations have decreased from a historic maximum of 50 µg/L in 1998 to 29 µg/L (February 2010). Remediation has also mitigated risk to onsite workers in the HE Process Area OU.

DOE has performed a Five-Year Review for the High Explosives Process Area OU (Dibley et al., 2007b).

1.5. Building 850/Pit 7 Complex (OU 5)

This OU has been divided into two areas for cleanup evaluation purposes: (1) the Building 850 Firing Table area, and (2) the Pit 7 Complex.

1.5.1. Building 850 Firing Table (OU 5)

High-explosives experiments were conducted at the Building 850 Firing Table from 1958 to 2008. Tritium was used in some of these experiments, primarily between 1963 and 1978. As a result of the destruction and dispersal of test assembly debris during detonations, surface soil was contaminated with metals, polychlorinated biphenyls (PCBs), dioxins, furans, High-Melting Explosive (HMX), and depleted uranium. Leaching from firing table debris has resulted in tritium and depleted uranium contamination in subsurface soil and ground water. Nitrate and perchlorate are also COCs in ground water. Tritium is the only COC in surface water (Well 8 Spring).

Gravel was removed from the firing table in 1988 and placed in the Pit 7 Landfill. PCB-contaminated shrapnel and debris were removed from the area around the firing table in 1998. The Building 850 remedy consists of MNA, monitoring, and risk and hazard management. A remedial design was completed in 2004. The remedial design included the excavation and off-site disposal of contaminated surface soil and sand pile. This remedy was not implemented due to a large increase in transportation and offsite disposal costs. DOE and the regulatory agencies agreed to perform remediation of contaminated surface soil as a non-time critical removal action. An Engineering Evaluation/Cost Analysis (Dibley et al., 2008a) and Action Memorandum (Dibley et al., 2008b) were completed in 2008. A removal action was completed in 2010 for the excavation and solidification of PCB-, dioxin-, and furan-contaminated soil and sand pile. Metals, HMX, and uranium in surface soil at Building 850 do not pose a risk to human health or threat to ground water, therefore a no further action remedy was selected. However, these constituents in surface soil were removed during the soil excavation/solidification removal action.

Natural attenuation has reduced tritium activities from a historic maximum of 566,000 picoCuries per liter (pCi/L) in 1985 to 58,400 pCi/L (April 2010). Uranium activities are below the cleanup standard and are within the range of natural background levels. The extent of nitrate with concentrations above cleanup standards is limited and does not pose a threat to human health or the environment. The current maximum perchlorate concentration in this OU is 79 µg/L (February 2010), and a treatability study to evaluate *in situ* biodegradation of perchlorate is planned.

A Five-Year Review for this OU is scheduled for 2012.

1.5.2. Pit 7 Landfill Complex (OU 5)

The Pit 3, 4, 5, and 7 Landfills are collectively designated the Pit 7 Landfill Complex. Firing table debris containing tritium, depleted uranium, and metals was placed in the pits in the 1950s through the 1980s. The Pit 4 and 7 Landfills were capped in 1992. During years of

above-normal rainfall (i.e., 1997-1998 El Niño event), ground water rose into the bottom of the landfills and the underlying contaminated bedrock. This resulted in the release of tritium, uranium, VOCs, perchlorate, and nitrate to ground water. There are no COCs in surface water or surface soil. Tritium and depleted uranium are COCs in subsurface soil.

DOE and the regulatory agencies agreed that the Pit 7 Complex required additional study; accordingly, this area was not included in the 2002 Interim ROD and an area-specific Remedial Investigation/Feasibility Study (Taffet et al., 2005) was completed. An Amendment to the Interim ROD for the Pit 7 Complex was signed in 2007 (U.S. DOE, 2007) that described the selected remedy for the Pit 7 Complex including monitoring, risk and hazard management, MNA, ground water extraction and treatment, and source control. The interim remedial design and remedy implementation were completed in 2008. A hydraulic drainage diversion system was constructed to control contaminant sources by preventing ground water from rising into the pit waste and underlying contaminated bedrock. Also, a ground water extraction and treatment system was constructed to treat uranium, nitrate, perchlorate, and VOCs in ground water.

Natural attenuation has reduced tritium activities in ground water from a historic maximum of 2,660,000 pCi/L in 1998 to 255,000 pCi/L (January 2010) and has mitigated risk to onsite workers from inhalation of tritium vapors. Uranium activities have also decreased from a historic maximum of 781 pCi/L in 1998 to 120 pCi/L (April 2010). VOC concentrations are currently near or below cleanup standards. Nitrate concentrations in ground water remain relatively stable, while perchlorate concentrations have decreased.

A Five-Year Review for this OU is scheduled for 2012.

1.6. Building 854 (OU 6)

TCE was released to soil and ground water through leaks and discharges of heat-exchange fluid, primarily between 1967 and 1984. Nitrate and perchlorate are also COCs in ground water. HE compounds, PCBs, dioxins, furans, tritium, and metals were identified as COCs in surface soil. No further action was selected as the remedy for metals, HMX, and tritium in surface soil.

In 1983, TCE-contaminated soil was excavated at the northeast corner of Building 854F. Ground water extraction and treatment has been conducted since 1999 to reduce VOC, nitrate, and perchlorate concentrations in ground water. PCB-, dioxin-, and furan-contaminated soil in the Building 855 former rinsewater lagoon was excavated in 2005 (Holtzapple, 2005). The selected remedy for this OU includes monitoring, risk and hazard management, and ground water and soil vapor extraction and treatment. The interim remedial design was completed in 2003. Construction completion for the OU was achieved in September 2007. Three ground water extraction and treatment systems and one soil vapor extraction and treatment system currently operate in the OU.

Ground water remediation has reduced VOC concentrations from a historic maximum of 2,900 µg/L in 1997 to 97 µg/L (April 2010). Nitrate concentrations have decreased from a historic maximum of 260 milligrams per liter (mg/L) in 2003 to 180 mg/L (June 2010). Perchlorate concentrations in ground water have also decreased from 27 µg/L to 17 µg/L (June 2010). Risks to onsite workers from inhalation of VOC vapors and from exposure to PCBs, dioxins, and furans in surface soil have been mitigated.

A Five-Year Review of remediation in the Building 854 OU was completed in January 2009 (Dibley et al., 2009a).

1.7. OU 8

Operable Unit 8 includes the contaminant release sites that have a monitoring-only remedy: the Building 801 Dry Well and Pit 8 Landfill, Building 833, Building 845 and Pit 9 Landfill, the Building 851 Firing Table, and the Pit 2 Landfill. OU 8 release sites have a monitoring-only interim remedy because either: (1) contaminants in surface and subsurface soil/bedrock do not pose a risk to humans or plant and animal populations or a threat to ground water, (2) there is no ground water contamination, (3) contaminant concentrations in ground water do not exceed cleanup standards, and/or (4) the extent of contamination in ground water is limited. A Five-Year Review for this OU is scheduled for 2012. These release sites are summarized below.

1.7.1. Building 801 Dry Well and the Pit 8 Landfill (OU 8)

The Building 801 Firing Table was used for explosives testing and operations resulting in contamination of adjacent soil with metals and uranium. Use of this firing table was discontinued in 1998, and the firing table gravel and some underlying soil were removed. Waste fluid was discharged to a dry well (sump) located adjacent to Building 801D from the late 1950s to 1984. The dry well was decommissioned and filled with concrete in 1984. VOCs, perchlorate and nitrate are COCs in ground water due to the past releases from the Building 801 Dry Well. VOC and nitrate concentrations in ground water are currently near or below cleanup standards or at background levels. Perchlorate is not currently detected in ground water. VOCs are COCs in subsurface soil, but do not pose a risk to human health. The adjacent Pit 8 Landfill received debris from the Building 801 Firing Table until 1974, when it was covered with compacted soil. There is no evidence of contaminant releases from the landfill.

The selected remedy for this area includes monitoring and risk and hazard management. No Remedial Design documents are required for this area.

1.7.2. Building 833 (OU 8)

TCE was used as a heat-exchange fluid in the Building 833 area from 1959 to 1982 and was released through spills and rinsewater disposal, resulting in TCE-contamination of subsurface soil and shallow perched ground water. No contamination has been detected in the deeper regional aquifer. No COCs were identified surface soil at Building 833.

The selected remedy for Building 833 includes monitoring and risk and hazard management. No Remedial Design document is required for this area. Ground water monitoring at Building 833 has shown a decline in VOC concentrations from a historic maximum of 2,100 µg/L in 1992 to 110 µg/L (February 2010).

1.7.3. Building 845 Firing Table and the Pit 9 Landfill (OU 8)

The Building 845 Firing Table was used from 1958 until 1963 to conduct explosives experiments. Leaching from firing table debris resulted in minor contamination of subsurface soil with depleted uranium and HMX but no unacceptable risk to human or ecological receptors

or threat to ground water was identified. No contaminants have been detected in surface soil or in ground water at the Building 845 Firing Table. Debris generated at the Building 845 Firing Table was buried in the Pit 9 Landfill. There has been no evidence of contaminant releases from the Pit 9 Landfill.

The selected remedy for Building 845 and the Pit 9 Landfill includes monitoring and risk and hazard management. No Remedial Design documents are required for this area.

1.7.4. Building 851 Firing Table (OU 8)

The Building 851 Firing Table has been used for high-explosives research since 1962. VOCs and uranium-238 were identified as COCs in subsurface soil, and RDX, uranium-238, and metals as surface soil COCs. However, there is no risk to humans or animal populations, or threat to ground water associated with these contaminants in surface and subsurface soil. Uranium-238 was identified as a COC in ground water. However, it poses no risk to human or ecological receptors, and uranium activities are well below cleanup standards and within the range of background levels.

In 1988, the firing table gravel was removed and has been replaced periodically since then. The selected remedy for Building 851 includes monitoring and risk and hazard management. No Remedial Design document is required for this area.

1.7.5. Pit 2 Landfill (OU 8)

The Pit 2 Landfill was used from 1956 until 1960 to dispose of firing table debris from Buildings 801 and 802. Ground water data indicate a discharge of potable water to support a red-legged frog habitat located upgradient from the landfill may have leached depleted uranium from the buried waste. The frogs were relocated and the water discharge was discontinued, thereby removing the leaching mechanism. No contaminants were identified in surface or subsurface soil at the Pit 2 Landfill. No risk to human or ecological receptors has been identified at the Pit 2 Landfill.

The selected remedy for the Pit 2 Landfill includes monitoring and risk and hazard management. Monitoring data indicate that uranium activities remain below the cleanup standard. No Remedial Design document is required for this area.

1.8. Building 812 (OU 9)

The Building 812 Complex was built in the late 1950s-early 1960s and was used to conduct explosives tests and diagnostics until 2008. A Characterization Summary Report for this area was completed in 2005 (Ferry and Holtzapple, 2005). The Building 812 Complex was designated as OU 9 in March 2007 based on characterization results that indicated the presence of uranium, VOCs, HE compounds, nitrate, and perchlorate in environmental media. In 2008, a draft Remedial Investigation/Feasibility Study (RI/FS) describing the results of characterization activities and remedial alternatives for the Building 812 OU was submitted to the regulatory agencies. A DOE task force reviewed the soil washing alternative and determined that it would not be effective at Site 300, therefore a soil washing treatability study will not be performed. DOE is currently evaluating a new remedial strategy for contaminated soil at Building 812. Additional characterization is scheduled to begin in 2011. A new RI/FS will be prepared

following the completion of the characterization. A Proposed Plan will subsequently present the alternatives and a preferred remedy for public comment. A remedy will then be selected in an Amendment to the Site-Wide ROD.

1.9. Building 865/Advanced Test Accelerator

Building 865 facilities were used to conduct high-energy laser tests and diagnostics in support of national defense programs from 1980 to 1995. The Building 865 Complex housed a 275-foot linear electron accelerator called the Advanced Test Accelerator (ATA). The ATA was designed to produce a repetitively pulsed electron beam for charged particle beam research. In 2006, a Characterization Summary Report for this area was submitted to the regulatory agencies (Ferry and Holtzapple, 2006). Freon 113, Freon 11, and tetrachloroethene (PCE), were identified as COCs in ground water. The remediation pathway for Building 865 is currently being negotiated.

2. Site Chronology

A chronology of important environmental restoration events at the Building 832 Canyon OU is summarized below.

1950s–1960s

- The Building 830 and 832 Complexes were used to test the stability of weapon components under various environmental conditions.

1970s–1980s

- Testing at the Building 830 and 832 facilities was discontinued in 1985.

1990

- LLNL Site 300 was placed on the National Priorities List.

1992

- An Federal Facility Agreement for Site 300 was signed.

1996

- The Building 832 Canyon Study Area Fact Sheet (Ziagos and Sutherland, 1996) was issued. This Fact Sheet summarized the historical operations, use, and chemical releases in the OU, as well as plans for additional investigations.

1997

- The Building 832 Canyon Operable Unit Characterization Summary letter report was issued (Ziagos and Ko, 1997).

1999

- The Site-Wide Feasibility Study (Ferry et al., 1999) for Site 300 was issued that included the Building 832 Canyon OU.

- The Building 832-Source (832-SRC) ground water and soil vapor extraction and treatment facility began operating.

2000

- The Building 830-Proximal North (830-PRXN) ground water extraction and treatment facility began operating.
- The Building 830-Distal South (830-DISS) ground water extraction and treatment facility began operating.

2001

- An Interim Site-Wide ROD for Site 300 was signed. The Interim Site-Wide ROD specified no further action for: (1) HMX in surface soil and nitrate in subsurface soil and bedrock at Building 830, and (2) HMX and nitrate in soil and bedrock at Building 832. Soil vapor and ground water extraction and treatment, ground water monitoring, and administrative controls (i.e., risk and hazard management) were also selected as components of the remedy for the Building 832 Canyon OU.
- A Remedial Design Work Plan was issued that contained the strategic approach and schedule to implement the remedies in the Interim Site-Wide ROD (Ferry et al., 2001b).

2002

- The Compliance Monitoring Plan/Contingency Plan for Interim Remedies was issued (Ferry et al., 2002b).

2003

- The Building 830-Source (830-SRC) ground water and soil vapor extraction and treatment facility began operating.

2004

- A risk evaluation performed for the 2004 Annual Compliance Monitoring Report (Dibley et al., 2005a) indicated no further onsite worker risk from the inhalation of VOCs volatilizing from the subsurface into outdoor air in the vicinity of Building 830 and indoor air inside Building 832F.

2005

- The Building 832-Source ground water extraction wellfield was expanded into the downgradient portion of the contaminant plumes.
- Building 832F was decontaminated and demolished.

2006

- The Building 832 Canyon Interim Remedial Design Report was submitted to the regulatory agencies.
- Use of 830-PRXN treatment facility was discontinued. Additional extraction wells were connected to 830-SRC treatment facility and the 830-PRXN treatment unit was removed.

2007

- Modifications were performed on the 830-DISS to remove the bioreactor and granular activated carbon (GAC) components. A pipeline was built to the Central GSA ground water extraction and treatment system.
- Construction of the interim remedy was completed.

2008

- The EPA performed the OU construction completion inspection.
- The Site-Wide ROD with selected remedies and cleanup standards for Site 300, including the Building 832 Canyon OU, was signed. The remedy for the Building 832 Canyon OU did not change between the 2002 and 2008 Site-Wide ROD, with the exception that: (1) ground water cleanup standards were added in the 2008 Site-Wide ROD, and (2) the remedy for nitrate in ground water changed from extraction and treatment to monitored natural attenuation.

2009

- The revised Compliance Monitoring Plan/Contingency Plan for Interim Remedies was issued (Dibley et al., 2009b).
- Two 830-SRC ground water extraction wells were converted to monitor wells due to lack of water.

2010

- Modifications were performed on the 830-SRC treatment facility to allow high-flow extraction wells with perchlorate with concentrations below the 4 µg/L reporting limit to bypass the ion-exchange treatment columns. These modifications are expected to improve the long-term performance of the treatment facility.

3. Background

3.1. Physical Characteristics

3.1.1. Site Description

The Building 832 Canyon OU is located in a two mile-long, southeast-oriented canyon in the southeastern part of Site 300 (Figure 1). This 400-acre canyon is an ephemeral drainage that conveys surface runoff and shallow ground water into Corral Hollow Creek during heavy rainfall events. Starting in the late 1950s and early 1960s, facilities in the Building 830 and 832 areas were used to test the stability of weapon components under various environmental conditions. Testing at Building 830 and 832 facilities was discontinued in 1985.

The Building 830 Complex is a single building containing three test cells where experiments involving explosives chemicals and weapon components were conducted. When experiments ceased in 1985, the Building 830 Complex was used mainly for electrical equipment storage. The complex was returned to institutional control several years ago and is no longer in use.

The Building 832 Complex consists of eight buildings (Buildings 832 A-F and Buildings 831 and 838) where experiments were conducted. Since testing ceased in 1985, the Building 832 Complex has been used for storage of HE compounds, records storage and office space. HE is stored at Buildings 832B and D and in HE magazines 832-1 and 832-2. Building 832F was decontaminated and demolished in 2005.

The Building 832 Canyon OU includes the release sites at Buildings 830 and 832 and any associated contamination released to environmental media. The OU boundary is defined by the current extent of VOCs in ground water. As shown in Figure 1, the OU boundary is currently approximately 4,000 ft long and extends from the tributary canyon that contains the Building 832 Complex to the site boundary. The Building 830 Complex is located about midway between the Building 832 Complex and the site boundary. Three ground water and two soil vapor extraction and treatment systems are currently in place and operating to remediate VOC and perchlorate in ground water. Ground water is monitored for VOCs, nitrate, and perchlorate in eighty-two wells to evaluate the progress of remediation. The locations of existing monitor, extraction and water-supply wells and treatment facilities are shown on Figure 2.

3.1.2. Hydrogeologic Setting

This section describes the general hydrogeologic setting for the Building 832 Canyon OU including the unsaturated zone, the hydrostratigraphic units (HSUs) underlying the area, and surface water in the OU. A conceptual hydrostratigraphic column for the southeastern portion of Site 300 including the Building 832 Canyon area is shown on Figure 3. A hydrogeologic cross-section showing the vertical distribution of total VOCs in Building 832 Canyon is shown on Figure 4.

3.1.2.1. Vadose (Unsaturated) Zone

A seasonally variable unsaturated zone exists in the Building 832 Canyon OU. Quaternary alluvial sand and gravel and the underlying weathered bedrock within the canyon and tributary surface water drainages are generally dry in the summer months and during periods of drought. A 20- to 30-foot thick sandstone ($Tnsc_{1b}$) within the $Tnsc_1$ claystone/siltstone is variably saturated beneath the Building 832 and 830 source areas.

3.1.2.2. Saturated Zone

The HSUs in the Building 832 Canyon OU are described below.

Qal/WBR HSU – The Quaternary alluvium/weathered bedrock (Qal/WBR) HSU is comprised of alluvial sands and gravels and the underlying weathered Neroly bedrock within the canyon and tributary surface water drainages. In addition to the natural alluvial material, the Building 832 and Building 830 tributary canyons contain several feet of artificial fill underneath building foundations. This artificial fill is a heterogeneous mixture of sand, gravel, and native soil. It is generally of low permeability and is difficult to distinguish from the underlying natural alluvium. The Qal/WBR HSU typically contains ground water only after significant rainfall events and is highly responsive to seasonal rainfall. This response is typical of shallow alluvial water-bearing zones at Site 300 that transmit ground water following intense rainfall events, but are generally dry during summer months and during extended drought periods. When saturated

conditions exist, ground water in the Qal/WBR HSU flows in the down-canyon direction (generally southeast) where it eventually discharges into the alluvium that lies beneath Corral Hollow Creek. Due to the intersection of the $Tnsc_{1b}$ HSU water table with the canyon bottom, discharge from the $Tnsc_{1b}$ HSU may also contribute to flow the Qal/WBR HSU near Spring 3 and, as shown on Figure 4, where the $Tnsc_{1b}$ HSU intersects the canyon bottom south of monitor well W-830-25. A ground water elevation map for the Qal/WBR HSU is presented as Figure 5.

$Tnsc_{1b}$ HSU – The $Tnsc_{1b}$ HSU is a 20- to 30-foot thick, medium-grained sandstone that occurs within the Tertiary Neroly middle siltstone/claystone ($Tnsc_1$). The $Tnsc_{1b}$ HSU is laterally continuous over the southeast part of Site 300. Although this zone is widespread, its hydraulic properties are spatially variable. For example, $Tnsc_{1b}$ extraction wells in the Buildings 830 and 832 source areas exhibit such low yield that they cannot sustain continuous flow, while other wells screened in this HSU sustain long-term flow under natural artesian pressure at a rate of a few gallons per minute (gpm). The low-yield wells are generally located near the limit of saturation and extraction rates are limited by the available recharge from tributary canyons. The $Tnsc_{1b}$ HSU beneath these tributary canyons is difficult to distinguish from the weathered bedrock and artificial fill that exists beneath the buildings in these areas. The saturated thickness of the $Tnsc_{1b}$ HSU ranges from 0 to 30 ft. Depth to ground water in this HSU ranges from 15 to over 100 ft below ground surface (bgs). Ground water flows to the south-southeast. A potentiometric surface map for the $Tnsc_{1b}$ HSU is presented as Figure 6.

$Tnsc_{1a}$ HSU – The $Tnsc_{1a}$ HSU is a 20- to 30-foot thick, fine-grained siltstone/claystone that occurs within the $Tnsc_1$ siltstone/claystone. Although the $Tnsc_{1a}$ HSU is laterally continuous over the southeast part of Site 300, its hydraulic properties are spatially variable. For example, $Tnsc_{1a}$ extraction well W-832-25 (located south of the Building 832 source area) exhibits such low yield that it cannot sustain continuous flow, while other wells screened in this HSU (monitor well W-830-2311, for example) can sustain long-term flow at a rate of a few gpm. The low-yield wells are generally located near the limit of saturation and yield is limited by the available recharge from tributary canyons. Because of the fine-grained nature of this HSU, hydraulic conductivity is primarily associated with interconnected fracture zones. These zones have been identified during drilling using geophysical methods such as optical televiewer (OTV) and caliper logs.

A map showing ground water elevation data for the $Tnsc_{1a}$ HSU is presented as Figure 7. Ground water flows to the south-southeast. The saturated thickness of the $Tnsc_{1a}$ HSU ranges from 0 to 30 ft. Depth to ground water in this HSU ranges from 15 to over 100 ft bgs. Due to a limited number of wells, the data are posted rather than contoured. Ground water occurs under unconfined to confined conditions, and flowing artesian conditions may be encountered.

At present, eight wells are screened in the $Tnsc_{1a}$ HSU, including new monitor well W-830-2311 and new guard well W-830-2610. Guard well W-830-2610 was installed during 2010 and is located near the Site 300 boundary (Figure 2). Based on preliminary sampling results, no TCE has been detected above the reporting limit in ground water from this well. The well will be sampled regularly after final well development and baseline sampling are complete.

$Tnbs_1$ HSUs – The Tertiary Neroly lower blue sandstone ($Tnbs_1$) HSUs consist of Neroly Formation sandstones interbedded with siltstones and claystones that are present throughout the Building 832 Canyon OU. There are two water-bearing zones within the $Tnbs_1$ stratigraphic unit, separated by a 10-ft thick claystone marker bed (CMB). Ground water occurs under

unconfined to confined conditions and flowing artesian conditions may be encountered in the upper and lower $Tnbs_1$ HSUs. In some wells, the artesian head is 10 to 15 ft above the ground surface. The saturated thickness of the upper $Tnbs_1$ ($UTnbs_1$) HSU ranges from 0 to 60 ft. depth to ground water in the $UTnbs_1$ HSU ranges from 60 to 280 ft bgs. The saturated thickness of the lower $Tnbs_1$ HSU is not known because this unit has never been fully penetrated. The depth to ground water in lower $Tnbs_1$ ranges from approximately 100 to 350 ft bgs. Ground water in the $UTnbs_1$ HSU generally flows to the southeast (Figure 8). The upper and lower $Tnbs_1$ HSUs are recharged in the upper reaches for Building 832 Canyon northwest of the Building 832 source area. Some of the ground water from the $Tnbs_1$ HSUs ultimately discharges into the Corral Hollow Creek alluvium in the Central GSA where these bedrock zones subcrop beneath the alluvium. Compared to the Qal/WBR HSU, the $Tnbs_1$ HSU exhibits lower magnitude, delayed responses to rainfall events.

3.1.2.3. Surface Water

Short-term surface water flows occur in the Building 832 Canyon OU drainages during or after significant rainfall events. Minor amounts of surface water are also present in Spring 3 near the southern end of the canyon (Figure 2). Discharge rates from this ephemeral spring are too low to measure and standing surface water is rarely observed. However, flow can be sufficient to moisten the soil and support vegetation in the vicinity of the spring. A vertical standpipe has been installed within the spring area from which samples can be collected. Surface water at Spring 3 likely originates from where the $Tnsc_{1b}$ HSU intersects the Building 832 Canyon bottom, and discharges into the Qal/WBR HSU (Figure 4). Spring 4 is located on the west canyon wall of Building 832 Canyon south of Building 832. Ground water from the Tps HSU (see Section 1.4 HE Process Area) feeds this spring. Due to the location of the spring on the canyon wall, surface water does not collect in Spring 4. However, flow can be sufficient to moisten the soil and support vegetation in the vicinity of the spring.

3.2. Land and Resource Use

Prior to the establishment of Site 300 as remote testing facility in 1955, the area was used for livestock grazing. Site 300 is currently an operating facility, and will remain under DOE control for the foreseeable future. Less than five percent of Site 300's 7000-acre property-area is developed. There have been no changes in land or ground water use in the Building 832 Canyon OU since the Site-Wide ROD was signed in 2008 and, other than the changes in onsite water supply uses documented below, none are anticipated.

The Building 832 OU is accessible only to DOE/LLNL workers. Buildings located near the 832 source area are used for high explosives storage, records storage, and office space. Buildings located near the Building 830 source area are no longer used.

The Building 832 OU extends to the southeastern site boundary. Land use adjacent to the site boundary closest to the Building 832 Canyon OU consists of private rangeland: Gallo and Connolly Ranches that are located south of Site 300, Fireworks America, a private firm that operates a fireworks storage facility adjacent to the eastern border of Site 300, and the Carnegie State Vehicular Recreation Area (SVRA), located southwest of Site 300. The nearest major population center (Tracy, California) is 8.5 miles to the northeast. There is no known planned

modification or proposed development of the offsite rangeland closest to the OU. The SVRA continues to expand its infrastructure to accommodate increased public usage.

Several offsite private water-supply wells near the southern boundary of the Building 832 Canyon OU and Site 300 supply water for domestic and agricultural uses to neighboring ranches. Currently, onsite Wells 18 and 20 (Figure 2) are the water-supply sources for Site 300, although bottled water is the primary source for onsite drinking water. Site 300 is currently scheduled to transition to Hetch Hetchy water as its primary onsite water supply in 2011. Well 20 will be used as a backup water supply and Well 18 will be used even less frequently. Eventually, Well 18 will be sealed and abandoned. Following this transition to Hetch Hetchy water, the decrease in onsite water-supply well pumping may result in increases in ground water levels in the $Tnsc_1$ and $Tnbs_1$ HSUs. Some wells located near the Site 300 boundary may also become artesian. The increased regional water levels could have some positive impacts on Building 832 Canyon OU remediation. Higher ground water levels in the $Tnsc_{1b}$ HSU may increase extraction well flow and mass removal rates. Lower pumping rates at water-supply wells 18 and 20 may decrease the potential for downgradient migration of contaminants. Surface water at Site 300 is not consumed by humans.

Site 300 has unique environmental qualities, largely because it has not been grazed for over 50 years and contains several habitat types and numerous special status species (e.g., threatened and endangered species, migratory birds, and rare plants). Annual grasslands cover the majority of the Building 832 Canyon OU, with isolated patches of coastal sage scrub. Wetlands are found in association with Springs 3 and 4. Special status species found within the Building 832 Canyon OU include the Big Tarplant (*Blepharizonia plumosa*), an extremely rare late-season flowering plant included on the California Native Plant Society's List 1B. The entire OU resides within the upland habitat for the threatened California tiger salamander (*Ambystoma californiense*). The wetlands associated with Springs 3 and 4 provide breeding habitat for the threatened California red-legged frog (*Rana aurora draytonii*), and the entire OU resides within the upland dispersal habitat for this species. Loggerhead shrikes (*Lanius ludovicianus*), a California Species of Special Concern, are often observed in the Building 832 Canyon OU, and nesting has also been observed within the OU. A five-year ecological review reported on in the 2008 Annual Compliance Monitoring Report, which updated the assessment of the ecological impacts from Site 300 contaminants, found no impact to ecological receptors from releases within the Building 832 Canyon OU. The LLNL biologist reviewed ecological data collected between 2008 and 2011 for the Building 832 Canyon OU area to evaluate whether any changes in contaminant or ecological conditions that could impact ecological receptors. No changes were identified. Access to these unique animal and plant populations is controlled and interactions with the wildlife are avoided.

3.3. History of Contamination

TCE was used as a heat-exchange fluid as part of testing activities at Buildings 830 and 832. TCE and other VOCs were released to soil, bedrock, and ground water as a result of piping leaks and surface spills. Rinsewater containing HE compounds was disposed via floor drains in Building 832 leading to a surface discharge outside the building. As a result, HMX has been detected in soil and bedrock. However, no HE compounds have been detected in ground water. Nitrate in ground water in the OU is believed to be the result of a combination of HE-related

testing, some septic system releases, and natural sources. Although rinsewater containing HE compounds was likely discharged to a small disposal lagoon near Building 830, no HE compounds have been detected in any media in this area. However, the HE compounds released may have degraded and migrated downward as nitrogenous compounds. The source of perchlorate in Building 832 Canyon OU ground water is not known, but it is suspected that it was a component of HE test assemblies.

3.4. Initial Response

DOE/LLNL began environmental investigations in the Building 832 Canyon OU in the early 1980s to identify contaminant source areas and the distribution of contaminants in the soil, bedrock, and ground water. Since then, 82 boreholes have been drilled in the Building 832 Canyon OU; 65 of these boreholes have been completed as ground water monitor wells and 17 have been completed as extraction wells (ten ground water extraction wells, four dual-phase (soil vapor and ground water) extraction wells, and three passive artesian extraction wells) (Figure 2). Seven inactive extraction wells are also connected to the 832-SRC treatment facility, but these wells have not been used since 2003 due to lack of water. During 2009, two 830-SRC extraction wells (W-830-1929 and W-830-2213) were converted to monitor wells due to dry conditions.

The geologic and chemical data from these wells and boreholes have been used to characterize the site hydrogeology and to monitor temporal and spatial changes in saturation and dissolved contaminants. Site characterization also included surface soil sampling, soil vapor flux chamber measurements, soil vapor surveys, hydraulic testing, and soil vapor extraction testing.

As summarized in Section 2, remediation activities at the Building 832 Canyon OU conducted prior to the Interim Site-Wide ROD included extraction and treatment of contaminated ground water at the Building 832 source area, immediately downgradient of the Building 830 source area, and near the Site 300 boundary.

3.5. Contaminants of Concern

COCs in Building 832 Canyon OU ground water include: (1) VOCs (primarily TCE, but also including PCE, cis-1,2 DCE, and chloroform), (2) nitrate, and (3) perchlorate. HMX has been identified as a COC in surface soil in Building 832 Canyon OU. VOCs, HMX, and nitrate are COCs in subsurface soil and bedrock. VOCs are the primary COCs identified in surface water at Spring 3. Nitrate has also been detected in samples collected from Spring 3 at concentrations above the 45 mg/L Maximum Contaminant Level (MCL).

VOCs, primarily TCE (a suspected human carcinogen), are present in subsurface soil and rock, in surface water at Spring 3, and in ground water. An unacceptable baseline excess cancer risk (greater than 10^{-6}) was calculated for VOCs in the following environmental media in the Building 832 Canyon OU:

- Inhalation risk of 3×10^{-6} for onsite workers inside Building 830.
- Inhalation risk of 1×10^{-5} for onsite workers outside of Building 830.
- Inhalation risk of 3×10^{-6} for onsite workers inside Building 832.
- Inhalation risk of 7×10^{-5} for onsite workers in ambient air in the vicinity of Spring 3.

The HE compound HMX is a human carcinogen present in surface soil and subsurface soil and rock in the Building 832 Canyon. No risk or hazard associated with HMX in surface soil or subsurface soil/rock in the Building 832 Canyon OU has been identified.

Elevated nitrate is present in ground water as a result of a combination of natural and anthropogenic sources in the Building 832 Canyon OU. In addition to natural soil nitrate and septic system discharges, discharge of rinsewater containing nitrogenous HE-compounds to the ground surface occurred at Building 832 and possibly at small disposal lagoons or dry wells located near Building 830. Nitrate can cause non-carcinogenic health effects if ingested at elevated levels. No human health risk has been associated with nitrate in subsurface soil/rock or ground water in the Building 832 Canyon OU.

In the Building 832 Canyon OU, VOCs, perchlorate, and nitrate contamination are present in ground water in the Qal/WBR and $Tnsc_{1b}$ HSUs. In the $Tnsc_{1a}$ HSU, ground water is primarily contaminated with VOCs, and, to a lesser degree, perchlorate. Ground water in the $UTnbs_1$ HSU is primarily contaminated with VOCs, although perchlorate above 6 µg/L cleanup standard has been detected in the past.

In general, the highest concentrations of contaminants have been detected in or immediately downgradient of the Buildings 830 and 832 source areas. Total VOC concentrations in ground water in the Qal/WBR, $Tnsc_{1b}$, $Tnsc_{1a}$ and the $UTnbs_1$ HSUs are shown on Figures 9 through 12, respectively. Perchlorate concentrations in Qal/WBR, $Tnsc_{1b}$, $Tnsc_{1a}$ and the $UTnbs_1$ HSUs are shown on Figures 13 through 16, respectively. Nitrate concentrations in Qal/WBR, $Tnsc_{1b}$, $Tnsc_{1a}$ and the $UTnbs_1$ HSUs are shown on Figures 17 through 20, respectively. The highest VOC and nitrate concentrations are located in the Building 830 source area. The highest perchlorate concentrations are located in the Building 832 source area.

As shown on Figure 9, very low (<1 µg/L) concentrations of VOCs have been sporadically detected in guard wells screened in the Qal/WBR HSU. In guard well W-880-02, the only contaminant detected in groundwater during the past five years was PCE. In guard well W-35B-01, the only contaminant detected in groundwater during the past five years was 1,1-DCE. The source of these contaminants is unknown. DOE will continue to monitor VOCs in these Qal/WBR guard wells and if necessary, an additional guard well will be installed downgradient of guard well W-35B-01.

In the $Tnsc_{1b}$ HSU, the leading edge of the VOC plume is located near the southern boundary of Site 300 (Figure 10); $Tnsc_{1b}$ guard wells located in this area are uncontaminated. In both the Qal/WBR HSU and $Tnsc_{1b}$ HSUs, maximum VOC concentrations occur in the vicinity of Building 830. In the $Tnsc_{1a}$ HSU (Figure 11), VOCs are found in the 830-SRC area and downgradient of the 832-SRC and 830-SRC areas. In the $UTnbs_1$ HSU, maximum VOC concentrations occur in the vicinity of Building 830 (Figure 12). The distribution of perchlorate and nitrate in ground water collected in Qal/WBR, $Tnsc_{1a}$, and $Tnsc_{1b}$ HSUs does not extent beyond the limits of the VOC plumes. No COCs have been detected in ground water in the lower $Tnbs_1$ HSU.

A hydrogeologic cross-section showing the vertical distribution of total VOCs in Building 832 Canyon is shown on Figure 4. The cross-section shows the location of guard well W-830-2610, which was installed during 2010 to monitor the $Tnsc_{1a}$ HSU near the site boundary. Preliminary ground water samples collected from this well have not contained VOCs above the

reporting limit. The well will be sampled regularly after final well development and baseline sampling are completed.

Wells installed during the past five years, including guard well W-830-2610, are shown on Figure 2 and are discussed in Section 6.5.2.

3.6. Summary of Basis for Taking Action

Remedial actions were initiated in the Building 832 Canyon OU to address: (1) unacceptable human health risks associated with onsite worker inhalation exposure to VOCs volatilizing from subsurface soil into indoor air inside Building 830 and outdoor air in the vicinity of Building 830 and Building 832A, (2) an unacceptable human health risk was associated with onsite worker inhalation exposure to VOCs volatilizing from surface water in the vicinity of Spring 3, and (3) VOCs, nitrate, and perchlorate present in ground water at concentrations exceeding cleanup standards.

4. Remedial Actions

4.1. Remedy Selection

The remedy selected for the Building 832 Canyon OU is intended to achieve the following Remedial Action Objectives (RAOs):

For Human Health Protection:

- Restore ground water containing VOC, nitrate, and perchlorate concentrations above cleanup standards.
- Prevent human ingestion of ground water containing VOC, nitrate, and perchlorate concentrations (single carcinogen) above cleanup standards.
- Prevent human inhalation of VOCs volatilizing from subsurface soil to air that pose an excess cancer risk greater than 10^{-6} or hazard index greater than 1, a cumulative excess cancer risk (all carcinogens) in excess of 10^{-4}, or a cumulative hazard index (all noncarcinogens) greater than 1.
- Prevent human inhalation of VOCs volatilizing from surface water to air that pose an excess cancer risk greater than 10^{-6} or hazard index greater than 1, a cumulative excess cancer risk (all carcinogens) in excess of 10^{-4}, or a cumulative hazard index (all noncarcinogens) greater than 1.
- Prevent human exposure to contaminants in media of concern that pose a cumulative excess cancer risk (all carcinogens) greater than 10^{-4} and/or a cumulative hazard index greater than one (all noncarcinogens).

For Environmental Protection:

- Restore water quality to ground water cleanup standards within a reasonable timeframe and to prevent plume migration to the extent technically and economically practicable. Maintain existing water quality that complies with ground water cleanup standards to the

extent technically and economically practicable. This will apply to both individual and multiple constituents that have additive toxicology or carcinogenic effects.

- Ensure ecological receptors important at the individual level of ecological organization (listed threatened or endangered, State of California species of special concern) do not reside in areas where relevant hazard indices exceed 1.
- Ensure existing contaminant conditions do not change so as to threaten wildlife populations and vegetation communities.

An RAO for human health protection/applicable or relevant and appropriate requirements (ARARs) compliance for ingestion of surface waters (i.e., water from Site 300 springs) was not developed because there is not a complete exposure pathway for ingestion of surface waters for humans at Site 300. Humans do not drink water from Site 300 springs. In addition, the springs in which contaminants are detected do not produce a sufficient quantity of water to be used as a water supply (more than 200 gallons per day).

In the 2001 Interim Site-Wide ROD, an interim remedy for the Building 832 Canyon OU was selected based on its ability to contain contaminant sources, prevent further plume migration, remove contaminant mass from the subsurface, and protect human health and the environment.

The selected remedy for the Building 832 Canyon OU consisted of:

1. No Further Action for HE compounds in surface soil and nitrate in subsurface soil/bedrock at Building 830, and for HE compounds in subsurface soil/rock at Building 832.
2. Monitoring ground water to evaluate the effectiveness of the remedy in achieving cleanup standards, and to ensure there is no impact to downgradient water-supply wells.
3. Risk and hazard management to prevent onsite worker exposure to VOCs volatilizing from subsurface soil into indoor air at Building 830 and from surface water at Spring 3 until risk and hazard is mitigated through active remediation. Annual risk re-evaluation indicates that the inhalation risk for VOCs volatilizing from subsurface soil into outdoor air near Building 830 and to indoor air at Building 832F has been mitigated through remediation. Therefore, risk and hazard management for this exposure pathway is no longer necessary. These risk re-evaluation results are documented in the 2006 Annual Compliance Monitoring Report for LLNL Site 300 (Dibley et al., 2007). Institutional/land use controls will be implemented to prevent human exposure to contamination and to protect the integrity of the remedy.
4. Extracting and treating VOCs in soil vapor and ground water, and perchlorate, and nitrate in ground water to mitigate unacceptable VOC inhalation risk for onsite workers, prevent further impacts to ground water and offsite plume migration, and reduce contaminant concentrations in soil and ground water to cleanup standards.
5. MNA of nitrate in ground water.

4.2. Remedy Implementation

Three ground water extraction and treatment systems (GWTSs) and two soil vapor extraction and treatment systems (SVTS) are currently being operated in the Building 832 Canyon OU:

Building 832-Source (832-SRC), Building 830-Source (830-SRC), and Building 830-Distal South (830-DISS). The 832-SRC and 830-SRC facilities extract and treat both ground water and soil vapor, while the 830-DISS facility extracts and treats ground water only.

A map of Building 832 Canyon OU showing the location of monitor and extraction wells and treatment facilities is presented on Figure 2. The location of former treatment facility 830-PRXN is also shown on Figure 2.

The 832-SRC GWTS removes VOCs and perchlorate from ground water and the SVTS removes VOCs from soil vapor. The GWTS and SVTS began operation in September and October 1999, respectively. Initially, ground water was extracted from nine dual-extraction wells (W-832-12, -13, -14, -15, -16, -17, -18, -20, and -22) at a combined total flow rate that initially ranged from 30 to 300 gallons per day (gpd). The total flow eventually dropped to 5 to 50 gpd due to lowering of the water table by dewatering and lack of rainfall. In early 2005, it was observed that nearly all the ground water yield was attributable to Qal/WBR-$Tnsc_{1b}$ HSU extraction wells W-832-12 and W-832-15. Therefore, the source area extraction wellfield was reduced to two wells (W-832-12 and W-832-15) operating with vacuum enhancement and a combined flow rate ranging from 60 to 220 gpd. The increase in flow rate in these two wells may be a result of differing hydrologic conditions or the vacuum enhancement. Although no ground water is currently being extracted from wells W-832-13, -14, -16, -17, -18, -20, and -22, these wells are sampled whenever ground water is present.

In late 2005, the extraction wellfield was expanded to include three additional $Tnsc_{1b}$ downgradient wells (W-832-01, W-832-10, and W-832-11). As a result, the combined flow rate increased to about 1,300 gpd, and VOC concentrations in 832-SRC facility influent increased four-fold. $Tnsc_{1a}$ well W-832-25 was connected to 832-SRC in July 2006. Currently, ground water is extracted from wells W-832-01, W-832-10, W-832-11, W-832-12, W-832-15 and W-832-25 at an approximate combined flow rate of 0.1 to 1 gpm. Soil vapor is extracted from wells W-832-12 and W-832-15 at an approximate combined flow rate of approximately 3 to 4.4 standard cubic feet per minute (scfm). The current GWTS configuration includes a Cuno filter for particulate filtration, two ion-exchange columns with SR-7 resin connected in series to remove perchlorate, and three aqueous-phase GAC units (also connected in series) to remove VOCs. Nitrate-bearing treated effluent is then discharged via a misting tower over the landscape for uptake and utilization of the nitrate by indigenous grasses. A positive displacement rotary lobe blower is used to create a vacuum at selected wellheads through a system of piping manifolds. The contaminated vapors are treated using three vapor-phase GAC units connected in series. Treated soil vapors are then discharged to the atmosphere under a permit from the San Joaquin Valley Unified Air Pollution Control District.

The 830-SRC GWTS removes VOCs and perchlorate from ground water and the SVTS removes VOCs from soil vapor. The GWTS and SVTS began operation in February and May 2003, respectively. Ground water was extracted from three wells at a total flow rate ranging from 5 to 100 gpd. These wells included one Qal/WBR-$Tnsc_1$ well W-830-1807, and two $Tnsc_{1b}$ wells W-830-19 and W-830-59. The 830-SRC extraction wellfield was expanded in 2006 to include seven additional GWTS extraction wells: $Tnsc_{1b}$ wells W-830-49, W-830-1829, W-830-2213; $Tnsc_{1a}$ well W-830-2214; and Upper $Tnbs_1$ wells W-830-57, W-830-60, and W-830-2215. The expansion well testing began in 2006. The tests were completed and the expanded wellfield was in full operation during the first semester 2007. During the second

semester 2009, wells W-830-1829 and W-830-2213 were converted back to monitor wells due to lack of water. In early 2010, extracted ground water from higher flow extraction wells W-830-2215, W-830-60, W-830-57, that did not contain perchlorate at concentrations above the 4 µg/L reporting limit, were routed around the 830-SRC ion-exchange canisters. This bypass improved the capability of 830-SRC to extract and treat ground water by decreasing backpressure and is expected to increase ground water flow and mass removal rates from the 830-SRC UTnbs$_1$ extraction wells. Ground water extracted from low-flow Tnsc$_{1a}$ well W-830-2214 still contains perchlorate above the discharge limit; this well does not bypass the perchlorate treatment system.

As modified, the 830-SRC GWTS is currently extracting ground water at a combined flow rate of approximately 5 to 7 gpm. The GWTS configuration includes a Cuno filter for particulate filtration, two ion-exchange columns with SR-7 resin connected in series to remove perchlorate, and three in series aqueous-phase GAC units to remove VOCs in series. Nitrate-bearing treated effluent is then discharged via a misting tower over the landscape for uptake and utilization of the nitrate by indigenous grasses. The 830-SRC soil vapor extraction wellfield was also expanded to include well Tnsc$_{1b}$ W-830-49 in 2006. Soil vapor is extracted from Qal/WBR-Tnsc$_{1b}$ well W-830-1807 and Tnsc$_{1b}$ well W-830-49 using a liquid ring vacuum pump at a current combined flow rate of approximately 30 to 33 scfm. The contaminated vapors are treated using three vapor-phase GAC units connected in series. Treated soil vapors are then discharged to the atmosphere under a permit from the San Joaquin Valley Unified Air Pollution Control District.

The 830-DISS GWTS began operation in July 2000 and removes VOCs, perchlorate, and nitrate from ground water. Approximately 1 to 2 gpm of ground water is extracted from three Tnsc$_{1b}$ wells (W-830-51, W-830-52, and W-830-53) using natural artesian pressure. The GWTS configuration consisted of a Cuno filter for particulate filtration, two aqueous-phase GAC units in series to remove VOCs, two in-series ion-exchange columns with SR-7 resin to remove perchlorate, and three bioreactor units for nitrate reduction. These units were open-container wetland bioreactors containing microorganisms that use nitrate during cellular respiration. Acetic acid was added to the process stream as a carbon source. Treatment system effluent was discharged via a storm drain that discharges to the Corral Hollow alluvium. At the request of the RWQCB, the facility was modified during the first semester 2007 to cease discharge of treated water to a surface water drainage way. The modification included the addition of a fourth well, W-830-2216, to the extraction wellfield. The GWTS is now extracting ground water at a combined flow rate of approximately 2 to 3 gpm. Currently, extracted ground water flows through ion-exchange canisters to remove perchlorate at the 830-DISS location. The water is piped to the Central GSA GWTS for VOC removal. Nitrate-bearing treated effluent is then discharged via a misting tower over the landscape for uptake and utilization of the nitrate by indigenous grasses.

A fourth GWTS, Building 830-Proximal North (830-PRXN) operated in the OU from October 2000 until April 2006. Ground water was extracted from extraction well W-830-57 using a solar-powered ground water treatment unit at approximately 300 gallons per day. The ground water was treated using three aqueous-phase GAC units connected in series to remove VOCs. The effluent was discharged to the shallow subsurface via a French drain in a disposal trench. The 830-PRXN extraction well, W-830-57 was connected to 830-SRC as part of the 830-SRC expansion performed in 2006.

4.3. System Operations/Operation and Maintenance

In general, the Building 832 Canyon OU extraction and treatment systems are operating as designed and no significant operations, performance, maintenance, or cost issues were identified during this review. All required documentation is in place, and treatment system operation and maintenance (O&M) activities are consistent with established procedures and protocols.

O&M procedures for the Building 832 Canyon treatment systems are contained in the following documents:

- Health and Safety Plan and Quality Assurance/Quality Control Plan for the O&M of the Building 832 Canyon Treatment Facilities, contained within the Interim Remedial Design report.
- Operations and Maintenance Manual for Miniature Treatment Units, Ground Water Treatment Units, and Solar Treatment Units, Volume 13 (Martins, 2007).
- Operations and Maintenance Manual, Volume 1: Treatment Facility Quality Assurance and Documentation (LLNL, 2004).
- Integration Work Sheet Safety Procedure #11341: Ground Water and Soil Vapor Treatment Facility Operations at Site 300.
- Integration Work Sheet Safety Procedure #11314: Environmental Restoration Department (ERD) Site 300 Ion Exchange Resin Replacement (if resin is used at the facility).
- Integration Work Sheet Safety Procedure #11313: ERD Site 300 Off-Road Driving Training.
- Integration Work Sheet Safety Procedure #11343: ERD Routine Ground Water Sampling & Water Level Monitoring at Site 300.
- Integration Work Sheet Safety Procedure #14984: ERD Routine Electronic Operations at Site 300.
- Integration Work Sheet Safety Procedure #11339: ERD Site 300 Hydraulic Pump Operation.
- Integration Work Sheet Safety Procedure #11346: Spent Aqueous and Vapor-phase Granular Activated Carbon (GAC) Replacement at Site 300.
- Building 832 Canyon and Building 854 OU Substantive Requirements and the Monitoring and Reporting Program issued by the California RWQCB.
- Site-Wide Compliance Monitoring Plan/Contingency Plan for Interim Remedies at LLNL Site 300 (Ferry et al., 2002) until superseded by the Site-Wide Compliance Monitoring Plan/Contingency Plan for Remedies at LLNL Site 300 (Dibley et al., 2009).
- LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures (Goodrich and Lorega, 2009).

Monitoring and optimizing the performance and efficiency of the extraction and treatment systems comprises a large portion of the O&M activities. Extracted ground water is sampled

throughout the treatment process to ensure compliance with discharge requirements. Treatment system parameters such as pressure and flow are routinely recorded to anticipate potential mechanical problems and monitor system performance.

The major O&M activities for the Building 832 Canyon treatment systems include:

- Maintaining the particulate filters.
- Maintaining the misting towers used to discharge treated ground water.
- Protecting the units from freezing in cold weather.
- Replacing spent GAC and resin.
- Routinely inspecting and maintaining extraction well pumps, pipelines, and flow meters.

The budgeted and actual environmental restoration costs for the Building 832 Canyon OU are tracked closely and are generally within the allocated budget, except when extra costs were incurred to address unanticipated problems or regulatory requests. Table 1 presents the actual costs for the last five fiscal years, 2006 through 2010.

4.4 Institutional Controls

Institutional/land use controls are non-engineered actions or measures used to prevent or limit the potential for human exposure to contamination at the Building 832 Canyon OU and to protect the integrity of the remedy. The general types of institutional/land use controls that are used to prevent human exposure to contamination at the Building 832 Canyon OU include:

- Access controls – Measures such as fences, signs, and security forces that are used to prevent exposure by controlling and/or restricting access to areas of contamination.
- Administrative controls – Measures such as pre-construction review and controls for limiting or restricting access to contaminated areas and prohibitions on water-supply well drilling.

Table 2 presents descriptions of: (1) the institutional/land use control objective and duration, (2) the risk necessitating land use controls, and (3) the specific institutional/land use controls and implementation mechanisms used to prevent exposure to contamination at the Building 832 Canyon OU. Figure 21 shows the specific areas of the Building 832 Canyon OU where the institutional/land use controls have been maintained or implemented.

Monitoring and inspection of the Building 832 Canyon OU will continue to be performed throughout the remediation period to determine whether the institutional/land use controls remain protective and consistent with all remedial action objectives. In addition, DOE will continue to review facility and land use to evaluate changes in exposure pathway conditions that could affect the risk assessment assumptions and calculations.

Institutional/land use controls are included in the Risk and Hazard Management Program contained in the Site-Wide Compliance Monitoring Plan. Any new or modified institutional/land use controls resulting from the Five-Year Review process will be incorporated in the Risk and Hazard Management Program contained in the Site-Wide Compliance Monitoring Plan. Risk and hazard monitoring results conducted during the year are submitted to the EPA and State regulatory agencies in the Annual Site 300 Site-Wide Compliance Monitoring Reports. In

addition, DOE will work with LLNL Site 300 Management to incorporate these institutional/land use controls into the Site 300 Integrated Strategic Plan or other appropriate institutional planning documents.

The land use controls and requirements described herein are only applicable to the Building 832 Canyon OU and associated contaminated environmental media that are being addressed through the CERCLA process. DOE will continue to maintain and enforce these institutional/land use controls at the Building 832 Canyon OU for as long as necessary to protect human health and the environment.

If DOE later transfers these procedural responsibilities to another party by contract, property transfer agreement, or through another means, DOE will retain ultimate responsibility for the integrity of the remedy. In the event that the property is transferred in the future, DOE will execute a land use covenant at the time of transfer in compliance with California Code of Regulations Title 22, Division 4.5, Chapter 39, Section 67391.1. If the Site 300 property were to be transferred to an entity outside the U.S. DOE, the necessary institutional/land use controls would be determined prior to the property transfer based on: (1) the intended land use subsequent to the property transfer, and (2) contamination and associated risk, if any, remaining at the Building 832 Canyon OU.

The institutional controls were reviewed and are still effective for preventing exposure to contaminated media.

5. Five-Year Review Process

Claire Holtzapple, the Site 300 Remedial Project Manager for the DOE/National Nuclear Security Administration-Livermore Site Office, led the Five-Year Review of the Building 832 Canyon OU at LLNL Site 300. The following team members assisted in the review:

- Leslie Ferry, Program Leader, LLNL.
- Valerie Dibley, Deputy Program Leader, LLNL.
- Victor Madrid, Hydrogeologic Team Leader, LLNL.
- Anne Helmig, Hydrogeologist, Weiss Associates.
- John Valett, Hydrogeologist, Weiss Associates.

This Five-Year Review included examination of the following relevant project documents and site data:

- Final Site-Wide Remedial Investigation for Lawrence Livermore National Laboratory Site 300.
- Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300.
- Interim Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300.
- Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300.

- Remedial Design Work Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300.
- Interim Remedial Design for the Building 832 Canyon Operable Unit at Lawrence Livermore National Laboratory Site 300.
- Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300 (Ferry et al., 2006).
- Semi-annual Site-Wide Compliance Monitoring Reports that include evaluations of remediation progress in the Building 832 Canyon OU (Dibley et al., 2006b; 2007c, 2007d, 2008c, 2009c, 2009d, 2010a, and 2010b and LLNL, 2008).

This Five-Year Review evaluates subsurface contaminant concentration and remediation system performance data collected through first semester 2010 (June-2010).

The completed report will be placed in the Administrative Record file and the Information Repositories located in the LLNL Discovery Center in Livermore, California and in the Tracy Public Library in Tracy, California. Notice of its initiation and completion will be placed in two publications: *The Tracy Press* and *San Joaquin Herald*. The initial notice was published in *The Tracy Press* and *San Joaquin Herald* on April 1.

6. Five-Year Review Findings

6.1. Interviews and Site Inspection

DOE/LLNL meets monthly with the EPA, RWQCB, and DTSC Remedial Project Managers (RPMs) and quarterly with a community action group at Technical Assistance Grant Meetings to discuss remediation activities, issues, and cleanup status and progress.

There is a continuous presence of Site 300 Environmental Restoration Program staff at Site 300 that routinely inspect the: (1) extraction wellfield and treatment facilities weekly, and (2) monitoring wellfield during sampling activities. The Site 300 Environmental Restoration Program conducts self-assessment inspections of facilities and DOE conducts quarterly inspections of remediation activities at Site 300. The RWQCB RPM performs site inspections twice a year, and EPA and DTSC RPMs perform site inspections as requested. The EPA performed the construction completion inspection on February 5, 2008. Operational issues and resulting corrective actions identified during routine inspections associated with the Building 832 Canyon OU extraction wellfields and treatment facilities are: (1) described in detail in the semiannual Site 300 Compliance Monitoring Reports, and (2) discussed and presented in the monthly RPM Project Updates. The Project Updates are incorporated into the RPM meeting minutes that are distributed following the meetings.

6.2. Changes in Cleanup Standards and To-Be-Considered Requirements

The following action-specific applicable or relevant and appropriate requirements (ARARs) have been adopted since the Interim Site-Wide ROD was signed in 2001:

- The California Code of Regulations, Title 22, Section 67391.1 was adopted April 19, 2003. It contains requirements for imposing legal limitations on future site uses and activities through a land use covenant. There is no impact on the protectiveness of the remedy related to the new requirement for a land use covenant at the time of property transfer.
- The State of California established an MCL (6 µg/l) for perchlorate on October 18, 2007.

This action-specific ARAR and ARARs related to ground water cleanup were included in the 2008 Site-Wide ROD.

The EPA National Pollution Discharge Elimination System (NPDES) Pesticide Rule changed in 2011, however, no Site 300 treatment systems currently discharge to the ground surface or fall under an NPDES permit.

There have been no changes in cleanup standards since the 2008 Site-Wide ROD.

6.3. Changes in Land, Building, or Ground Water Use

There have been no significant changes in land or ground water use in the Building 832 Canyon OU since the Site-Wide ROD was signed in 2008. The OU is still accessible only to DOE/LLNL workers. Buildings near the 832-SRC treatment facility continue to be used for high-explosives storage and office space. Building 832F was decontaminated and demolished in 2005. Buildings near the 830-SRC treatment facility have been returned to institutional control and are no longer used. Ground water underlying the OU is not used for human consumption, and bottled water is currently used for drinking water at the site. In January 2011, Hetch Hetchy water became the primary water supply at Site 300, and Well 20 became a backup water supply to be used for fire control, explosives processing and dust suppression. Well 18 is currently on stand-by status but will eventually be abandoned. Wells 18 and 20 are located near the southern site boundary, southwest of the Building 832 Canyon OU.

6.4. Changes in Exposure Pathways, Toxicity, and Other Contaminant Characteristics

There have been no changes in exposure pathways, toxicity, and other contaminant characteristics in the Building 832 Canyon OU since the Site-Wide ROD was signed in 2008.

6.5. Data Review and Evaluation

6.5.1. Vadose Zone Remediation Progress

Vadose zone remediation in the form of dual-phase soil vapor/ground water extraction and treatment has been ongoing at the Building 832 and 830 source areas since 1999 and 2003, respectively. The remediation strategy in these low-yield, high-VOC source area extraction wells is to maintain a vacuum in the well while simultaneously lowering the water table by pumping. This dual-phase extraction approach is the most effective way to lower the water table and expose VOC-contaminated soil and bedrock to soil vapor extraction while enhancing ground water yield. In 2005, a test conducted at the 832-SRC area showed that vacuum-enhanced

ground water extraction increased ground water yield and dissolved-phase mass removal by a factor of two as compared to non-vacuum-enhanced ground water extraction. Similar results have been observed elsewhere at Site 300. To date, an order-of-magnitude more VOC mass has been removed in the vapor phase than in the dissolved phase using dual-phase extraction at 830-SRC and 832-SRC treatment facilities (Dibley et al., 2010a).

The 832-SRC facility system operated from 1999 to 2003 using nine dual-phase extraction wells. During this period, TCE soil vapor concentrations in the facility influent declined from 5.4 $ppm_{v/v}$ to below the 0.2 parts per million on a volume-to-volume basis ($ppm_{v/v}$) reporting limit. The facility was shutdown in October 2003 for an extended period to determine if any significant VOC vapor rebound occurred. One and half years after system shutdown, TCE vapor concentrations remained below the reporting limit. When the system was restarted in 2004, soil vapor concentrations were still low (0.3 $ppm_{v/v}$) based on a vapor sample collected from dual extraction well W-832-15 in early 2005. During 2006; however, higher TCE vapor concentrations were detected during both operational and non-operational periods, reaching a maximum of 1.1 $ppm_{v/v}$ in November 2008 in dual-phase extraction well W-832-12. Higher TCE concentrations were also observed after the system was offline from May 2009 to June 2010. As shown on Figure 22, a modest rebound in soil vapor VOC concentrations at both dual-phase extraction wells was observed after this shutdown period. These higher VOC vapor results may also be due in part to an improved soil vapor sampling methodology.

The 830-SRC dual-phase soil vapor/ground water extraction and treatment system has been operating since May 2003. Initial vapor flow rates were very low (less than 0.2 scfm), and the under-sized treatment facility blower was replaced in March 2006. As shown on Figure 23, this new blower resulted in a higher vacuum and significantly higher soil vapor flow rates. Also shown on Figure 23, TCE concentrations in soil vapor peaked at a maximum concentration of 120 $ppm_{v/v}$ in extraction well W-830-49 during April 2007 after a period of extended shutdown. This elevated VOC vapor concentration accounts for a large increase in total mass removed from this facility. In May 2009, TCE soil vapor concentrations had declined to 46 $ppm_{v/v}$ in dual-phase extraction well W-830-49.

In the future, DOE/LLNL will continue to conduct rebound testing at both the 832-SRC and 830-SRC facilities to assess source area cleanup performance. As described in the Building 832 Canyon Remedial Design report (Madrid et al., 2006), both dual-phase systems will continue to operate until the appropriate shutdown criteria have been met.

As of the first semester of 2010, the 832-SRC extraction and treatment system had removed 2 kg of VOCs, the 830-SRC extraction and treatment system removed 50 kg of VOCs.

6.5.2. Ground Water Remediation Progress

Significant progress has been made towards remediating ground water in the Building 832 Canyon OU. Ground water remediation was initiated in 1999 and all planned treatment facilities (832-SRC, 830-SRC, and 830-DISS) are now in place. However, ground water remediation efforts in the Building 832 Canyon OU continue to be constrained by:

- Steep topography that limits the availability of accessible locations for additional extraction and monitor well.
- Low yields due to fine-grained geologic materials and limited recharge.

- The need to balance site boundary pumping and upgradient source area pumping to avoid pulling contaminants farther downgradient.

During the last five years, both the 832-SRC and 830-SRC extraction wellfields have been expanded to ensure that the remedial objectives are met. These expansions included installing four new ground water extraction wells and converting six existing monitor wells to extraction wells. At 832-SRC treatment facility, four ground water extraction wells were connected to the extraction wellfield. One new extraction well W-832-25 ($Tnsc_{1a}$ HSU) was installed and three existing $Tnsc_{1b}$ HSU monitor wells (W-832-01, W-832-10, W-832-11) were converted to extraction wells. At 830-SRC treatment facility, six wells were connected to the extraction wellfield. Two existing $UTnbs_1$ HSU monitor wells (W-830-57 and W-830-60) were converted to ground water extraction wells. One $Tnsc_{1b}$ HSU monitor well (W-830-49) was converted to a dual-phase extraction well. Three new ground water extraction wells (W-830-2213 [$Tnsc_{1b}$ HSU], W-830-2214 [$Tnsc_{1a}$ HSU] and W-830-2215 [$UTnbs_1$ HSU]) were installed. W-830-2213 and W-830-1829 were converted to monitor wells in 2009 due to lack of water. All wells drilled during the past five years, including monitor and extraction wells, are color-coded by HSU on Figure 2.

Ongoing performance of the Building 832 Canyon ground water remediation systems is evaluated by:

- Comparing historic maximum ground water COC concentrations and the extent of contamination to current levels,
- Periodically reviewing ground water COC mass removal data, performance well concentration trends, and guard well data, and
- Evaluating extraction wellfield capture zones.

These performance indicators are summarized and documented in the annual CMR reports. Performance assessment data indicate that maximum contaminant ground water concentrations in the Building 832 Canyon Operable Unit have decreased significantly over time. VOC concentrations have decreased from an historic maximum of over 13,000 µg/L in dual-phase extraction well W-830-49 in 2003 to 4,200 µg/L in dual-phase extraction well W-830-19 in the first semester 2010. Perchlorate concentrations have decreased from an historic pre-remediation maximum of over 51 µg/L in monitor well W-830-34 in 1998 to 17.3 µg/L in inactive dual-phase extraction well W-832-18 in the first semester 2010. Nitrate concentrations have decreased from an historical, pre-remediation maximum of over 501 mg/L in dual-phase extraction well W-830-49 in 1998 to 190 mg/L in the same well in the first semester 2010. Decreasing nitrate concentration trends in confined portions of the $Tnsc_{1b}$ and $Tnsc_{1a}$ HSUs indicate that natural attenuation continues to reduce nitrate concentrations and that the MNA remedy is protective. In the Qal/WBR HSU, adequate anaerobic conditions for microbial degradation of nitrate are not present; however, as discussed below, nitrate concentrations have continued to decline in all source areas and nitrate concentrations have not been detected near the site boundary in groundwater above the MCL. In the $UTnbs_1$ HSU, nitrate concentrations are not present in groundwater above the MCL. Table 3 lists the historical and current maximum concentrations of total VOCs, perchlorate and nitrate detected in groundwater in the Building 832 Canyon OU by HSU.

Remediation progress in the Qal/WBR, $Tnsc_{1b}$, $Tnsc_{1a}$, and $UTnbs_1$ HSUs is discussed in Sections 6.5.2.1 through 6.5.2.4. Contaminant mass removal and concentration trends are discussed in Section 6.5.2.5.

6.5.2.1. Remediation Progress in the Qal/WBR HSU

Total VOC concentrations in Qal/WBR HSU ground water in the Building 830 source area have decreased from a historical maximum of 10,000 μg/L in monitor well SVI-830-035 in 2003 to a maximum of 1,100 μg/L in the same well in March 2010. Total VOC concentrations in Qal/WBR HSU ground water in the Building 832 source area have decreased from a historical maximum of 1,800 μg/L in inactive extraction well W-832-18 in 1998 to a maximum of 140 μg/L in the same well in March 2010. The maximum total VOC concentration shown on Figure 9 (second semester of 2009) in the Qal/WBR HSU was 1,400 μg/L in monitor well SVI-830-031.

While maximum VOC concentrations have significantly decreased in Qal/WBR HSU ground water, low yields and small areas of hydraulic influence limit remediation efforts in both the Building 832 and 830 source areas. Remediation efforts in the Qal/WBR HSU near the 830-DISS treatment facility have been more successful, but sporadic detections of low VOC concentrations continue in the Qal/WBR HSU guard wells (Figure 9).

During the five-year review period, PCE has been sporadically detected in Qal/WBR HSU well W-880-02 at concentrations up to 1 μg/L. While TCE has also been sporadically detected in this well, it has not been detected since January 2005. No VOCs, including PCE, have been detected in well W-880-02 in the five samples collected since March 2010. No PCE has ever been detected in Qal/WBR HSU guard well W-35B-01, located downgradient from well W-880-02.

The VOCs sporadically detected in Qal/WBR HSU well W-35B-01 consist entirely of 1,1-dichloroethene (DCE). The maximum concentration of 1,1-DCE in samples collected from this well during the five-year review period was 0.8 μg/L. 1,1-DCE has never been detected in upgradient Qal/WBR HSU wells W-880-02, W-832-SC4, or W-832-SC3, or in up/cross-gradient Qal/WBR HSU wells W-870-01, W-6ES, or W-35C-06. The source of these contaminants is unknown. DOE will continue to monitor VOCs in these Qal/WBR guard wells. The installation of an additional guard well downgradient of well W-35B-01 will be considered and discussed with the regulatory agencies if concentrations of 1,1-DCE increase and/or if PCE is detected in well W-35B-01. Perchlorate concentrations in Qal/WBR HSU ground water have decreased from a historical maximum of 51 μg/L in monitor well W-830-34 in 1998 to a maximum of 17.3 μg/L in inactive dual-phase extraction well W-832-18 in March 2010. The historic maximum perchlorate concentration of 51 μg/L occurred near the Building 830 source area, but more recent maximum concentrations have occurred near the Building 832 source area. Perchlorate concentrations in both source areas continue to decline in the Qal/WBR HSU. The maximum perchlorate concentration shown on Figure 13 (first semester of 2009) was 18 μg/L in inactive dual-phase extraction well W-832-13.

Nitrate concentrations in Qal/WBR HSU ground water have decreased from a historical maximum of 240 mg/L in monitor well SVI-830-033 in 2008 to a maximum of 180 mg/L in the same well in March 2010. The maximum nitrate concentration shown on Figure 17 (first semester of 2009) was 200 mg/L in monitor well SVI-830-033. Both the current and historic

maximum nitrate concentrations were detected in wells located near the Building 830 source area. Nitrate concentrations in wells near the site boundary continue to decrease to near or below the nitrate reporting limit, indicating that nitrate continues to naturally attenuate in Qal/WBR HSU ground water.

Hydraulic capture zones are not shown for the Qal/WBR HSU because there are not enough ground water elevation data points to contour these data. No additional wells are proposed for the Qal/WBR HSU at this time.

6.5.2.2. Remediation Progress in the $Tnsc_{1b}$ HSU

Total VOC concentrations in $Tnsc_{1b}$ HSU ground water in the Building 830 source area have decreased from a historical maximum of 13,000 μg/L in dual-phase extraction well W-830-49 in 2003 to a maximum of 4,207 μg/L in dual-phase extraction well W-830-19 in February 2010. The maximum total VOC concentration shown on Figure 10 (second semester of 2009) was 4,700 μg/L in dual-phase extraction well W-830-19. Total VOC concentrations in $Tnsc_{1b}$ HSU ground water in the Building 832 source area have decreased from a historical maximum of 1,800 μg/L in inactive dual-phase extraction well W-832-18 in 1998 to a maximum of 140 μg/L in the same well in March 2010. The leading edge of the $Tnsc_{1b}$ VOC plume continues to be contained within the Site 300 boundaries based on total VOC concentrations below the 0.5 μg/L reporting limit in guard wells W-830-1730, W-880-03 and W-4C. Since sampling began in 1996, VOCs have never been detected in $Tnsc_{1b}$ HSU guard Well W-880-03. The well was not sampled during 2009 due to a failed pump and subsequent wellhead redesign. Because the data presented in Figure 10 is from the second semester of 2009, the well is shown as not sampled. However, the well has been sampled six times since 2009; however, and VOC concentrations were below the reporting limit in all six samples. VOCs have never been detected in $Tnsc_{1b}$ HSU guard well W-4C. No VOCs have been detected in $Tnsc_{1b}$ HSU guard well W-830-1730 since 2002.Figure 24 shows a comparison of the distribution of total VOCs in ground water in the $Tnsc_{1b}$ HSU in second semester 2004 versus second semester 2009. To facilitate the comparison, the 2009 extent of saturation was used for both data sets. Only extraction wells are shown. As shown by the comparison, the areas with the highest VOC concentrations in both the Building 830 and Building 832 source areas have been significantly reduced due in part to the extraction wellfield expansions. The area of highest concentrations near the 830-DISS treatment facility has also declined due to an increase in passive extraction well flow rates. The downgradient migration of the VOC plume's leading edge has also been minimized and VOCs have not reached any $Tnsc_{1b}$ guard wells.

Perchlorate concentrations in $Tnsc_{1b}$ HSU ground water have decreased from a historical maximum of 26 μg/L in monitor well W-830-58 in 2001 to a maximum of 17 μg/L in inactive dual-phase extraction well W-832-18 in March 2010. The maximum perchlorate concentration shown on Figure 14 (first semester of 2009) was 18 μg/L in inactive dual-phase extraction well W-832-13. Nitrate concentrations in $Tnsc_{1b}$ HSU ground water have decreased from a historical maximum of 501 mg/L in dual-phase extraction well W-830-49 in 1998 to a maximum of 190 mg/L in the same well in February 2010. The maximum nitrate concentration shown on Figure 18 (first semester of 2009) was 220 mg/L in dual-phase extraction well W-830-49. Nitrate concentrations decrease downgradient from the source areas to near or below the

0.5 mg/L reporting limit in wells near the site boundary, indicating that nitrate continues to naturally attenuate in $Tnsc_{1b}$ HSU ground water.

Figure 10 shows the hydraulic capture zones for the ground water extraction and treatment remedy in the $Tnsc_{1b}$ HSU. The hydraulic capture zones are based on pumping water levels from extraction wells and nearby performance monitor wells. Capture zones presented in Figure 10 were prepared using data from the second semester 2009. However, if a treatment facility was shut down or if an extraction well was offline during the second semester 2009, then capture zones are from previous semesters when the treatment facility and/or extraction well were operating. Because the perchlorate plume is commingled with the VOC plumes, this COC is captured by the VOC-focused extraction wellfields.

Extraction well hydraulic capture, while generally effective at removing and reducing high VOC source area concentrations, is constrained at the Building 832 and 830 source areas by low yields and limited recharge. Both the 832-SRC and 830-SRC facilities use dual-phase extraction to enhance ground water yield and expand hydraulic influence. As shown on Figure 10, the 832-SRC, 830-SRC, and 830-DISS extraction well hydraulic capture zones target the zones with the highest VOC concentrations in the $Tnsc_{1b}$ HSU. Nevertheless, due to low yields and limited recharge, the zones of hydraulic influence for many $Tnsc_{1b}$ HSU extraction wells are limited. The steep topography present in the Building 832 Canyon also limits the locations where new extraction wells can be safely installed. Near the 830-DISS treatment facility, hydraulic capture associated with passive extraction captures the leading edge of the VOC plume. This is demonstrated by a declining VOC trend in downgradient well W-830-56 and the absence of VOCs in guard wells W-830-1730 and W-880-03.

In the Building 832 source area, additional proposed dual-phase extraction well W-832-2702 (Figure 10) is needed to expand the area of hydraulic capture in the $Tnsc_{1b}$ HSU. This new extraction well would be connected to the 832-SRC facility where ground water and soil vapor would be treated. The proposed extraction well would be slanted to gain better access to an area with steep topography and limited locations available for well installation. Dual-phase extraction, while limited by low yields and limited recharge, remains a key approach in cleaning up the Building 832 and Building 830 source areas and in preventing downgradient migration of contaminants.

The need for additional Qal/WBR and/or $Tnsc_{1b}$ HSU extraction wells in the Building 830 source area will be assessed after the buildings near 830-SRC are demolished. In the area near the 830-DISS treatment facility, the area of hydraulic capture is adequate (see discussion below) and no additional extraction or monitor wells are planned for this area in the $Tnsc_{1b}$ HSU.

In 2005, a ground water sample collected in $Tnsc_{1b}$ HSU monitor well W-832-05 indicated that it was contaminated by storm water runoff, suggesting that VOC concentrations detected in this well are not representative of $Tnsc_{1b}$ ground water. This contamination occurred because the well was not properly sealed at the surface and because the Christie box used to complete the well did not have an adequate drain. For this reason, it is recommended that this monitor well be abandoned and replaced. This new well will be located in the Building 832 source area near the existing monitor well W-832-05, and will be screened in the $Tnsc_{1a}$ HSU.

Well W-830-2216 was originally drilled to serve as a $Tnbs_2$ HSU guard well for the High Explosive (HE) Process Area OU. When VOCs were detected in water samples from this well,

the well was completed as an extraction well and connected to the closest treatment facility (B830-Distal South). However, the source of VOCs detected in $Tnbs_2$ HSU extraction well W-830-2216 is unknown. The VOCs detected in this well may have: (1) migrated in $Tnbs_2$ ground water from upgradient sources in the HE Process Area, (2) migrated downward into the $Tnbs_2$ HSU ground water where it subcrops beneath the Qal/WBR HSU (see cross-section in Figure 4), and/or (3) migrated upward into the $Tnbs_2$ HSU through fractures from confined ground water in the underlying $Tnsc_{1a}$ HSU. Extraction well W-830-2216 is not included on the contaminant distribution maps provided with this document because of the uncertainty associated with the source of the VOCs detected in $Tnbs_2$ well W-830-2216, and because most of the VOC contamination in the $Tnbs_2$ HSU originates from sources in the HE Area (OU 4). It is included on contaminant distribution maps provided in the Compliance Monitoring Reports and Five-Year Reports associated with the HE Process Area OU.

6.5.2.3. Remediation Progress in the $Tnsc_{1a}$ HSU

Total VOC concentrations in $Tnsc_{1a}$ HSU ground water have decreased from a historical maximum of 1,700 μg/L in monitor well W-830-27 in 1998 to a maximum of 812 μg/L in extraction well W-830-2214 in the first semester of 2010. The maximum total VOC concentration shown on Figure 11 (first semester 2009) was 460 μg/L in monitor well W-830-27. VOC concentrations in the $Tnsc_{1a}$ HSU have increased or remained stable in downgradient monitor wells W-830-24, -27 and -2311 and in extraction well W-832-25. VOC concentrations have increased in extraction well W-830-2214. As a result, an additional $Tnsc_{1a}$ HSU ground water extraction well (W-830-2701) is proposed to increase hydraulic capture and prevent migration of VOCs downgradient of extraction well W-830-2214. This new extraction well would be connected to the 830-SRC facility where extracted ground water would be treated.

Perchlorate concentrations in $Tnsc_{1a}$ HSU ground water have decreased from a historical maximum of 13 μg/L in extraction well W-832-25 in 1999 to a maximum of 7.3 μg/L in the same well in February 2010. The maximum perchlorate concentration shown on Figure 15 (first semester of 2009) was 8.3 μg/L in the same well. Nitrate concentrations in $Tnsc_{1a}$ HSU ground water have decreased from a historical maximum of 160 mg/L in monitor well W-830-27 in 2002 to a maximum of 88 mg/L in extraction well W-832-25 in the first semester of 2010. The maximum nitrate concentration shown on Figure 19 (first semester 2009) was 110 mg/L in the same well. The extent of both perchlorate and nitrate are confined within the boundaries of the VOC plume and no additional remediation strategies are needed for these COCs in the $Tnsc_{1a}$ HSU.

Hydraulic capture zones for the $Tnsc_{1a}$ HSU extraction wells are not shown on Figure 11 because there are not enough data points available to contour ground water elevations in this HSU at this time. As a result, hydraulic capture zones for $Tnsc_{1a}$ HSU extraction wells W-832-25 and W-830-2214 are not shown, but are expected to be similar to $Tnsc_{1b}$ HSU extraction wells W-832-10 and W-830-1830, respectively. These extraction wells also have low yields and are located in areas with limited recharge. An analysis of hydraulic capture zones for $Tnsc_{1a}$ extraction wells will be included future Compliance Monitoring Reports after proposed monitor wells W-830-2803 and W-832-3102 (Figure 11) are installed. Proposed extraction wells such as W-832-2702 ($Tnsc_{1b}$ HSU) and W-830-2701 ($Tnsc_{1a}$ HSU) should help to increase the areas of hydraulic capture in and above the $Tnsc_{1a}$ HSU.

Several new monitor wells are also proposed for installation in the $Tnsc_{1a}$ HSU. These wells are needed because the lateral extent of VOCs in $Tnsc_{1a}$ HSU ground water is not currently well delineated to the west and southwest of the Building 830 source area and downgradient of the Building 832 source area. The drilling of monitor wells W-832-3102 and W-830-2803 are proposed to delineate the VOC plume in the $Tnsc_{1a}$ HSU west and southwest of the Building 830 source area, respectively. The drilling of monitor well W-832-3001 is proposed to delineate the extent of VOC contamination in the $Tnsc_{1a}$ HSU downgradient of the Building 832 source area. Proposed monitor well W-832-3001 may be converted to an extraction well if ground water yields and VOC concentrations are sufficient. To the east of Building 832 Canyon, the extent of saturation in the $Tnsc_{1a}$ HSU is expected to be similar to the $Tnsc_{1b}$ and $Tnbs_1$ HSUs.

Currently, only one monitor well, W-832-06, that samples water in the $Tnsc_{1a}$ HSU is located in the Building 832 source area. The well is screened across the $Tnsc_{1b}$ and $Tnsc_{1a}$ HSUs. VOC concentrations in this well have been below the reporting limit since 2000; however, because of its location and because the well is screened across two HSUs, samples from the well may not be representative of VOC concentrations near 832-SRC in the $Tnsc_{1a}$ HSU. Monitor well W-832-06 could also act as a conduit by allowing the downgradient migration of contaminants from the $Tnsc_{1b}$ to the $Tnsc_{1a}$ HSU. As a result, it will be abandoned and replaced with a new $Tnsc_{1a}$ HSU monitor well located in the Building 832 source area near existing monitor well W-832-06.

6.5.2.4. Remediation Progress in the Upper $Tnbs_1$ HSU

Figure 25 shows a comparison of the distribution of total VOCs in ground water in the $UTnbs_1$ HSU in the second semester 2004 and in the second semester 2009. To facilitate the comparison, the 2009 extent of saturation was used for both data sets. Only extraction wells are shown.

Total VOC concentrations in $UTnbs_1$ HSU ground water in the Building 832 Canyon OU have decreased from a historical maximum of 100 μg/L in monitor well W-830-28 in 1998 to a maximum concentration of 27 μg/L in extraction wells W-830-2215 and W-830-60 in February 2010. The maximum total VOC concentration shown on Figure 12 (first semester 2009) was 38 μg/L in extraction well W-830-60. While ground water remediation has been successful in reducing the areas with the highest concentrations, the overall extent of contamination in the $UTnbs_1$ HSU has not significantly changed. Nevertheless, total VOC concentrations in samples collected from monitor well W-830-1832, which is located on the leading of the edge of the plume, continue to decline from a 2005 maximum total VOC concentration in ground water of 13.7 μg/L to below the 0.5 μg/L reporting limit in March 2010. Ground water pumping from this HSU is carefully managed to minimize any downward migration of VOCs from overlying HSUs. In the downgradient areas, VOC trends in monitor and guard wells are used to assess extraction wellfield performance. As shown on Figure 12, the 830-SRC $UTnbs_1$ extraction wells adequately capture the VOC plume. The hydraulic capture zones shown on this figure are estimated based on pumping water levels from extraction wells and nearby performance monitor wells using data from the second semester of 2009.

Perchlorate concentrations in $UTnbs_1$ HSU ground water have decreased from a historical maximum of 15 μg/L in extraction well W-830-57 in 2004 to below the 4 μg/L reporting limit in March 2010 (Figure 16). Nitrate concentrations in $UTnbs_1$ HSU groundwater reached a

maximum concentration of 21 mg/L in monitor well W-830-28 in 1997 and remain below the 45 mg/L cleanup standard at this time (Figure 20).

A new monitor well (W-832-2901) is proposed to be installed in the $UTnbs_1$ HSU downgradient of the Building 832 source area (Figure 12). This well would be used as a guard well to verify that no contaminants from the Building 832 source area have reached the $UTnbs_1$ HSU.

6.5.2.5. Contaminant Mass Removal and Concentration Trends

Time-series plots of cumulative VOC and perchlorate mass removed by treatment facility are shown on Figures 26 and 27, respectively. As shown on Figure 26, vapor phase extraction is more effective than dissolved phase extraction in the Building 832 Canyon OU due to low ground water yields. The 830-SRC treatment facility exhibits the highest cumulative total VOC mass removed due to the high VOC concentrations and flow rates at this facility relative to 832-SRC and 830-DISS treatment facilities.

As shown on Figure 27, the highest perchlorate mass removal rates are attained by the 830-DISS treatment facility. Although higher perchlorate concentrations exist at the 832-SRC treatment facility, the long-term sustained flow rate at 830-DISS treatment facility is higher. As of the first semester of 2010, approximately 75 grams of perchlorate, have been removed from ground water by the 832-SRC, 830-SRC, and 830-DISS ground water treatment facilities.

Long-term VOC trends in ground water extraction wells at the 832-SRC, 830-SRC, and 830-DISS treatment facilities are presented on Figures 28, 29 and 30, respectively. Although cis-DCE and vinyl chloride have been sporadically detected in Building 832 Canyon ground water, there is generally no evidence of widespread anaerobic VOC degradation at these sites because the bacteria necessary for complete dechlorination are not present. As shown, all extraction wells, with the exception of $Tnsc_{1a}$ HSU extraction well W-830-2214, generally exhibit decreasing VOC trends. As of first semester 2010, approximately 5.86 kg of VOCs have been removed from ground water by the 832-SRC, 830-SRC, and 830-DISS ground water treatment facilities.

DOE/LLNL will continue to evaluate the extent of hydraulic capture and the progress of each extraction wellfield toward achieving ground water RAOs, especially in light of anticipated changes in hydraulic gradients associated with the shutdown of Site 300 water supply Well 20. The transition from Wells 18 and 20 is an ongoing process and the overall schedule and post-transition plans are still being developed. It is not possible to predict what the effects of this change in operating conditions will be on the hydraulic capture and progress of each extraction wellfield in advance. However, some increase in regional water levels in the $Tnsc_1$ and $Tnbs_1$ HSUs is expected, particularly near the site boundary where some wells are expected to become artesian. If performance data indicate that the extraction wellfields are not performing as expected, wellfield optimization will be conducted.

6.5.3. Ground Water Flow and Contaminant Transport Modeling

Two FEFLOW numerical models were developed to simulate ground water flow and contaminant transport in the $Tnsc_{1b}$ and $UTnbs_1$ HSUs. The purpose of these models was to enhance the understanding of groundwater flow and contaminant transport in the Building 832

Canyon OU, to create a series of decision-making tools to aid in extraction wellfield management and to provide preliminary estimates of the time required to achieve cleanup standards under long-term pumping conditions. Previous predictions of cleanup times for the $UTnbs_1$ and $Tnsc_{1b}$ HSUs were developed using the WINFLOW analytical model and documented in the Site-Wide Remediation Evaluation Summary Report (Ferry et al., 2006). FEFLOW modeling results are summarized in Appendix A.

Preliminary FEFLOW modeling results indicate that cleanup standards for TCE of 5 μg/L will be achieved in the $Tnsc_{1b}$ HSU in approximately 150-250 years, and in the Upper $Tnbs_1$ HSU in approximately 75-125 years. The impact of future Well 20 pumping on cleanup time estimates was not considered. Cleanup time estimates for the $Tnsc_{1b}$ model were higher than the cleanup times predicted using the WINFLOW analytical model for the Site-Wide Remediation Evaluation Summary Report (Ferry et al., 2006). These faster cleanup times can be expected given that the WINFLOW model assumes an infinite aquifer. Specific cleanup time estimates for the $UTnbs_1$ HSU were not included in the Site-Wide Remediation Evaluation Summary Report, so no comparison can be made. In the future, both the $Tnsc_{1b}$ and $UTnbs_1$ models may be modified to improve the match between measured and modeled data. After this calibration phase is complete, the models will be used to support extraction wellfield management and optimization. The models can also be used to support budgeting and planning functions, by helping to constrain the time frames required to clean up each aquifer.

6.5.4. Risk Mitigation Remediation Progress

The baseline risk assessment was presented in the Site-Wide Remedial Investigation (Webster-Scholten et al., 1994) and updated in the Site-Wide Feasibility Study (Ferry et al., 1999). A baseline excess cancer risk was calculated for onsite workers of 1×10^{-5} for the inhalation of VOCs that volatilize from the subsurface soil into outdoor air in the vicinity of Building 830 and 3×10^{-6} for the inhalation of VOCs that volatilize from the subsurface soil into Building 832F indoor air. The remediation in the Building 832 Canyon OU mitigated these risks prior to the implementation of the CMP risk evaluations that began in 2003. The risk evaluations performed for the 2003 and 2004 Annual Compliance Monitoring Reports (Dibley et al., 2004 and 2005) indicated there were no longer onsite worker risks from the inhalation of VOCs volatilizing from the subsurface into outdoor air at Building 830 or into Building 832F indoor air.

A baseline excess cancer risk for onsite workers of 3×10^{-6} was calculated for the inhalation of VOCs that volatilize from the subsurface soil into the indoor air of Buildings 830. The 2009 annual risk evaluation indicated that there was no longer an unacceptable risk; however, the Risk and Hazard Management Program will continue in this area until the risk evaluations indicate the risk and hazard index are below 10^{-6} and 1, respectively for two consecutive years.

A baseline excess cancer risk for onsite workers of 7×10^{-3} was calculated for the inhalation of VOCs that volatilize from surface water into outdoor air in the vicinity of Spring 3. The risk evaluations performed for the 2008 and 2009 Annual Compliance Monitoring Reports (Dibley et al., 2009c and 2010a) indicated there was no longer an unacceptable risk at Spring 3.

No newly or previously unidentified unacceptable ecological risk or hazard has been identified in the baseline ecological assessment or subsequent ecological reviews.

6.5.5. New Sources, Releases, or Contaminants

Ground water and soil vapor data indicate that there are no new sources, releases, or contaminants in the Building 832 Canyon OU.

6.5.6. New Technology Assessment

No new technologies have been identified that are capable of accelerating or achieving cleanup in a more cost-effective manner in the Building 832 Canyon OU.

7. Technical Assessment

The protectiveness of the Building 832 Canyon remedy was assessed by determining if:

1. The remedy is functioning as intended at the time of the decision documents.
2. The assumptions used in the decision-making process are still valid.
3. Any additional information has been identified that would call the protectiveness of the remedy into question.

This review determined that the remedy for the Building 832 Canyon OU was protective, based on the following:

1. The remedy was determined to be functioning as intended at the time of the decision documents because:
   - Ground water and dual-phase extraction and treatment are effectively reducing contaminant concentrations and mass in the subsurface. The maximum total VOC concentration in ground water has decreased by an order of magnitude. As of the end of first semester 2010, approximately 5.86 kg of total VOCs have been removed from ground water and 52 kg from vapor.

   - Ground water and vapor treatment systems are performing as designed and will continue to be operated and optimized. Optimization may include installing new extraction wells, adding higher capacity pumps to maximize yield and to increase hydraulic capture, upgrading treatment facilities to accommodate increased flow, and adding additional effluent discharge technologies, including injection wells and misting towers, where appropriate.

   - System operation procedures are consistent with requirements.

   - No early indicators of potential interim remedy failure were identified.

2. The assumptions used in the decision-making process were determined to still be valid because:
   - On April 19, 2003, the California Code of Regulations, Title 22, Section 67391.1 was adopted that contains requirements for imposing legal limitations on future site uses and activities through a land use covenant. However, there is no impact on the protectiveness of the remedy related to this new requirement for a land use covenant

at the time of property transfer. In addition, the State of California enacted a MCL for perchlorate on October 18, 2007. These changes occurred after the 2002 Interim ROD, but prior to the 2008 Site-Wide ROD. There have been no changes in location-, chemical-, or action-specific ARARs or to-be-considered requirements since the 2008 Site-Wide ROD for Site 300 was signed, nor have there been changes in exposure pathways, toxicity, and other contaminant characteristics.

- There have been no changes in land, building, or water use in the Building 832 Canyon OU since the Site-Wide ROD for Site 300 was signed that impact the protectiveness of the remedy.

- All required institutional controls are in place and no current or planned changes in land use at the site suggest that they are not or would not be effective.

- Ground water and vapor treatment systems are performing as designed.

3. No additional information was identified that would call the protectiveness of the remedy into question:

   - The Health and Safety Plan and Site-Wide Contingency Plan are in place, sufficient to control risks, and properly implemented.

   - There have been no changes in risk assessment methodologies that would call the protectiveness of the remedy into question.

   - No new or previously unidentified unacceptable risk or hazard to human health or ecological receptors has been identified in annual risk re-evaluations or in ecological reviews.

   - No unanticipated events (i.e., natural disasters, new contaminants discovered, etc.) occurred that would call the protectiveness of the remedy into question.

   - No additional information has been identified that would call the protectiveness of the remedy into question.

   - In addition, costs to implement the remedy have generally been within budget, except when incidental costs were incurred to address unanticipated problems or regulatory requests.

8. Deficiencies

No deficiencies in the remedy were identified during this evaluation.

9. Recommendations and Follow-Up Actions

The following recommendations to be carried out by DOE were developed during the review process:

1. Drill and install one new extraction well (W-830-2701) to increase hydraulic capture and prevent migration of COCs in the $Tnsc_{1a}$ HSU. This new extraction well would be connected to the 830-SRC facility where extracted ground water would be treated.
2. Drill and install one new dual-phase extraction well (W-832-2702) to increase hydraulic capture of COCs in the $Tnsc_{1b}$ HSU and contaminant mass removal in the Building 832 source area, and prevent contaminant migration in this HSU. This new extraction well would be connected to the 832-SRC facility where extracted ground water and soil vapor would be treated.
3. Drill and install two $Tnsc_{1a}$ HSU monitor wells (W-832-3102 and W-830-2803) to better delineate the VOC plume in the $Tnsc_{1a}$ HSU west and southwest of the Building 830 source area, respectively.
4. Drill and install one $Tnsc_{1a}$ HSU monitor well (W-832-3001) to better delineate the extent of VOC contamination in this HSU downgradient of the Building 832 source area. This proposed monitor well W-832-3001 may be converted to an extraction well if ground water yields and total VOC concentrations are sufficient.
5. Drill and install one monitor well (W-832-2901 in the $UTnbs_1$ HSU downgradient of the Building 832 source area (Figure 12). This well will be used as an Upper $Tnbs_1$ ($UTnbs_1$) HSU guard well to verify that no contaminants from the Building 832 source area have reached this HSU.
6. Due to contamination by surface runoff, abandon $Tnsc_{1b}$ HSU monitor well W-832-05. Monitor well W-832-06, which is screened across the $Tnsc_{1b}$ and $Tnsc_{1a}$ HSUs, should also be abandoned because data collected from this well may not be fully representational of VOC concentrations in the $Tnsc_{1a}$ HSU near the Building 832 source area, and could act as a conduit allowing the downgradient migration of contaminants from the $Tnsc_{1b}$ HSU into the $Tnsc_{1a}$ HSU. After abandonment, replace wells with new monitor wells in the $Tnsc_{1b}$ and $Tnsc_{1a}$ HSUs. The locations of the replacement wells are to be determined, but will likely be located near the 832-SRC or 830-SRC treatment facilities.

No other follow-up actions were identified related to this Five-Year Review. As discussed below, these recommendations do not affect the protectiveness of the remedy.

DOE will: (1) estimate costs and the timeframe necessary to accomplish the new work scope; (2) prioritize new work scope and present these priorities to the regulatory agencies; (3) incorporate the new work scope into upcoming fiscal year budget requests; and (4) develop a schedule for implementing the work.

10. Protectiveness Statement

The remedy at the Building 832 Canyon OU is protective of human health and the environment for the site's industrial land use. The remedy protects human health because exposure pathways that could result in unacceptable risk to onsite workers are being controlled by the implementation of institutional controls, the Health and Safety Plan, and the Contingency Plan.

The cleanup standards for Building 832 Canyon OU ground water are drinking water standards. Because drinking water standards do not differentiate between industrial and residential use, the ground water cleanup remedy will be protective under any land use scenario.

The cleanup standards for VOCs in subsurface soil are to reduce concentrations to mitigate risk to onsite workers and prevent further impacts to ground water to the extent technically and economically feasible. Because some VOCs may remain in subsurface soil following the achievement of these cleanup standards, a land use control prohibits the transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use. This prohibition is included in the Site-Wide ROD. This prohibition will remain in place until and unless a risk assessment is performed in accordance with current U.S. EPA risk assessment guidance and is agreed by the DOE, the EPA, the DTSC, and RWQCB as adequately showing no unacceptable risk for residential or unrestricted land use.

11. Next Review

The next statutory review will be conducted within five years of the signature date of this report (2016).

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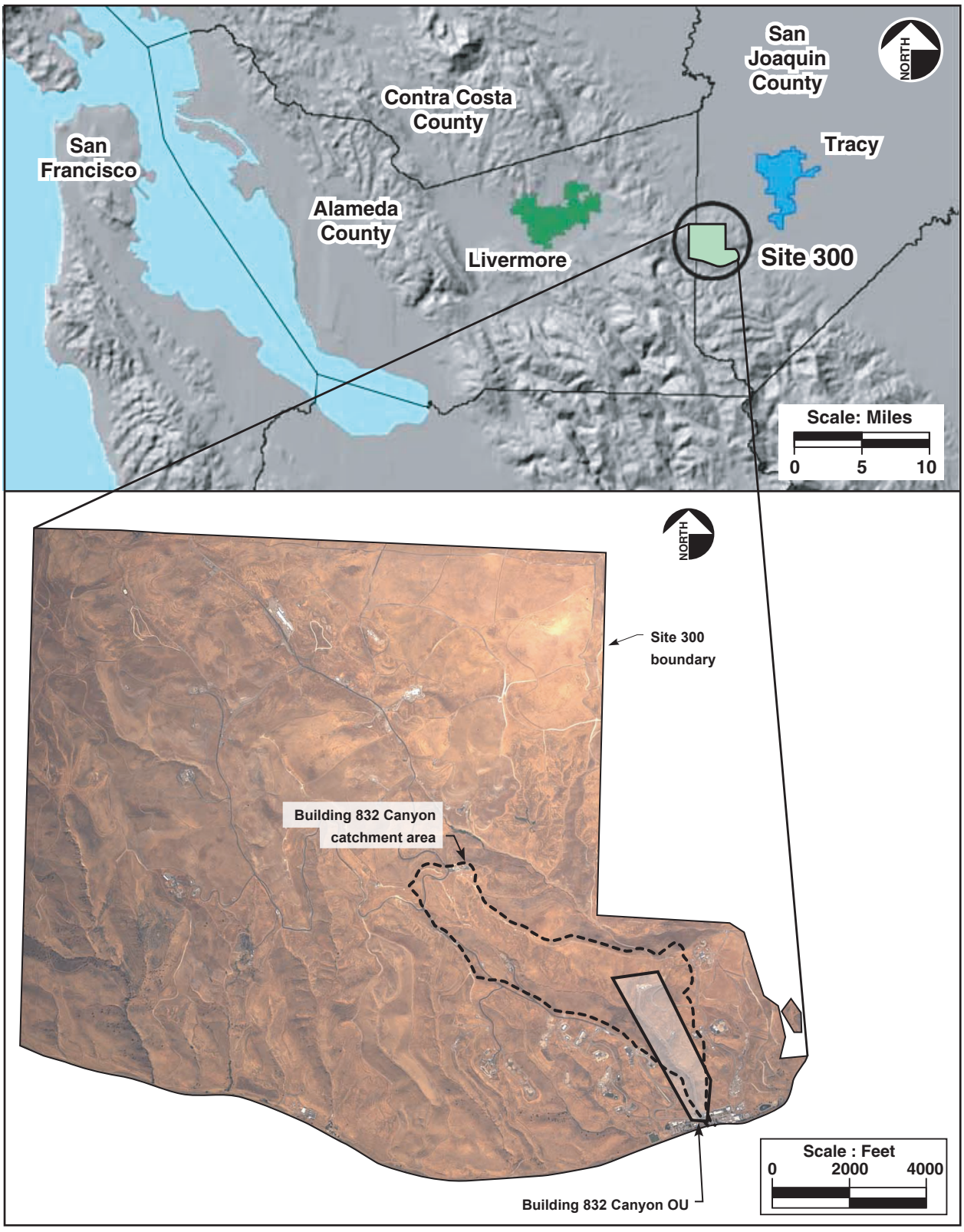
13. Acronyms and Abbreviations

830-DISS	Building 830-Distal South
830-SRC	Building 830-Source
832-PRXN	Building 830-Proximal North
832-SRC	Building 832-Source
ARARs	Applicable or relevant and appropriate requirements
ATA	Advanced Test Accelerator
bgs	Below ground surface
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CMB	Claystone marker bed
COCs	Contaminants of concern
DOE	Department of Energy
DTSC	Department of Toxic Substances Control
EPA	Environmental Protection Agency
ERD	Environmental Restoration Department
ft	Feet
g	Gram
GAC	Granular activated carbon
gpd	Gallons per day
gpm	Gallons per minute
GSA	General Services Area
GWTS	Ground water extraction and treatment system
HE	High explosives
HMX	High-Melting Explosive
HSU	Hydrostratigraphic unit
kg	Kilogram
LLNL	Lawrence Livermore National Laboratory
MCL	Maximum Contaminant Level
mg/L	Milligrams per liter
MNA	Monitored natural attenuation
O&M	Operation and maintenance
OTV	Optical televiewer
OU	Operable unit
PCBs	Polychlorinated biphenyls
PCE	Tetrachloroethene
pCi/L	picoCuries per liter
$ppm_{v/v}$	Parts per million on a volume-to-volume basis
Qal/WBR	Quaternary alluvium/ Weathered bedrock
RAOs	Remedial Action Objectives

RCRA	Resource Conservation and Recovery Act
RDX	Research Department explosive
ROD	Record of Decision
RPMs	Remedial Project Managers
RWQCB	Regional Water Quality Control Board
SARA	Superfund Amendment Reauthorization Act
scfm	Standard cubic flow per minute
SVRA	Carnegie State Vehicular Recreation Area
SVTS	Soil vapor extraction and treatment system
TBOS	Tetrabutyl orthosilicate
TCE	Trichloroethene
TKEBS	Tetrakis (2-ethylbutyl) silane
$Tnbs_1$	Tertiary Neroly Lower Blue Sandstone
$Tnsc_{1b}$	Sandstone bodies within the $Tnsc_1$ Neroly middle siltstone/claystone
Tps	Tertiary Pliocene nonmarine sediments
U.S.	United States
VOCs	Volatile organic compounds
yd^3	Cubic yards
µg/L	Micrograms per liter

Figures

List of Figures



ERD-S3R-10-0015

Figure 1. Location of LLNL Site 300 and the Building 832 Canyon Operable Unit.

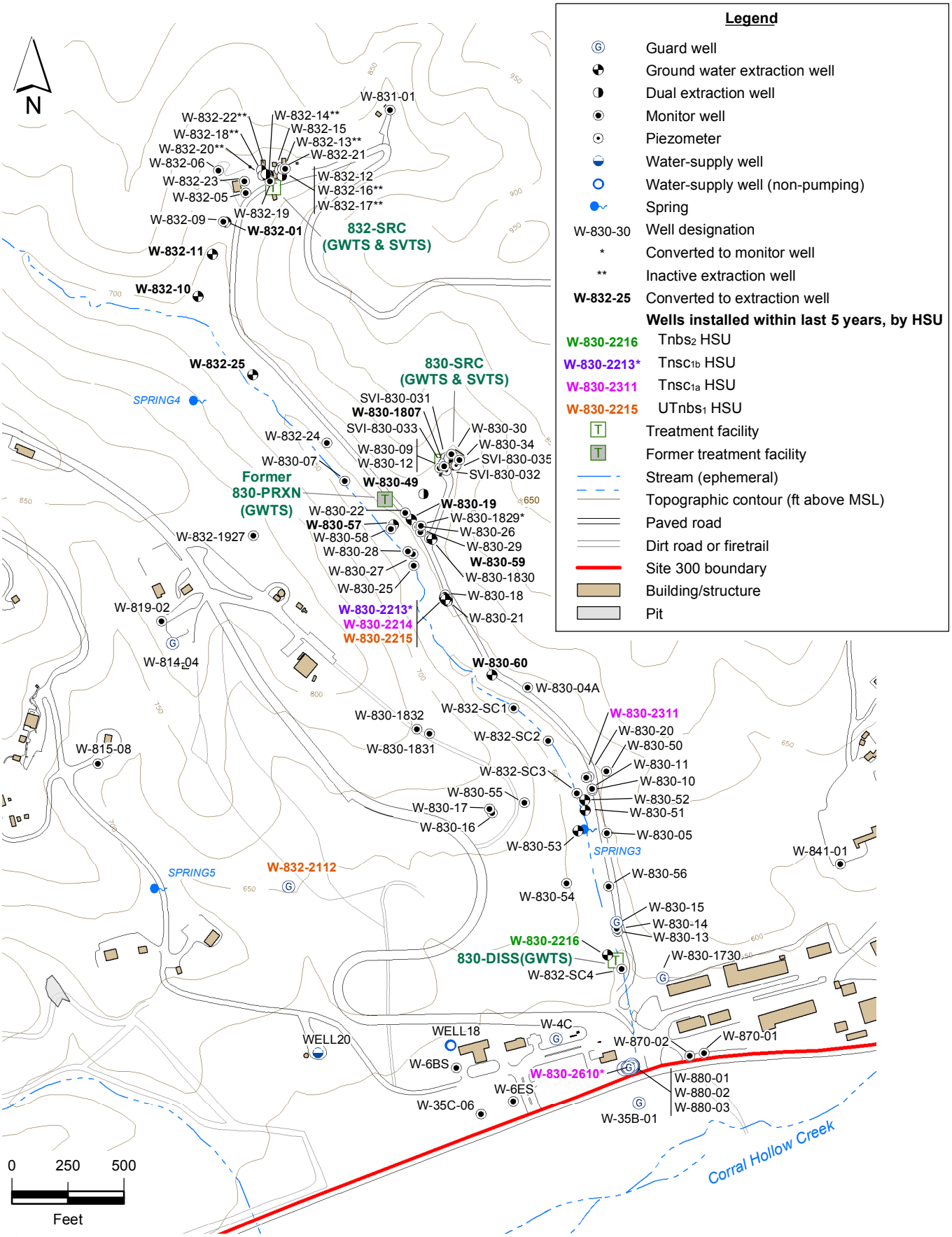


Figure 2. Site map showing monitor, extraction and water-supply wells, and treatment facilities.

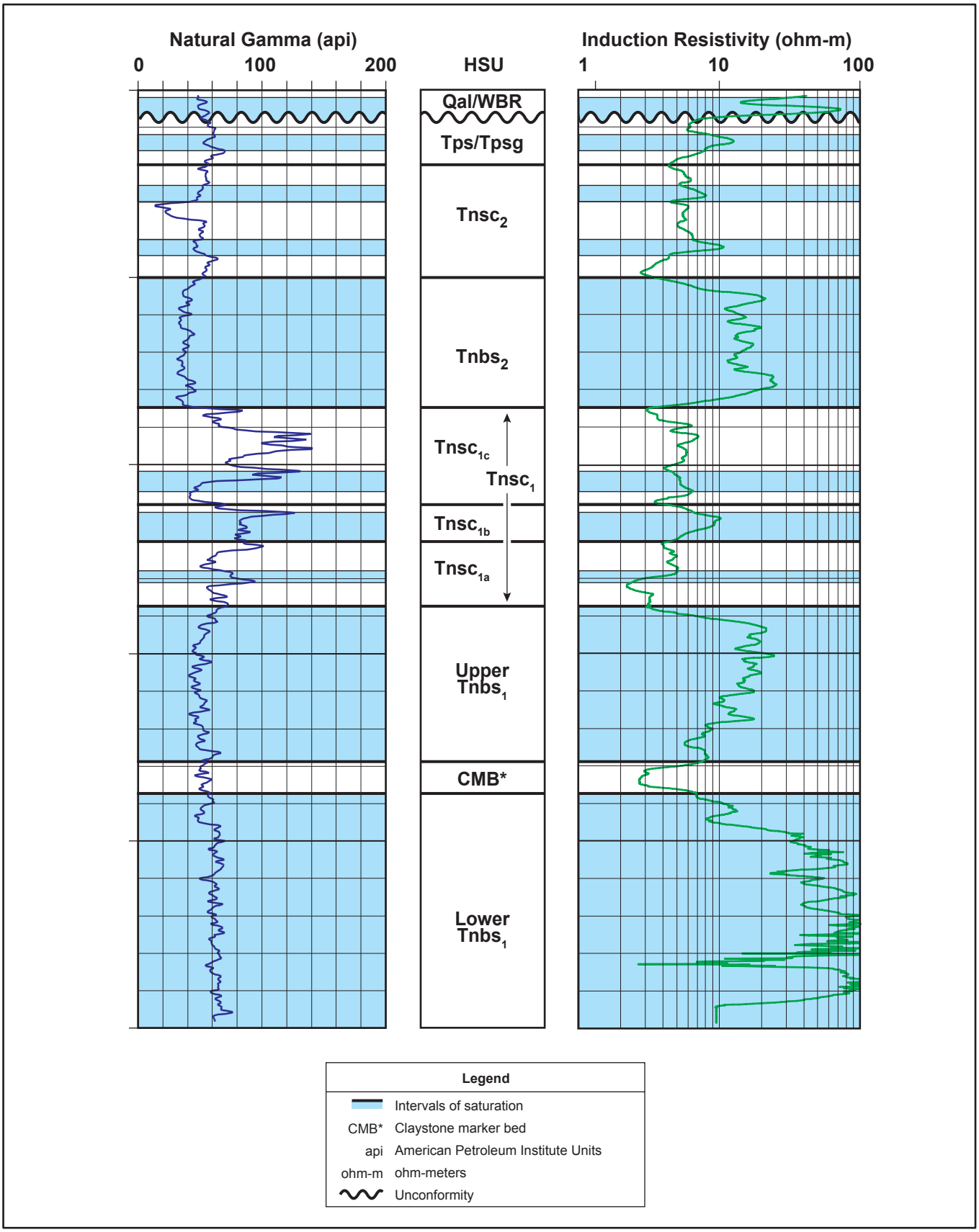


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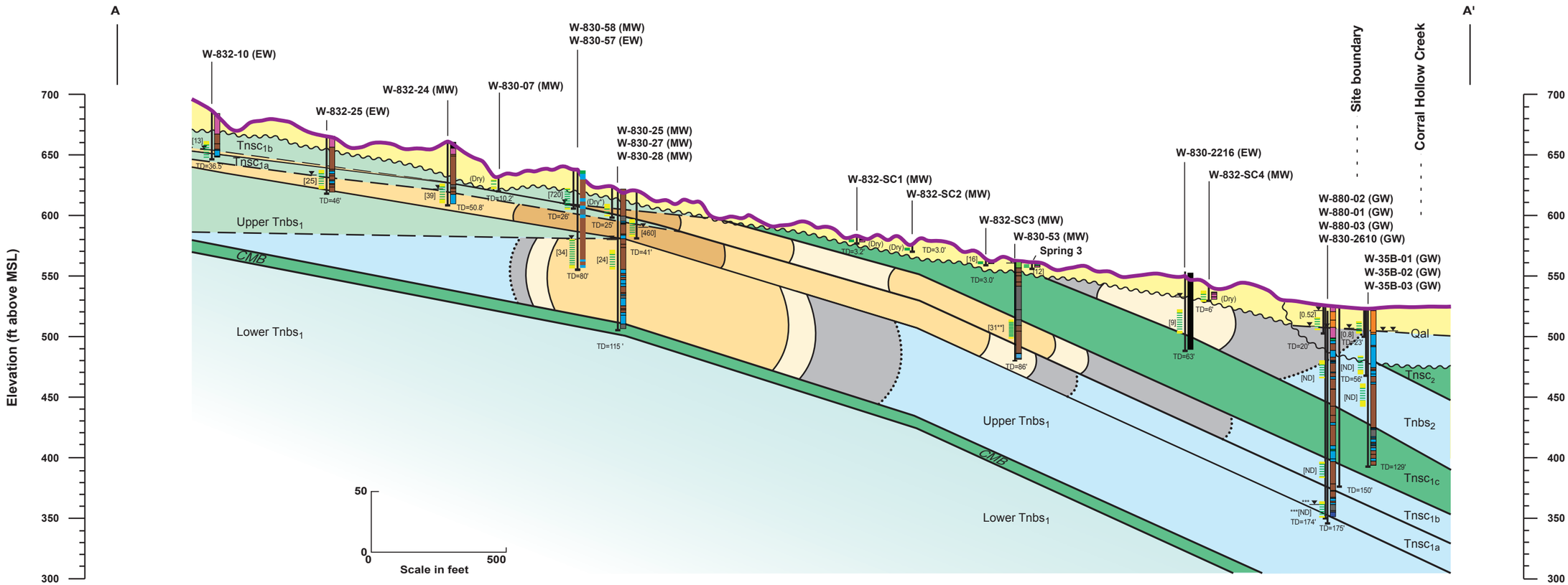
Figure 3. Summary of stratigraphy and hydrostratigraphy.



Legend

Qal	Quaternary alluvial deposit
$Tnsc_2$	Tertiary Neroly Formation, upper siltstone/claystone
$Tnbs_2$	Tertiary Neroly Formation, upper blue sandstone
$Tnsc_{1(c,b,a)}$	Tertiary Neroly Formation, middle siltstone/claystone
$UTnbs_1$	Tertiary Neroly Formation, lower blue sandstone (upper)
CMB	Clay stone marker bed
$LTnbs_1$	Tertiary Neroly Formation, lower blue sandstone (lower)

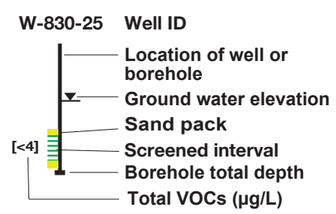
Unsaturated Tertiary Neroly Formation
Low permeability confining layer
Ground surface
Stratigraphic contact
Potentiometric surface
Unconformity

Well Designation
GW = Guard well
EW = Extraction well
MW = Monitoring well

Total VOC concentrations (µg/L)

<0.5	10 – 100
0.5 – 5	100 – 1000
5 – 10	

* W-830-25 was saturated in 2006 and TVOC concentration was 130 µg/L
** February 2009 concentration; not sampled 2nd semester 2009
*** Water level and TVOC concentration are preliminary



Lithology Groups
Gravel
Sand
Silt
Clay
Sandstone
Siltstone
Claystone
Not available

Well Details
Well Screen
Sand Pack

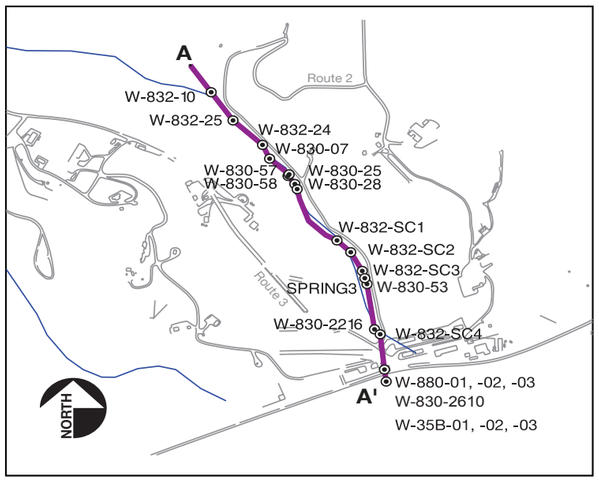


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Figure 4. Hydrogeologic cross-section A-A'.

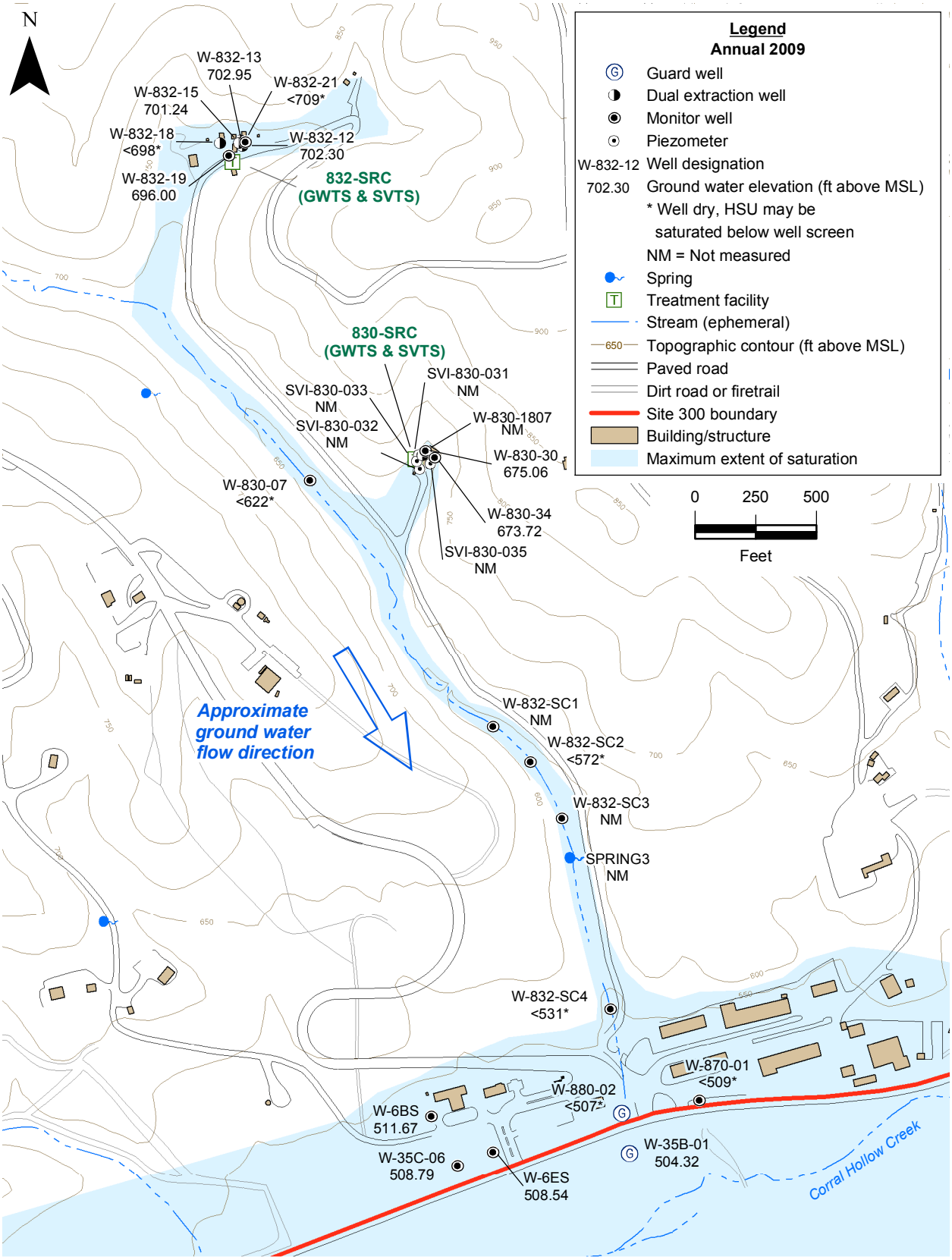

Figure 5. Ground water elevations and ground water flow direction for the Qal/WBR HSU.

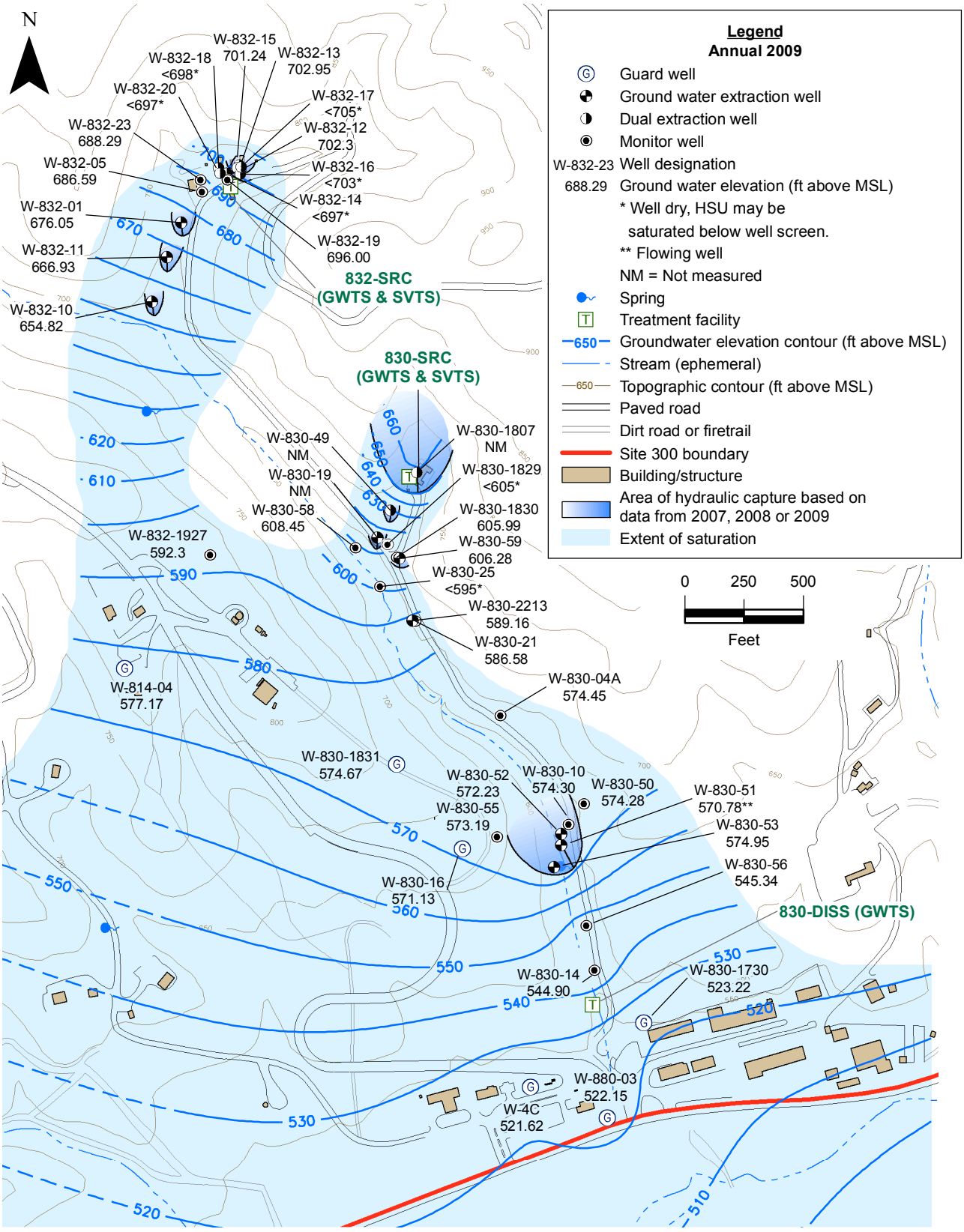

Figure 6. Ground water potentiometric surface map for the $Tnsc_{1b}$ HSU including hydraulic capture zones.

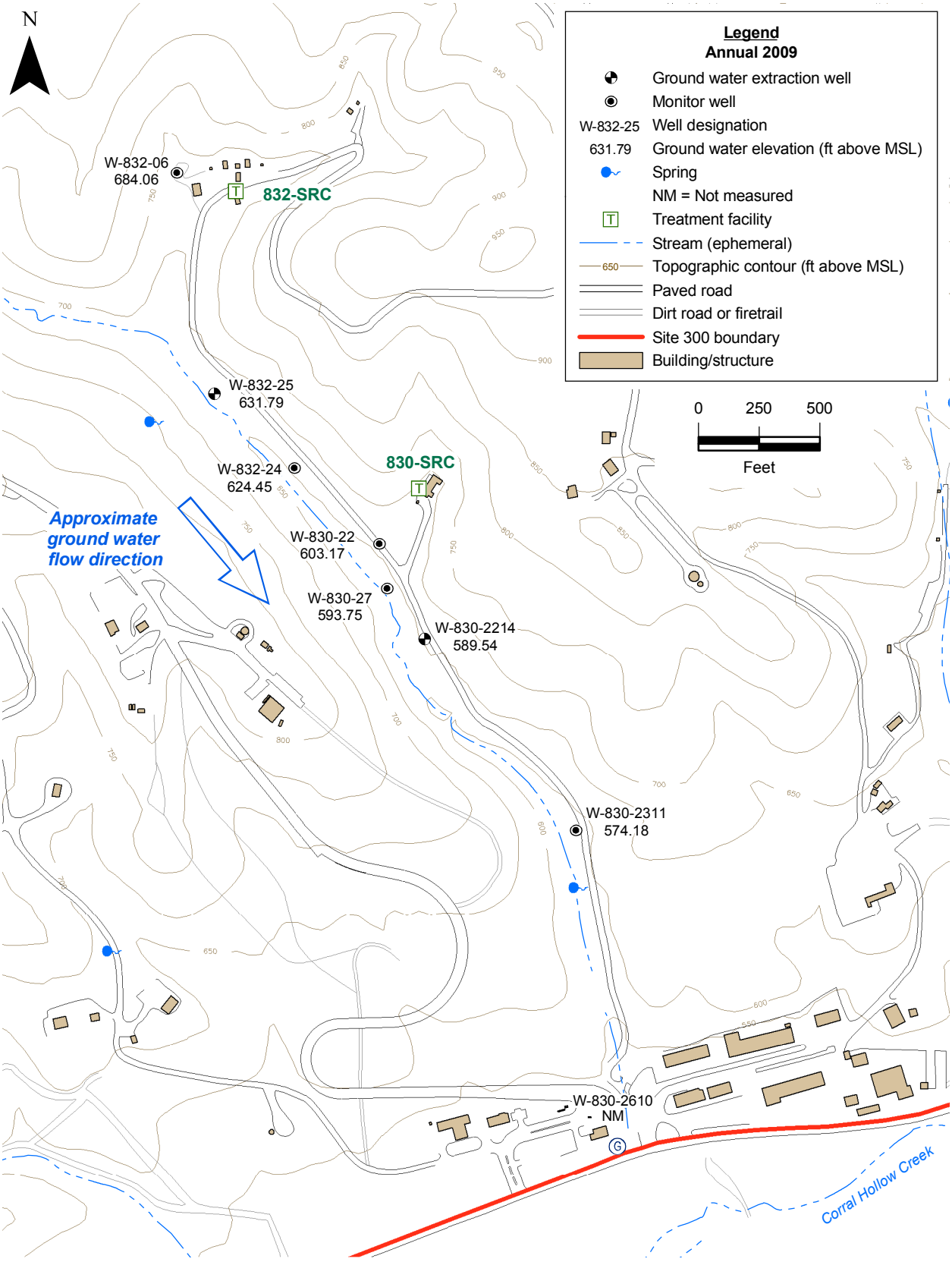

Figure 7. Ground water elevations and ground water flow direction for the $Tnsc_{1a}$ HSU.

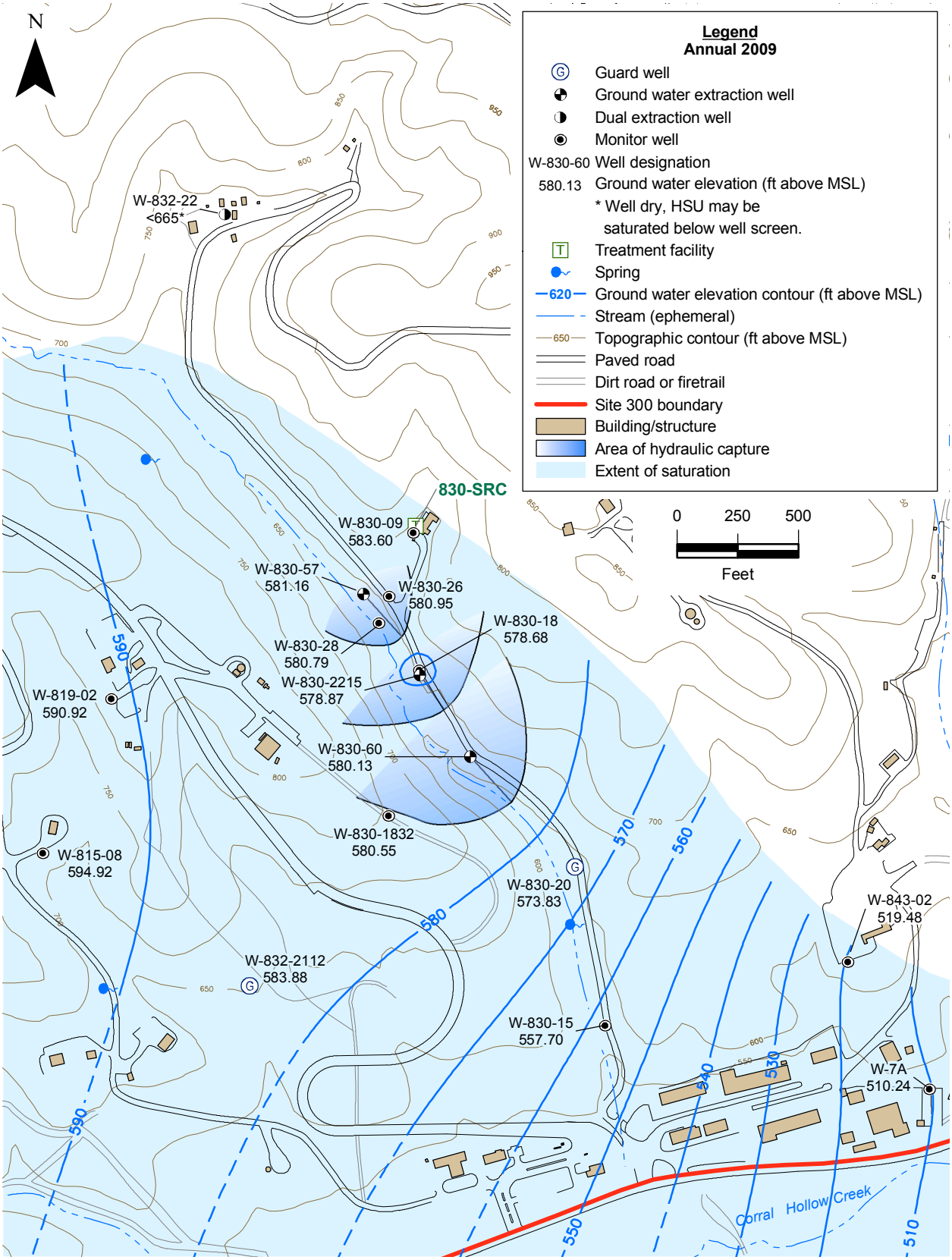

Figure 8. Ground water potentiometric surface map for the Upper Tnbs$_1$ HSU including hydraulic capture zones.

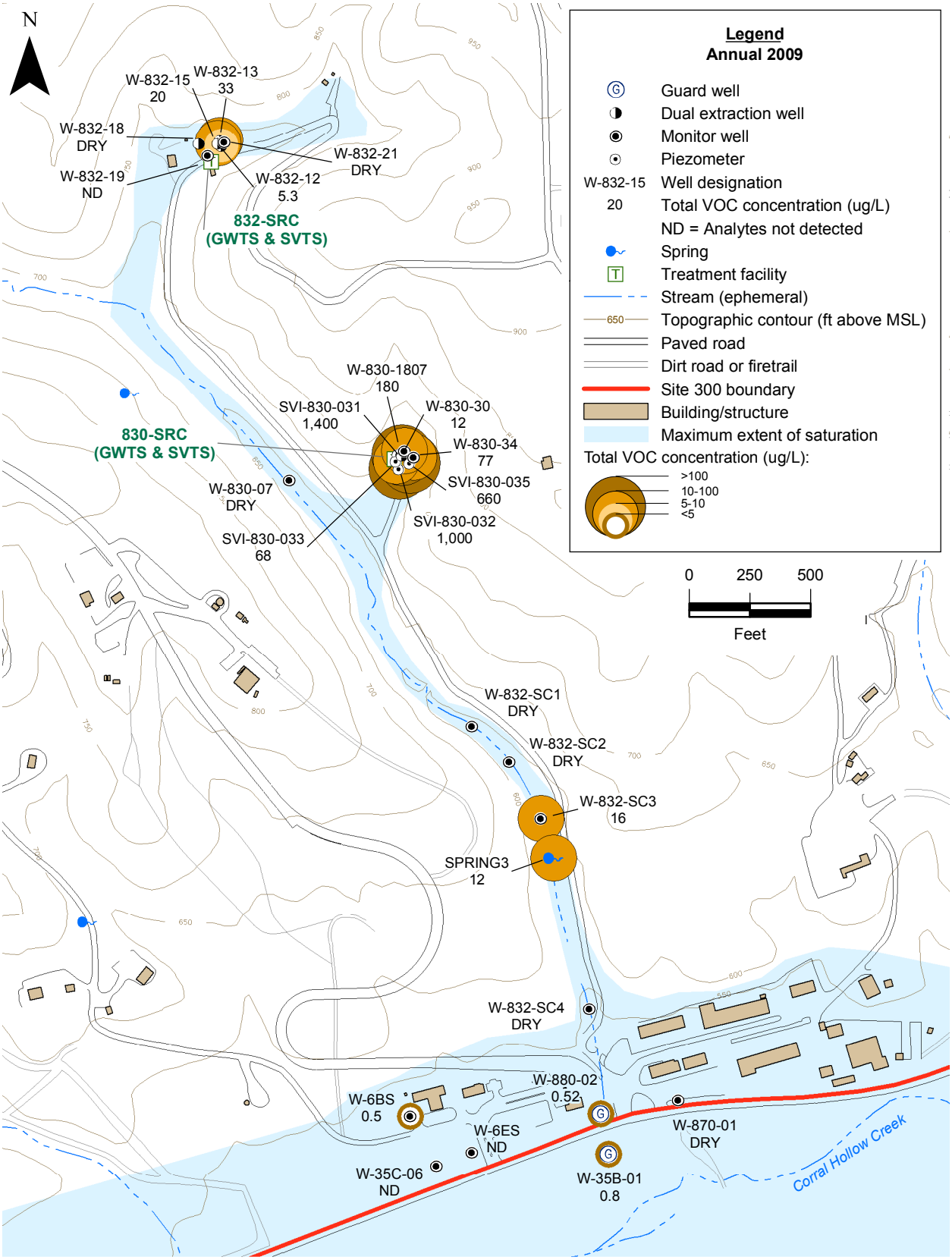

Figure 9. Total VOC concentrations for the Qal/WBR HSU.

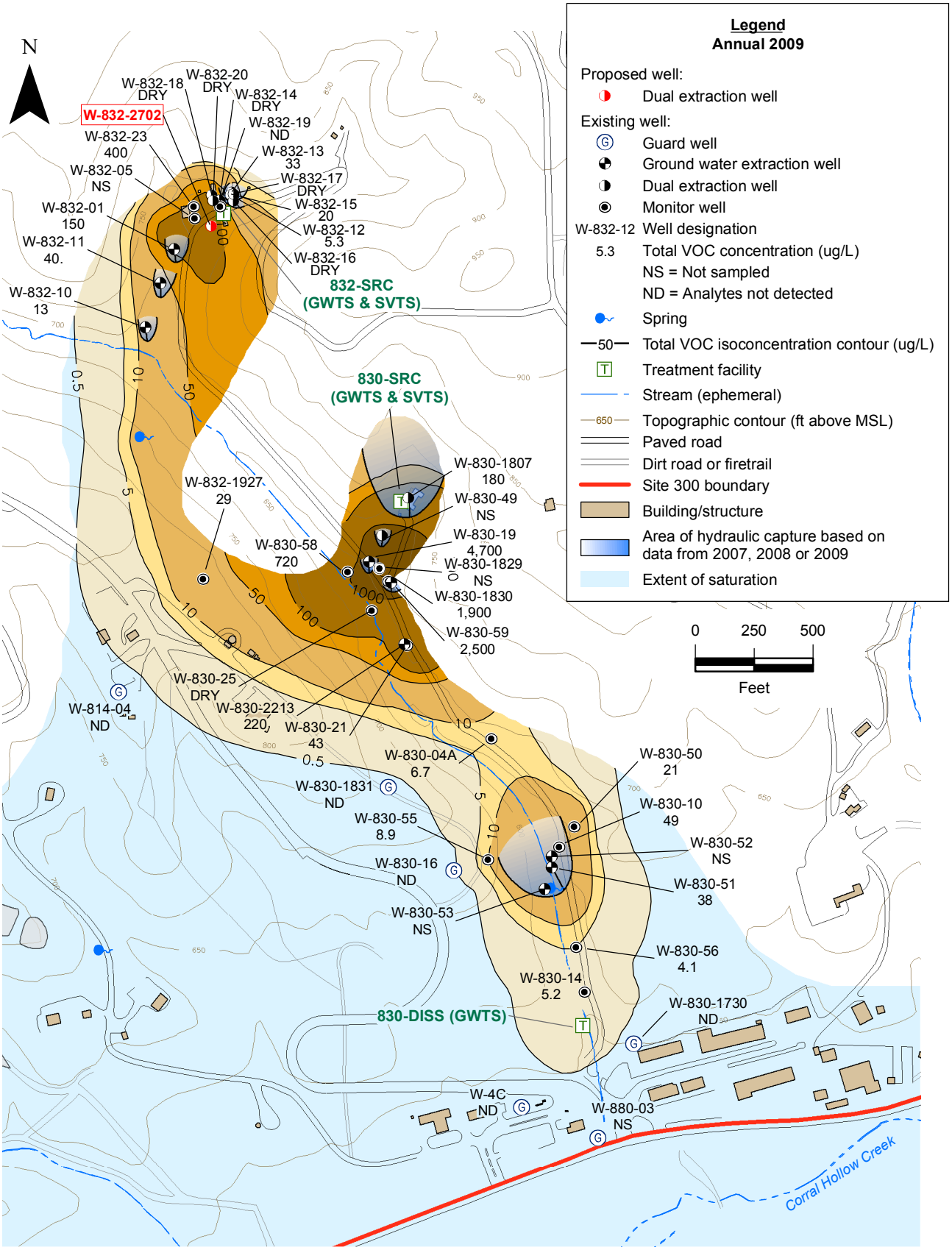

Figure 10. Total VOC isoconcentration contour map for the $Tnsc_{1b}$ HSU.

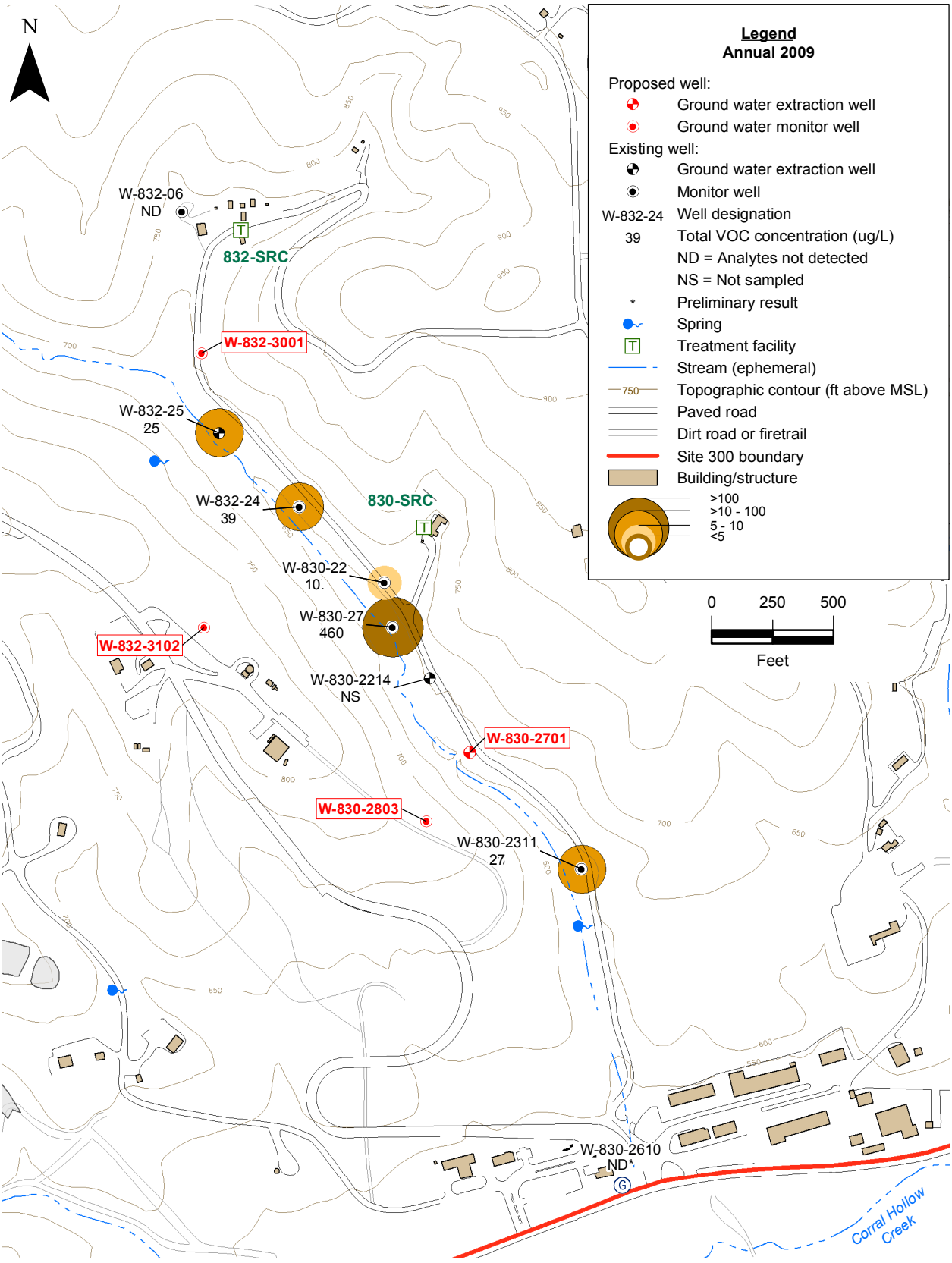

Figure 11. Total VOC concentrations for the $Tnsc_{1a}$ HSU.

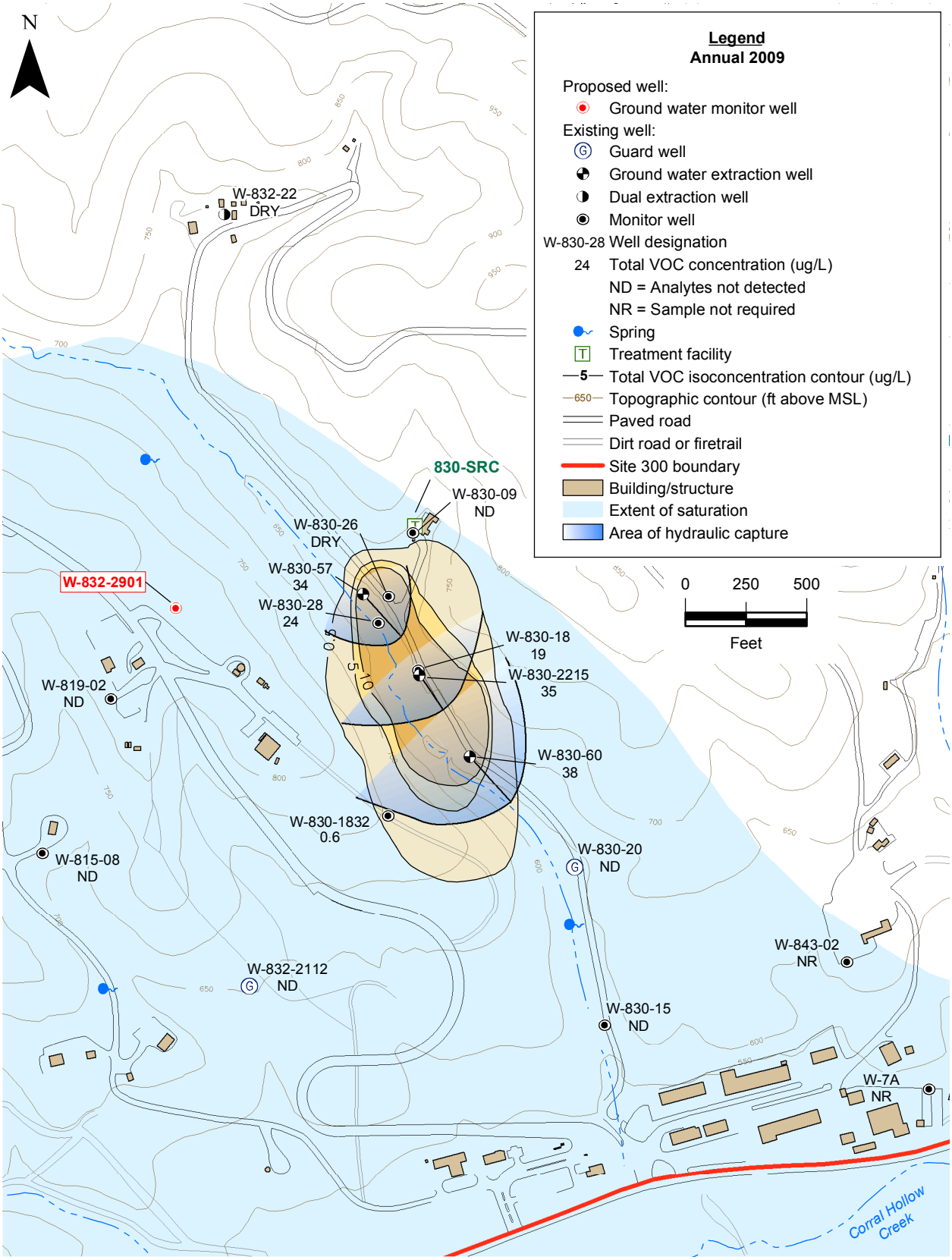

Figure 12. Total VOC isoconcentration contour map for the Upper Tnbs$_1$ HSU.

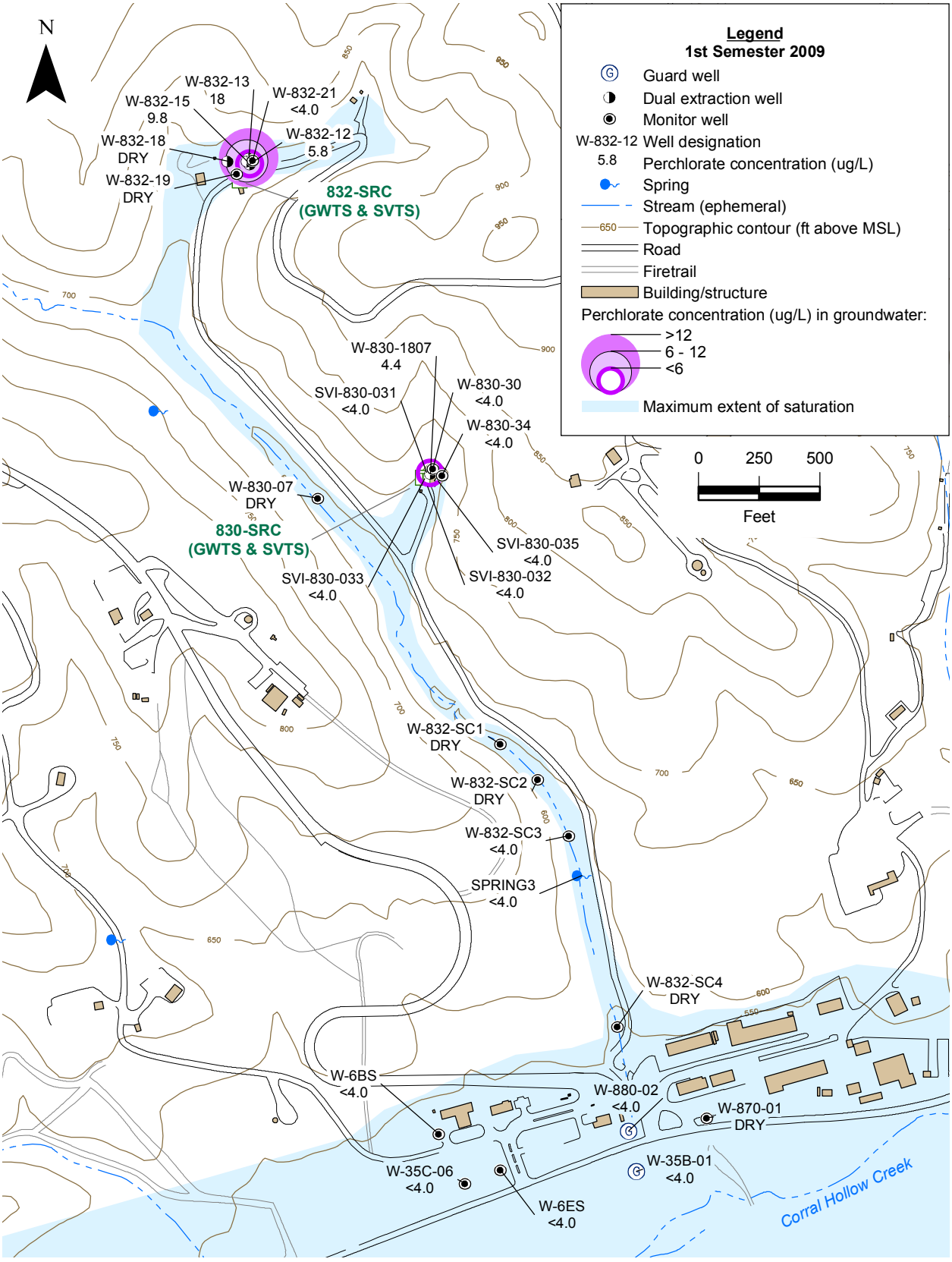

Figure 13. Perchlorate concentrations for the Qal/WBR HSU.

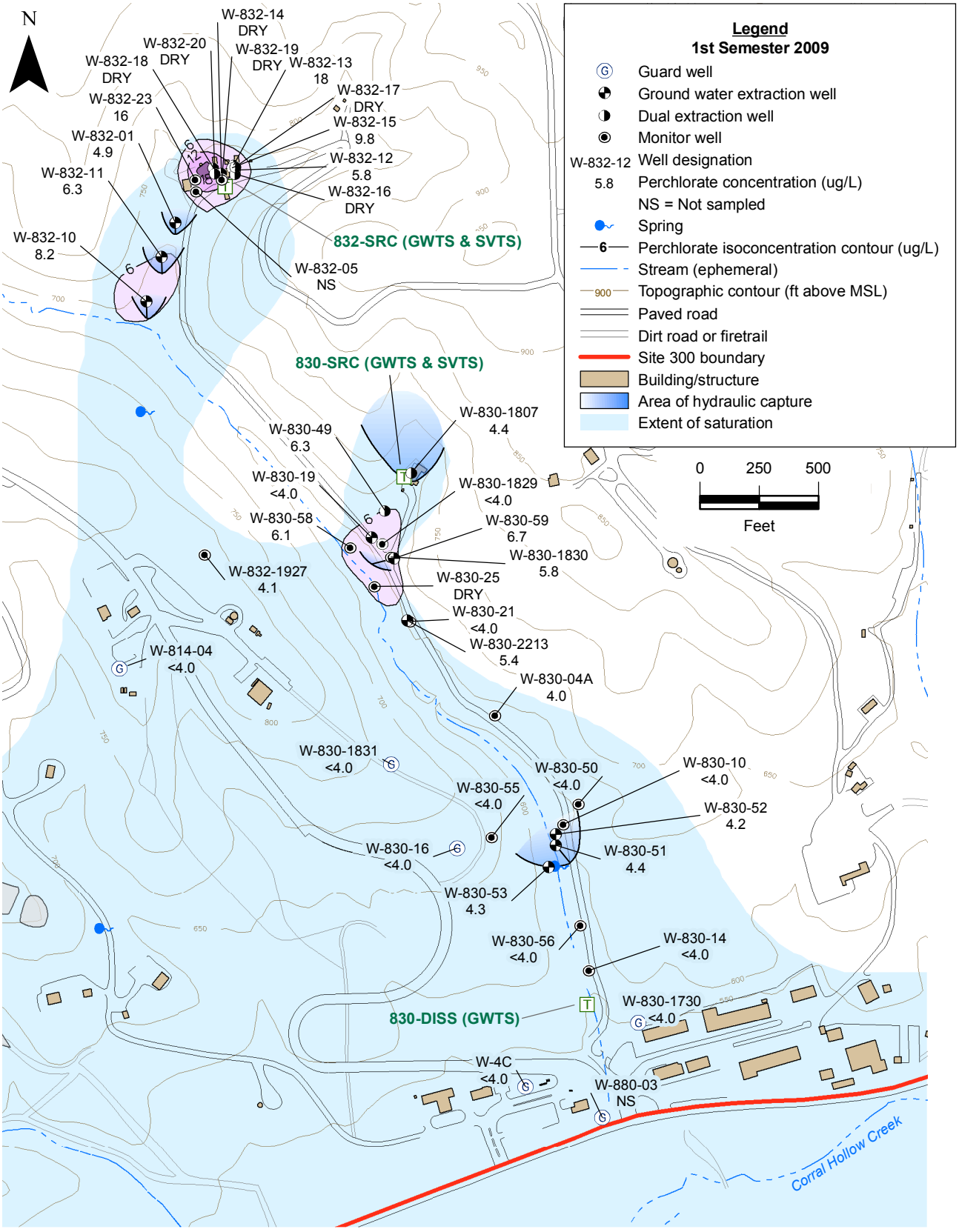

Figure 14. Perchlorate isoconcentration contour map for the $Tnsc_{1b}$ HSU.

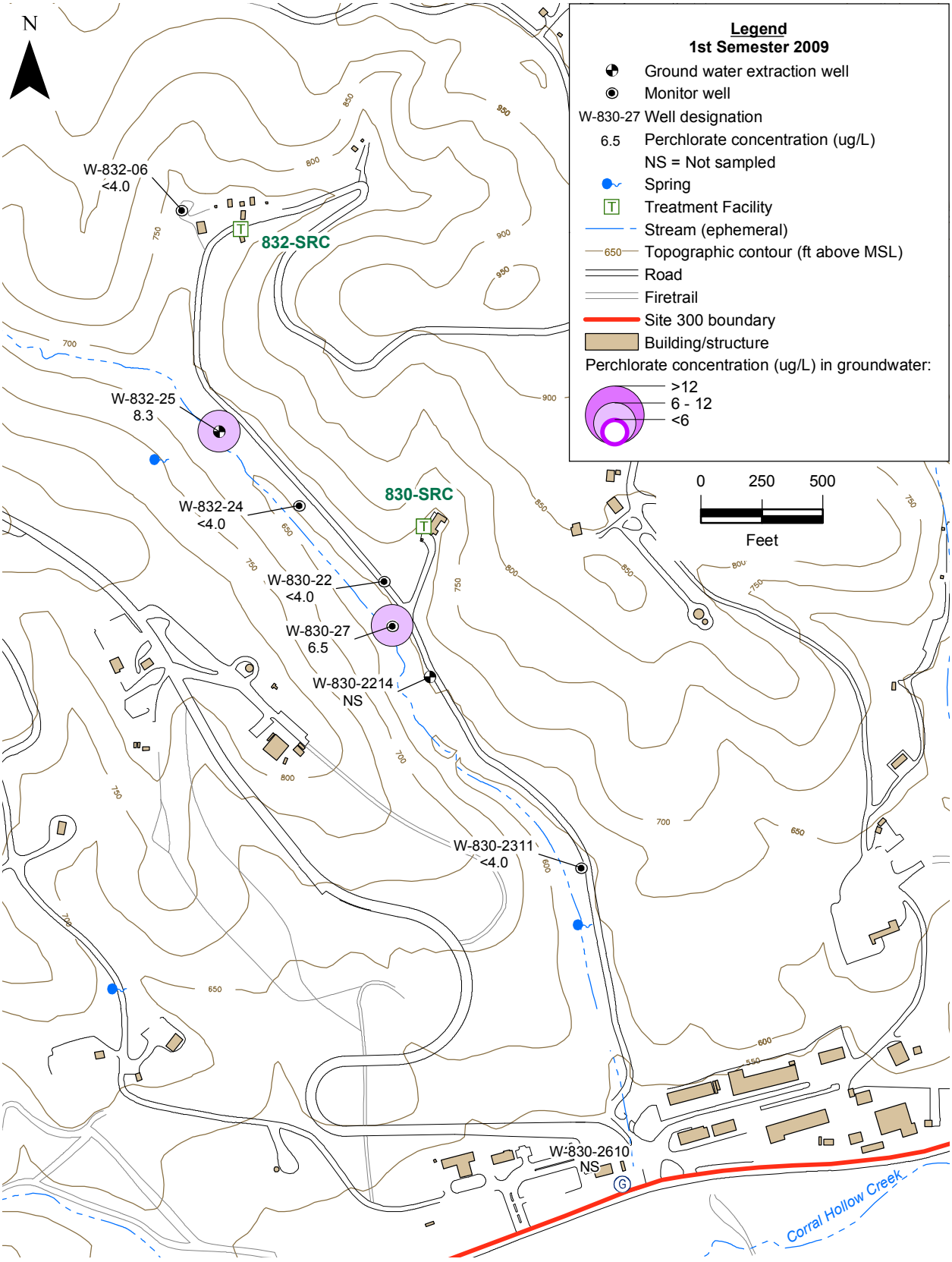

Figure 15. Perchlorate concentrations for the $Tnsc_{1a}$ HSU.

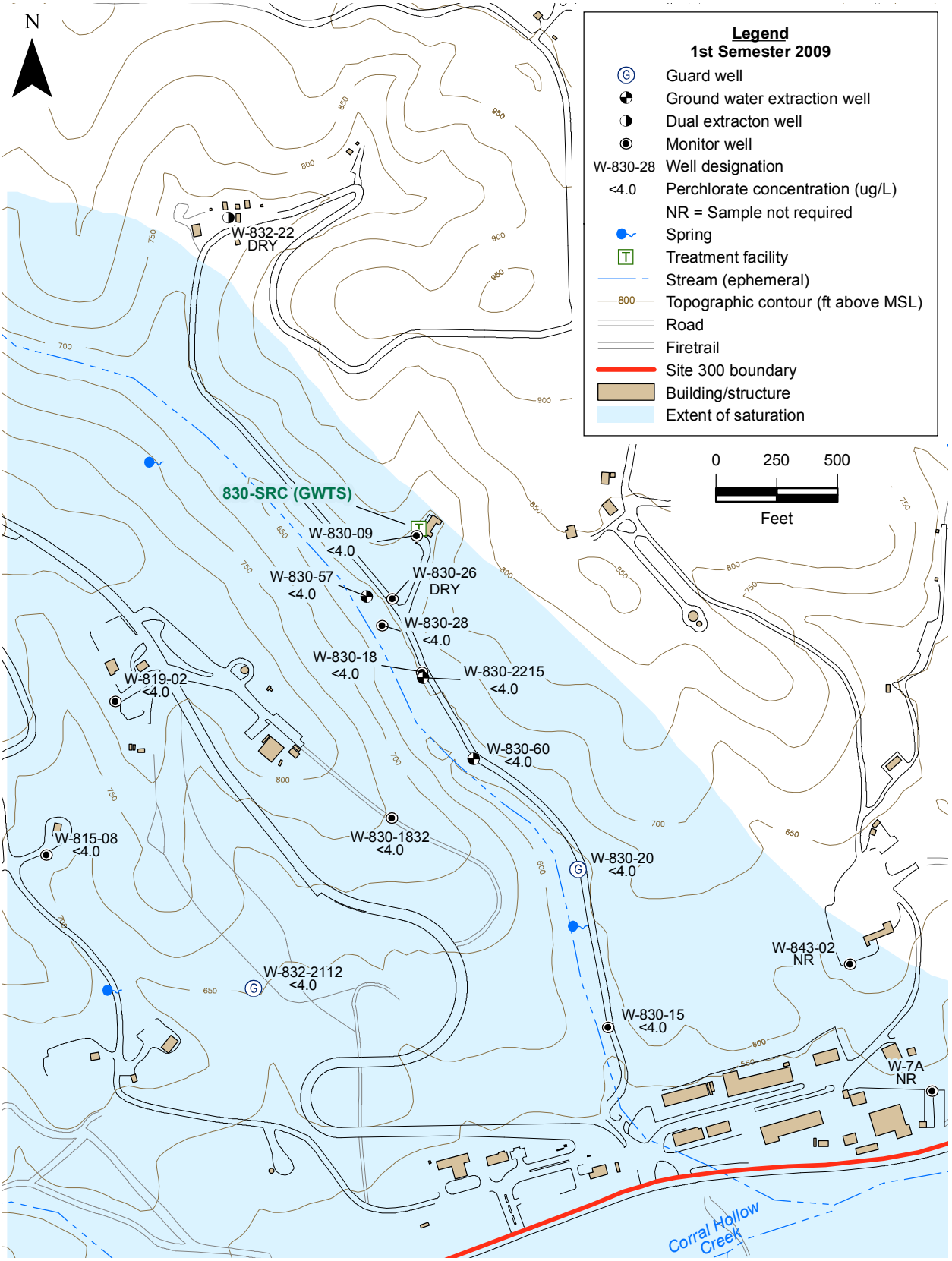

Figure 16. Perchlorate concentrations for the Upper $Tnbs_1$ HSU.

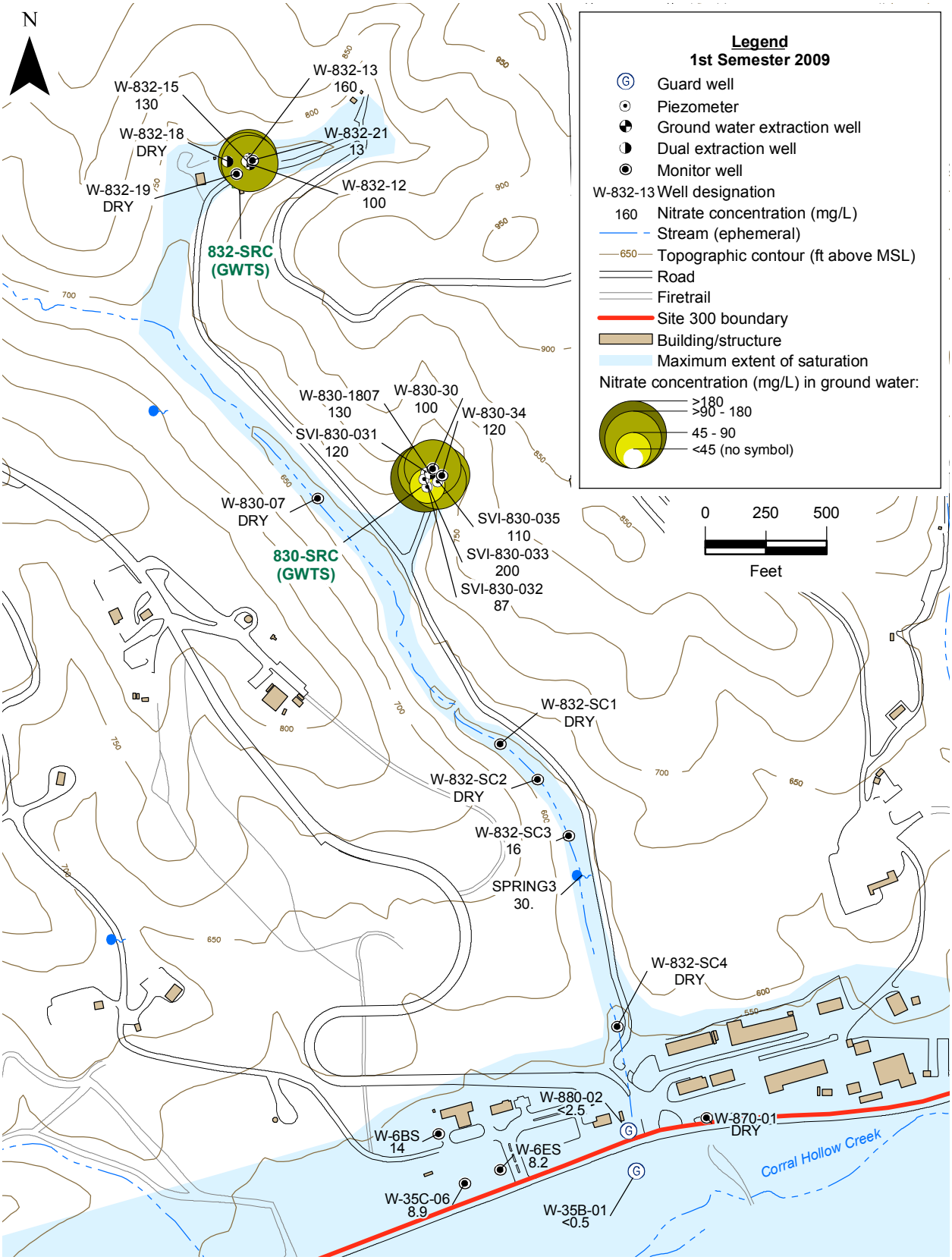

Figure 17. Nitrate concentrations for the Qal/WBR HSU.

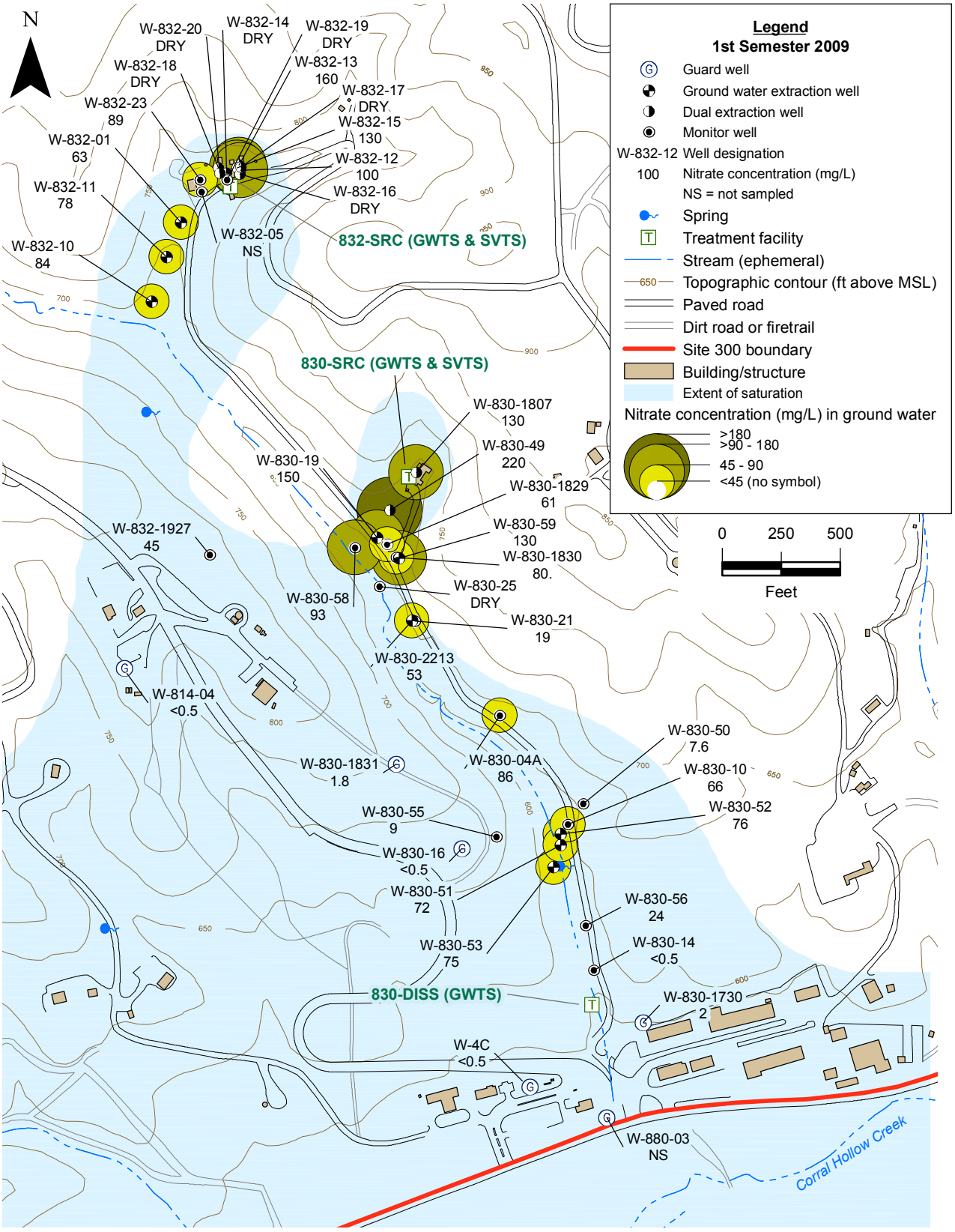

Figure 18. Nitrate concentrations for the $Tnsc_{1b}$ HSU.

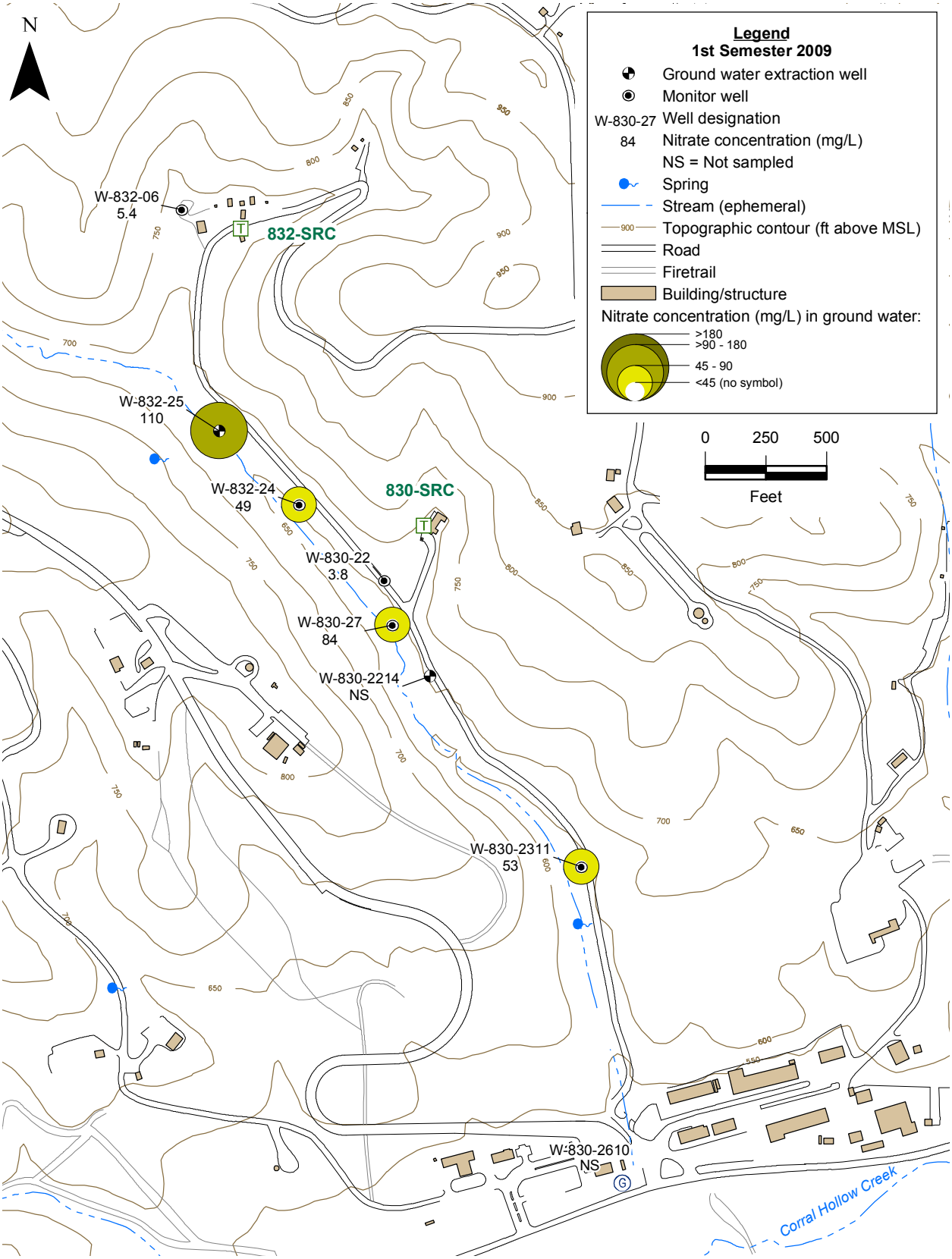

Figure 19. Nitrate concentrations for the $Tnsc_{1a}$ HSU.

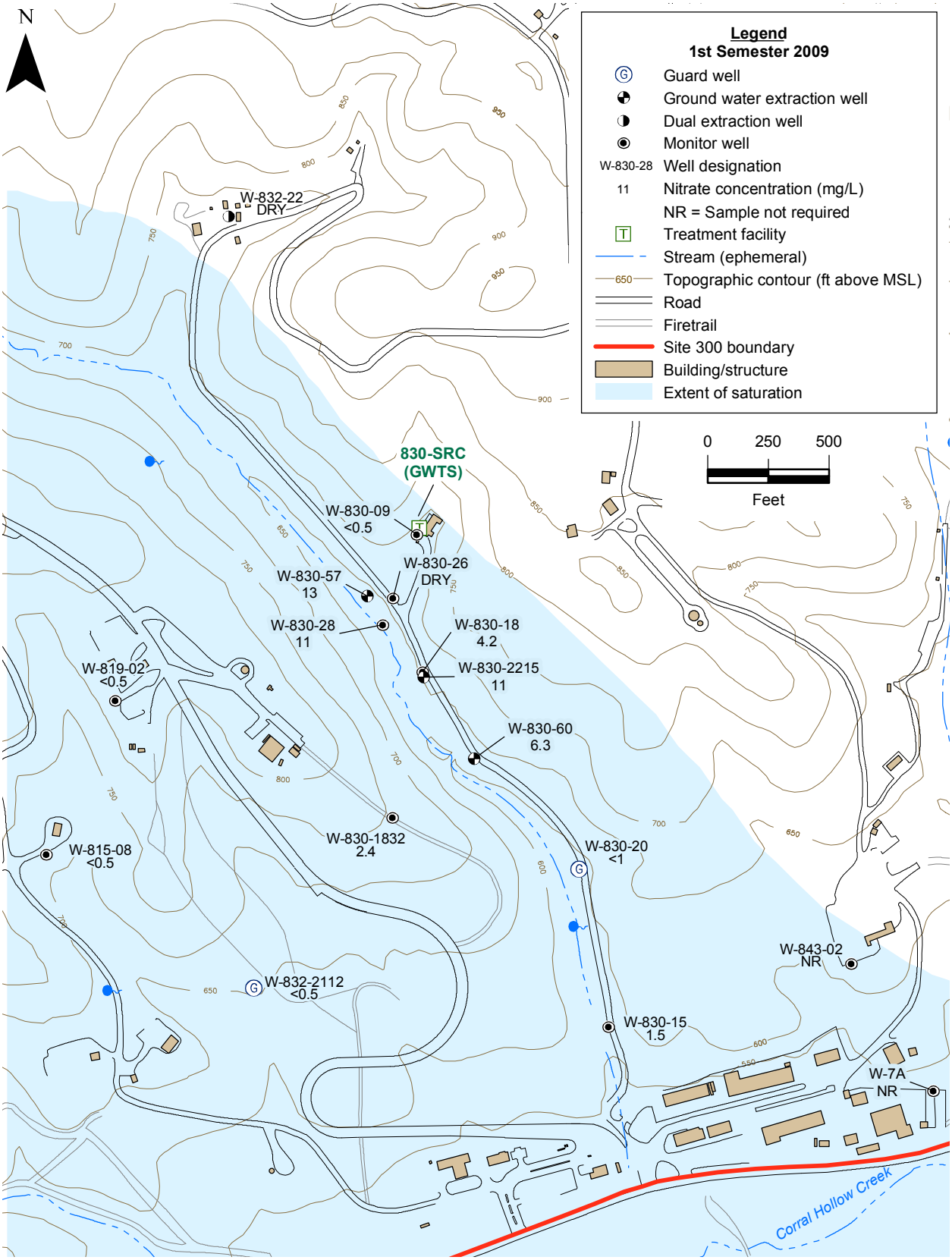

Figure 20. Nitrate concentrations for the Upper $Tnbs_1$ HSU.

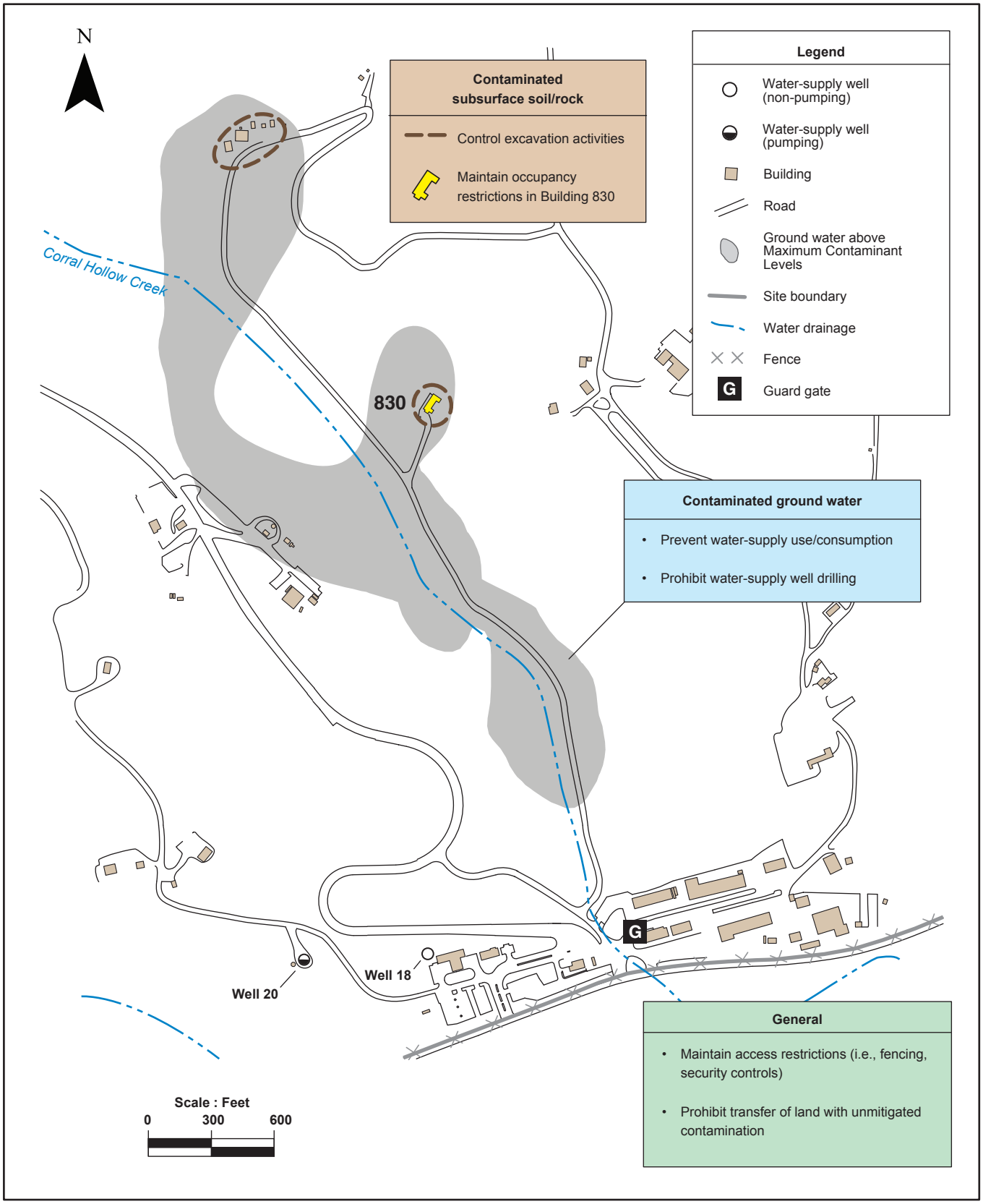

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Figure 21. Institutional/land use controls.

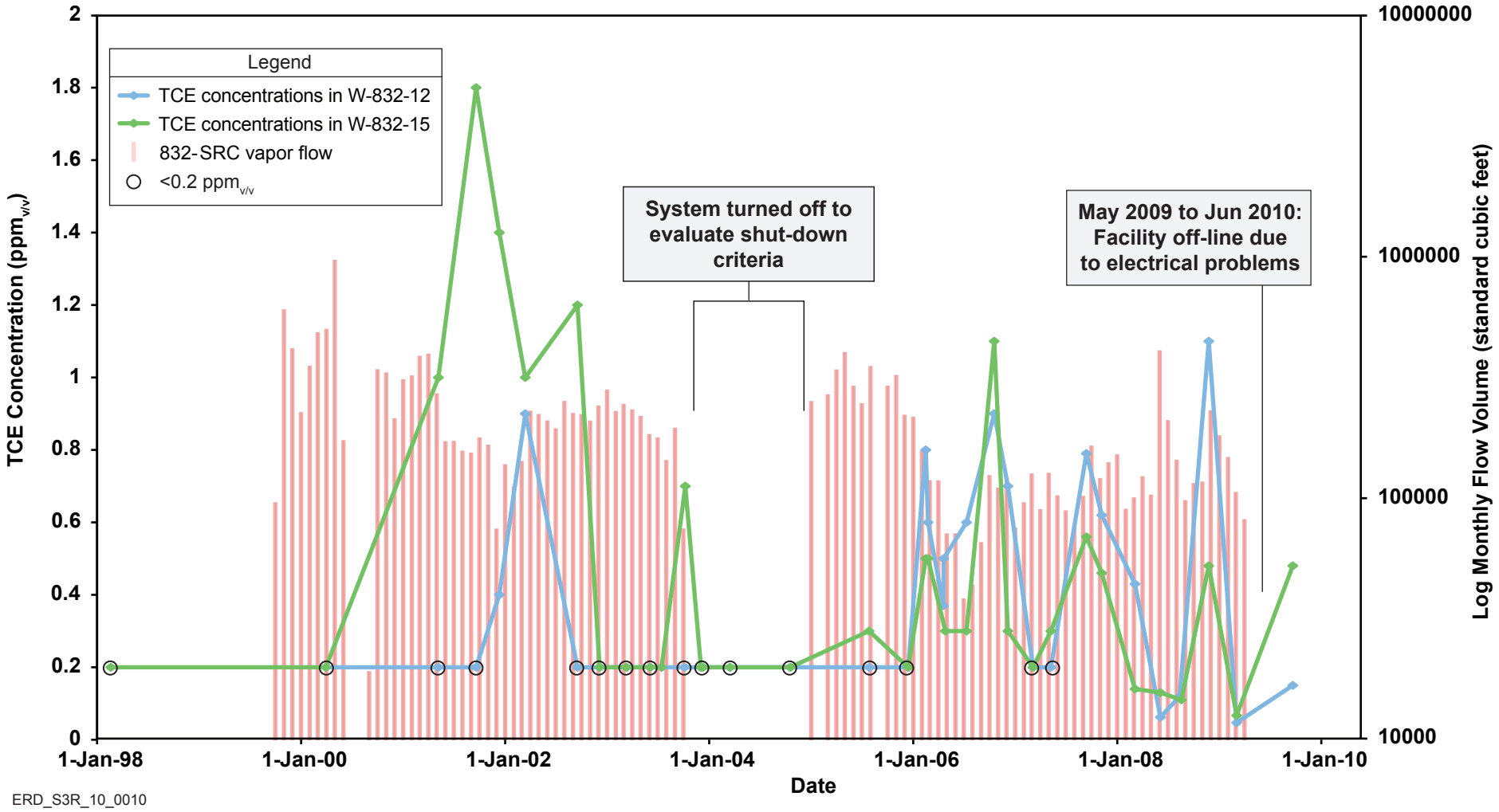

Figure 22. 832-SRC soil vapor extraction and treatment system: extraction well trichloroethene (TCE) vapor and monthly facility flow.

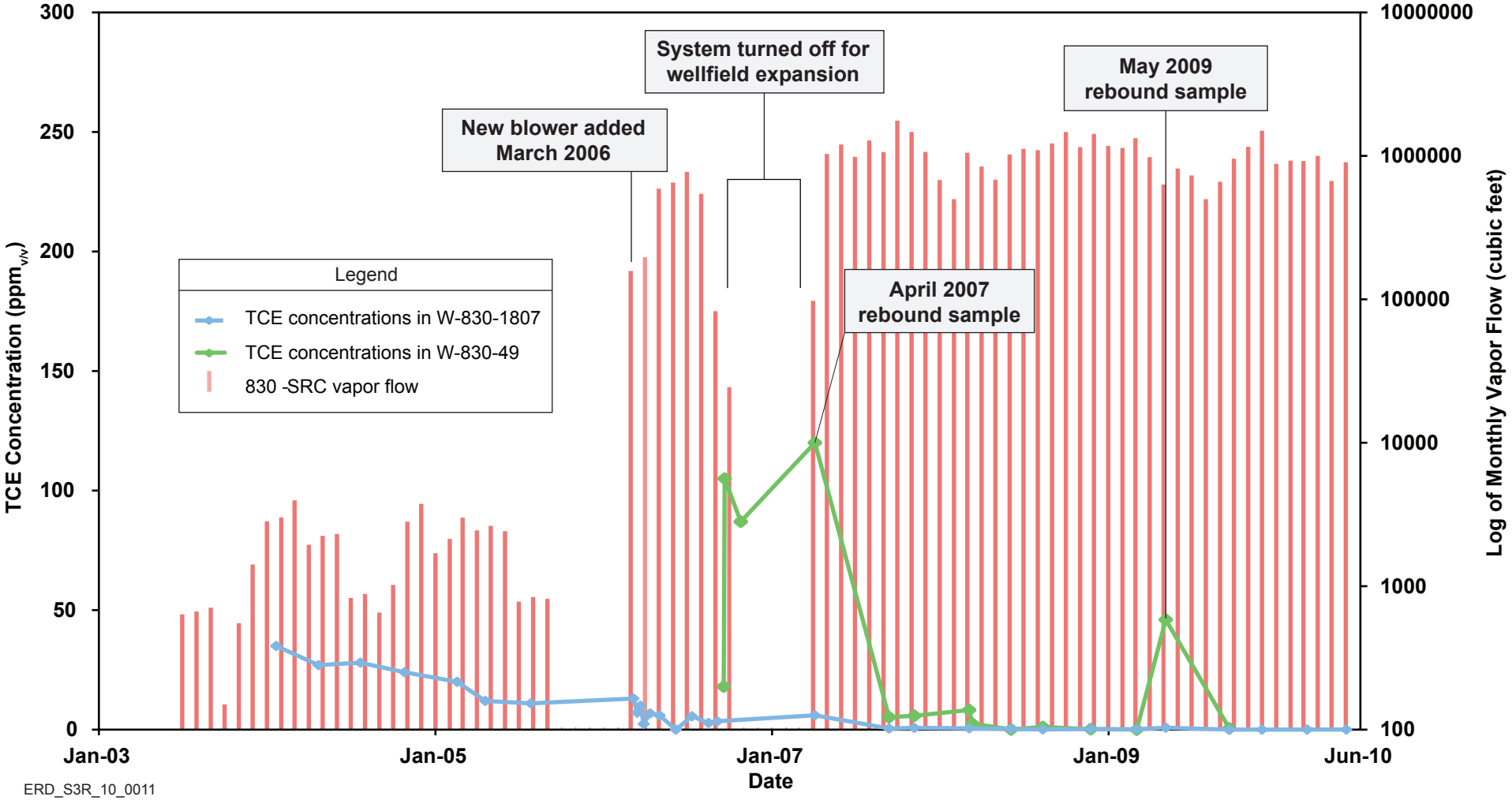

Figure 23. 830-SRC soil vapor extraction and treatment system: extraction well trichorothene (TCE) vapor and monthly facility flow.

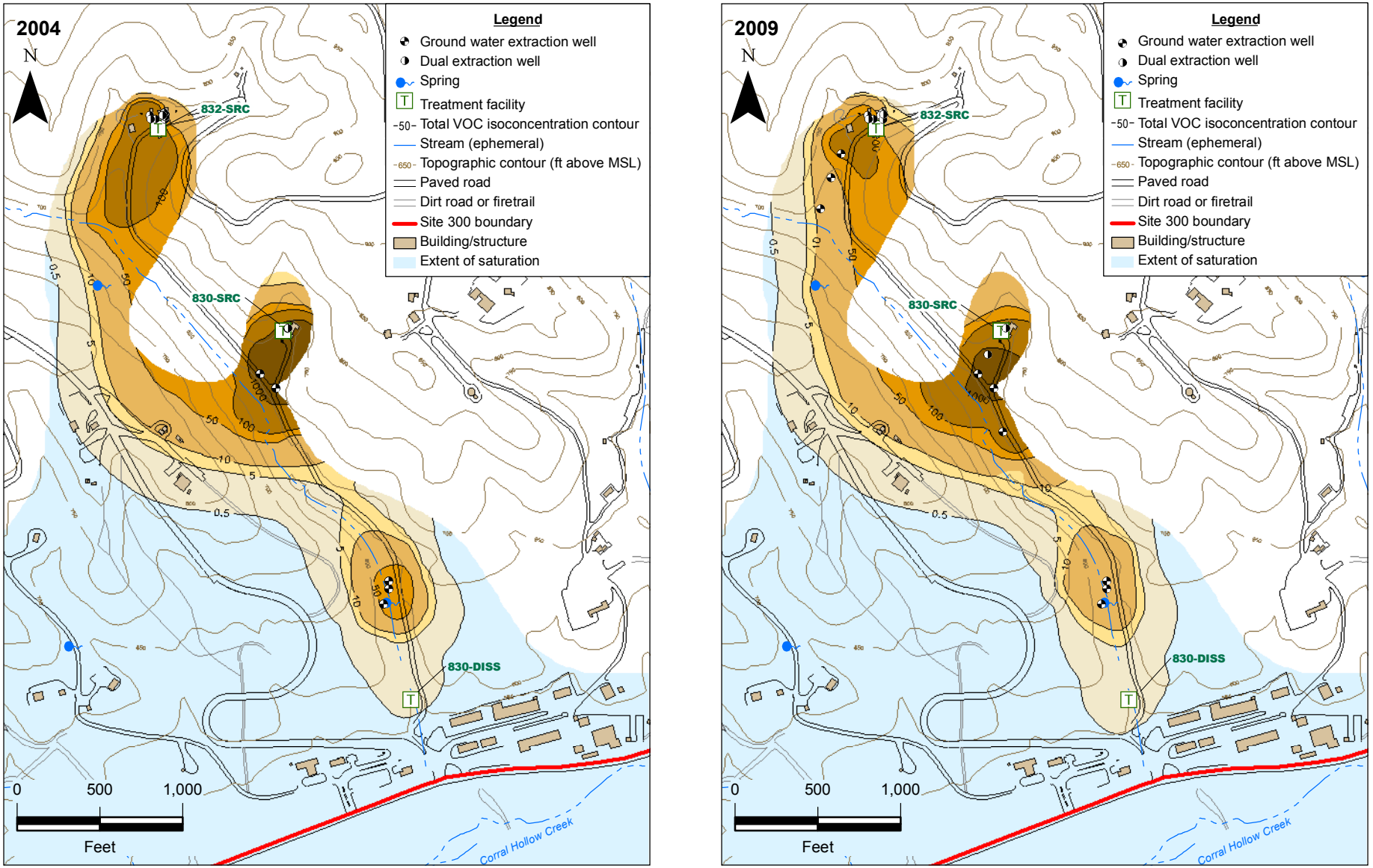

Figure 24. Comparison of existing extraction wells and the distribution of total volatile organic compounds (TVOCs) in ground water in the $Tnsc_{1b}$ hydrostratigraphic unit in second semester 2004 and second semester 2009.

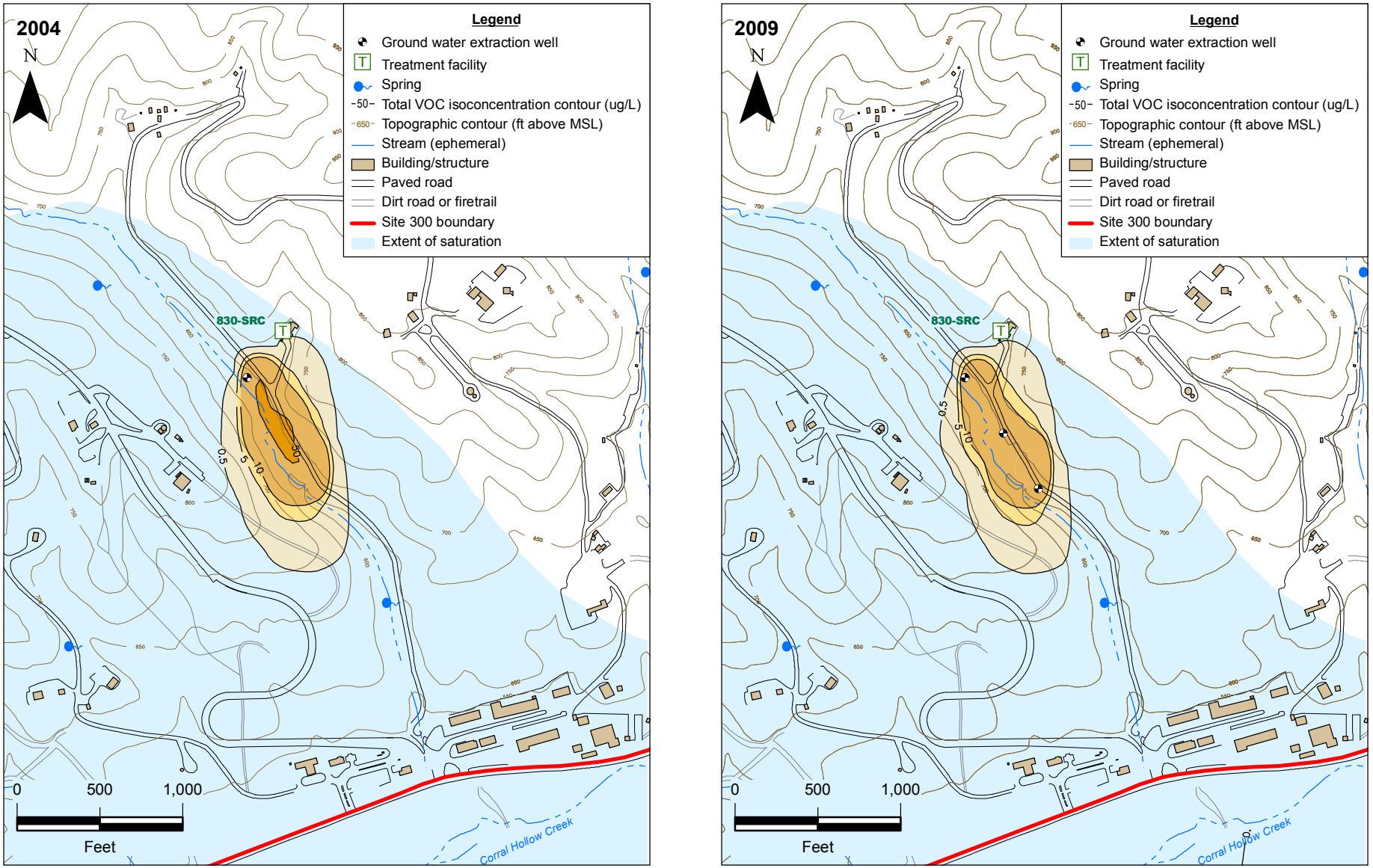

Figure 25. Comparison of existing extraction wells and the distribution of total volatile organic compounds (TVOCs) in ground water in the Upper $Tnbs_1$ hydrostratigraphic unit in second semester 2004 and second semester 2009.

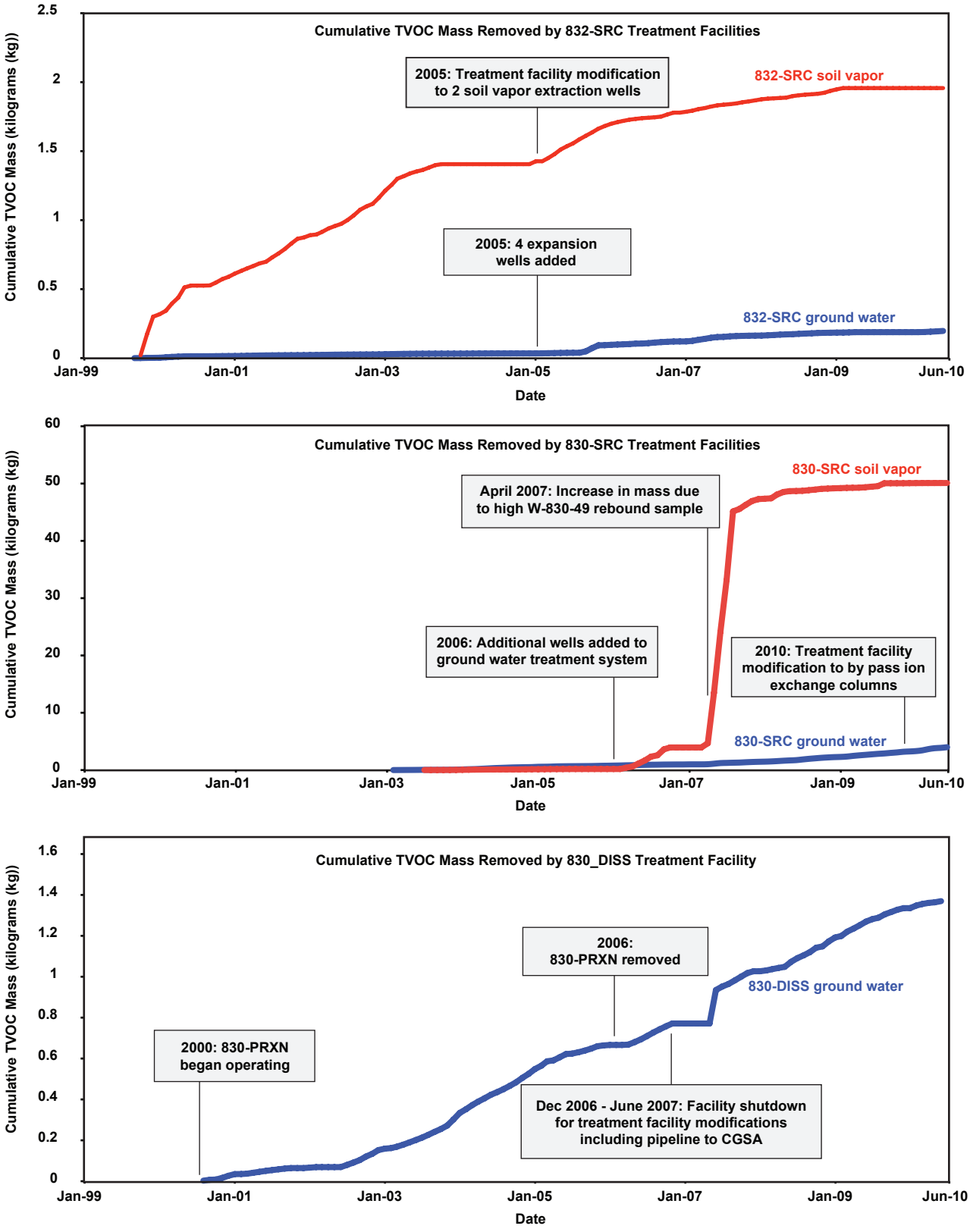

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Figure 26. Time-series plots of cumulative total volatile organic compound (TVOC) mass removed.

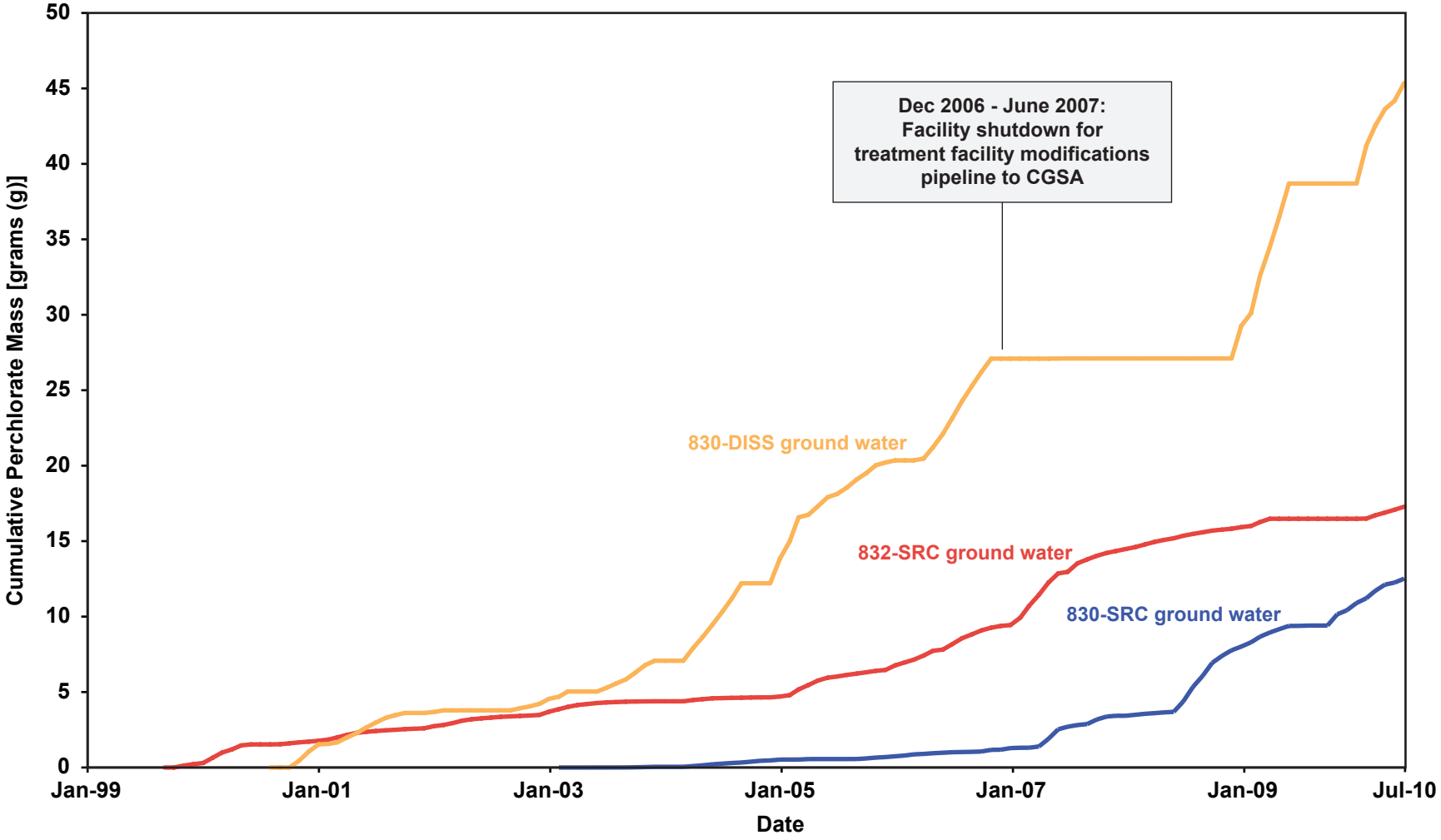


Figure 27. Time-series plot of cumulative perchlorate mass removed.

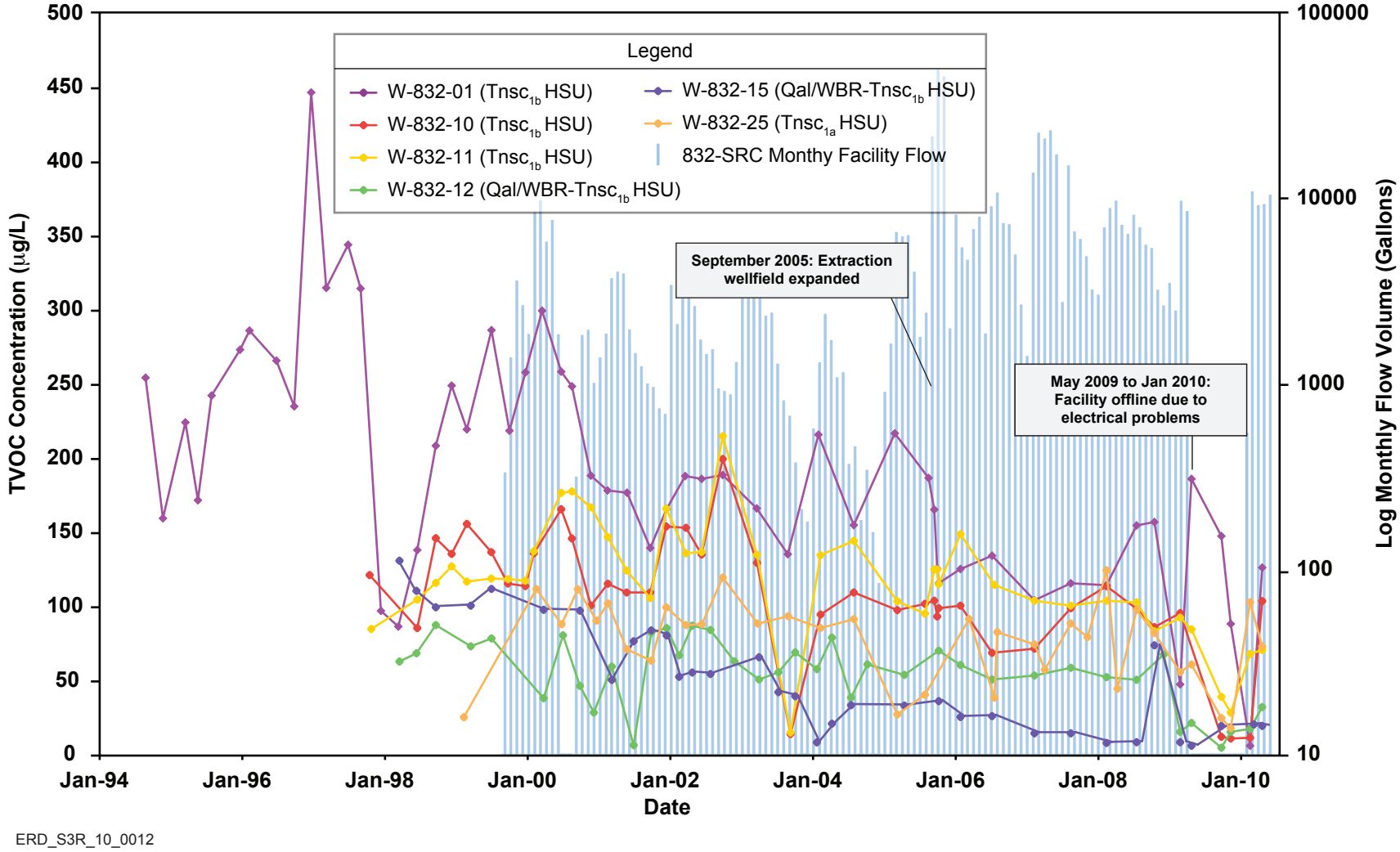
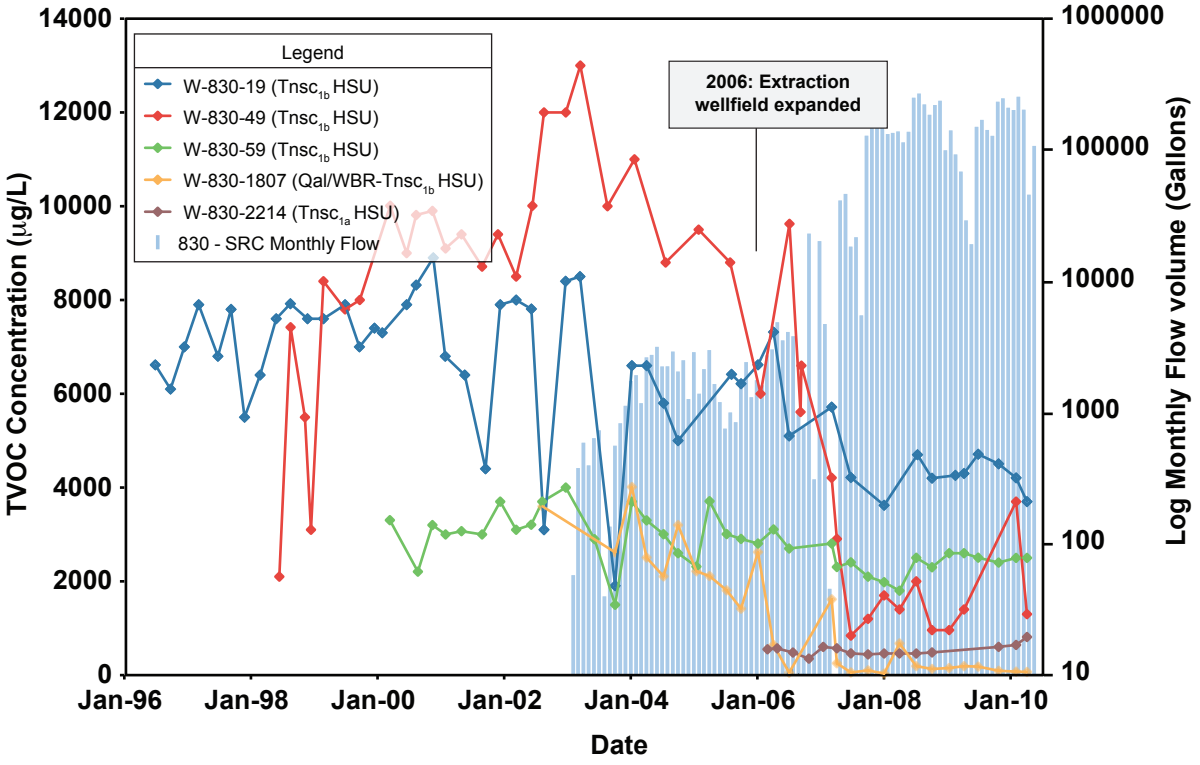


Figure 28. 832-SRC ground water extraction and treatment system: extraction well total volatile organic compound (TVOC) concentrations and monthly facility flow.

830-SRC Extraction Well ($Tnsc_{1a}$ & $Tnsc_{1b}$) TVOC Concentrations and Monthly Facility Flow



830-SRC Extraction Well ($UTnbs_1$) TVOC Concentrations and Monthly Facility Flow

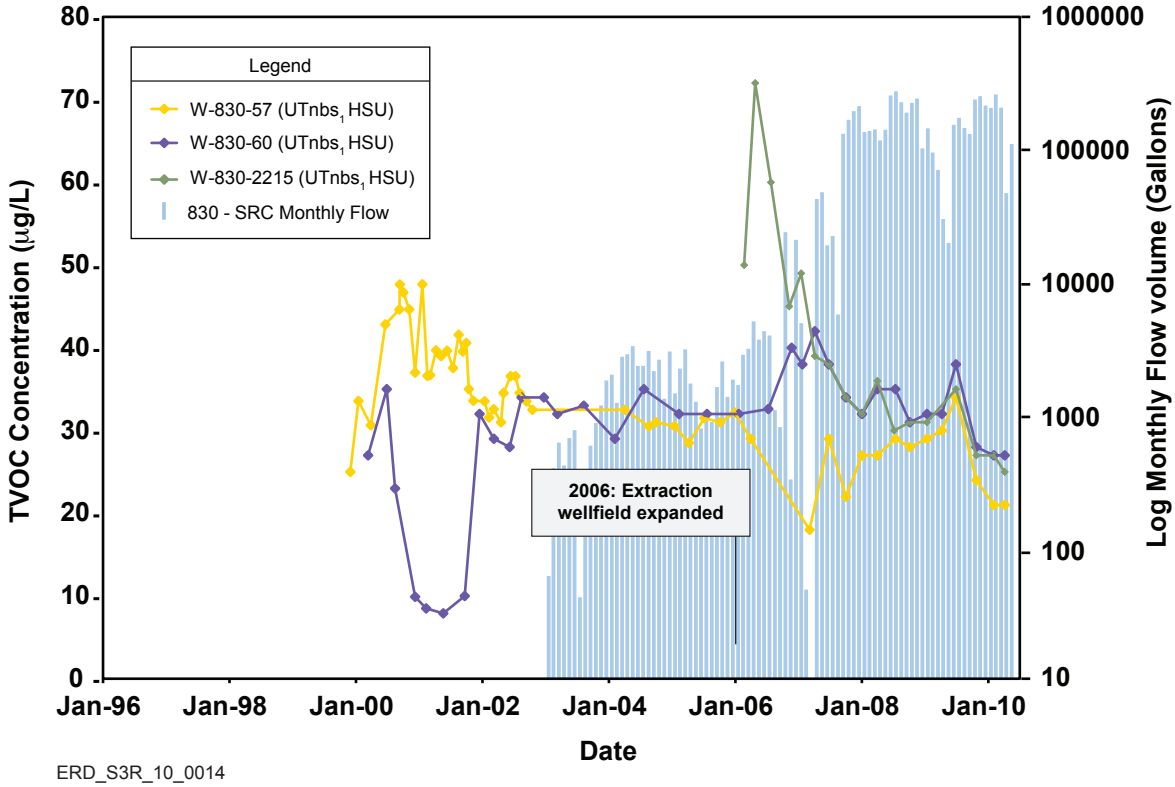


Figure 29. 830-SRC ground water extraction and treatment system: extraction well total volatile organic compound (TVOC) concentrations and monthly facility flow.

Tables

List of Tables

Table 1. Actual annual costs for the Building 832 Canyon Operable Unit for fiscal years 2006 through 2010.

Fiscal Year	Annual Budget	Actual Annual Cost	Cost Variance	Cost Variance Explanation
2006	$976,423	$1,167,440	-$191,017	Modifications to the 830-Distal South and expansion of Building 832-Source scheduled for FY 2007 were accelerated.
2007	$633,911	$605,370	$28,541	The FY was on budget (within +/-5% tolerance limits).
2008	$504,374	$343,811	$160,563	FY 2008 was under budget due to lower than expected O&M and optimization costs.
2009	$752,699	$717,371	$35,328	Two wells were not drilled as planned. Building 830-Source and Building 830-Distal South O&M cost more than planned.
2010	$630,392	$785,086	-$154,694	FY 2009 wells were drilled in FY 2010.

Notes:
FY = Fiscal year.
O&M = Operations and maintenance.

Table 2. Description of institutional/land use controls for the Building 832 Canyon Operable Unit.

Institutional/land use control performance objective and duration	Risk necessitating institutional/land use control	Institutional/land use controls and implementation mechanism
Prevent water-supply use/consumption of contaminated groundwater until ground water cleanup standards are met.	VOCs, nitrate, and perchlorate concentrations in ground water exceeding drinking water standards.	There are no existing or planned water-supply wells in the Building 832 Canyon Operable Unit. Any proposed well drilling activities would be submitted to the LLNL Work Induction Board, and are reviewed by the LLNL Environmental Restoration Department to ensure that new water-supply wells are not located in areas of ground water contamination. Prohibitions on drilling water-supply wells in areas of ground water contamination will be incorporated into the LLNL Site 300 Integrated Strategic Plan or other appropriate institutional planning documents. Contamination is limited to onsite ground water and ground water extraction is underway at the distal portion of the VOC plume to prevent offsite migration. Therefore, land use controls are not needed to prevent offsite water-supply use/consumption of contaminated ground water.
Control excavation activities to prevent onsite worker exposure to VOCs in subsurface soil until it can be verified that concentrations do not pose an exposure risk to onsite workers.	Potential exposure to VOCs, HMX, and nitrate at depth in subsurface soil at the Building 832 Canyon Operable Unit[a].	All proposed excavation activities must be cleared through the LLNL Work Induction Board and require an excavation permit. The Work Induction Board coordinates with the LLNL Environmental Restoration Department to identify if there is a potential for exposure to contaminants in the proposed construction areas. If a potential for contaminant exposure is identified, LLNL Hazards Control ensures that hazards are adequately evaluated and necessary controls identified and implemented prior to the start of work. The Work Induction Board including the LLNL Environmental Analyst will also work with the Program proposing the construction project to determine if the work plans can be modified to move construction activities outside of areas of contamination.

Table 2. Description of institutional/land use controls for the Building 832 Canyon Operable Unit (continued).

Institutional/land use control performance objective and duration	Risk necessitating institutional/land use control	Institutional/land use controls and implementation mechanism
Maintain building occupancy restriction to prevent onsite site worker inhalation exposure to VOCs inside Building 830 until annual risk re-evaluation indicates that the risk is less than 10^{-6}.	A pre-remediation risk of 3×10^{-6} was identified for onsite workers from inhalation of VOCs volatilizing from subsurface soil into ambient air inside Building 830.	Building 830 is not currently occupied. Warning signs will be maintained prohibiting full time occupancy without notification and authorization by LLNL Site 300 Management. Any significant changes in activities conducted in Building 830 must be cleared through the LLNL Work Induction Board. The Work Induction Board coordinates with the LLNL Environmental Restoration Department to identify if there is a potential for exposure to contaminants as a result of the proposed building usage. If a potential for contaminant exposure is identified as a result of the changes in building use, LLNL Hazards Control will be notified and determine any necessary engineered control requirements to prevent exposure. If full-time building occupancy is proposed, engineering controls will be implemented to prevent onsite worker exposure that could migrate from the subsurface into the building until the inhalation risk was mitigated through remediation. The building occupancy restrictions will be incorporated into the LLNL Site 300 Integrated Strategic Plan or other appropriate institutional planning documents. DOE will conduct annual risk re-evaluations to determine when the inhalation risk inside Building 830 has been mitigated. The risk re-evaluation results will be reported in the Annual Site-Wide Compliance Monitoring Reports. A pre-remediation risk of 3×10^{-6} was identified for onsite workers from potential inhalation of VOCs volatilizing from subsurface soil into ambient air inside Building 832F. The indoor air risk for Building 832F has been successfully mitigated since 2004 through ground water and soil vapor extraction and treatment, therefore this institutional/land use control is no longer needed to prevent onsite worker exposure to VOCs inside Building 832F. The baseline risk assessment also identified a human cancer risk of 1×10^{-5} for onsite workers continuously inhaling VOC vapors volatilizing from the vadose zone into outdoor air in the vicinity of Building 830 over a 25-year period, however this risk has been successfully mitigated since 2004 through ground water and soil vapor extraction and treatment, therefore this institutional/land use control is no longer needed to prevent onsite worker exposure to VOCs in outdoor air.

Table 2. Description of institutional/land use controls for the Building 832 Canyon Operable Unit (continued).

Institutional/land use control performance objective and duration	Risk necessitating institutional/land use control	Institutional/land use controls and implementation mechanism
Maintain land use restriction in the vicinity of Spring 3 until annual risk re-evaluation indicates that the risk is less than 10^{-6}.	A pre-remediation risk of 7×10^{-5} for onsite workers inhaling VOC vapors volatilizing from Spring 3 into outdoor air.	The risk to onsite workers inhaling VOC vapors volatilizing from surface water into the air in the vicinity of Spring 3 has been mitigated since 2009 through ground water and soil vapor extraction and treatment, therefore this institutional/land use control is no longer needed to prevent onsite worker exposure to VOCs in outdoor air.
Prohibit transfer of lands with unmitigated contamination that could cause potential harm under residential or unrestricted land use.	Potential exposure to contaminated waste and/or environmental media.	The Site 300 Federal Facility Agreement contains provisions that assure that DOE will not transfer lands with unmitigated contamination that could cause potential harm. In the event that the Site 300 property is transferred in the future, DOE will execute a land use covenant at the time of transfer in compliance with Title 22 California Code of Regulations, Division 4.5, Chapter 39, Section 67391.1. Development will be restricted to industrial land usage. These restrictions will remain in place until and unless a risk assessment is performed in accordance with then current U.S. EPA risk assessment guidance and is agreed by the DOE, U.S. EPA, DTSC, and the RWQCB as adequately showing no unacceptable risk for residential or unrestricted land use. These restrictions will be incorporated into the LLNL Site 300 Integrated Strategic Plan or other appropriate institutional planning document.

Notes:

DOE = United States Department of Energy.

DTSC = California Department of Toxic Substances Control.

U.S. EPA = United States Environmental Protection Agency.

LLNL = Lawrence Livermore National Laboratory.

RWQCB = California Regional Water Quality Control Board.

VOCs = Volatile organic compounds.

[a] **Risk for onsite worker exposure to VOCs at depth in subsurface soil during excavation activities was not calculated as this was not considered a long-term exposure scenario. As a result, land use controls based on the potential exposure to VOCs in subsurface soil during excavation activities conservatively assume that the VOCs in subsurface soil may pose a risk to human health.**

Table 3. Historical and current maximum concentrations of trichloroethene (TCE), perchlorate and nitrate by hydrostratigraphic unit in the Building 832 Canyon Operable Unit compared to ground water cleanup standards.

HSU	Constituent	Historical			Current			Cleanup Standard
		Maximum Concentration	Sample Location	Sample Date (month/year)	Maximum Concentration*	Sample Location	Sample Date (month/year)	
Qal/WBR								
	TCE	10,000 µg/L	SVI-830-035	2/03	1,100 µg/L	SVI-830-035	3/10	5 µg/L
	Perchlorate	51 µg/L	W-830-34	12/98	17.3 µg/L	W-832-18	3/10	6 µg/L
	Nitrate	240 mg/L	SVI-830-033	3/08	180 mg/L	SVI-830-033	3/10	45 mg/L
$Tnsc_{1b}$								
	TCE	13,000 µg/L	W-830-49	3/3	4200 µg/L	W-830-19	2/10	5 µg/L
	Perchlorate	26 µg/L	W-830-58	5/01	17 µg/L	W-832-18	3/10	6 µg/L
	Nitrate	501 mg/L	W-830-49	6/98	190 mg/L	W-830-49	2/10	45 mg/L
$Tnsc_{1a}$								
	TCE	1,700 µg/L	W-830-27	6/98	810 µg/L	W-830-2214	4/10	5 µg/L
	Perchlorate	13 µg/L	W-832-25	2/99	7.3 µg/L	W-832-25	2/10	6 µg/L
	Nitrate	160 mg/L	W-830-27	9/02	88 mg/L	W-832-25	2/10	45 mg/L
Upper $Tnbs_1$								
	TCE	100 µg/L	W-830-28	6/98	27 µg/L	W-830-2215 W-830-60	2/10	5 µg/L
	Perchlorate	15 µg/L	W-830-57	8/04	<4 µg/L	NA	NA	6 µg/L
	Nitrate	20.8 mg/L	W-830-28	8/97	9.7 mg/L	W-830-2215	2/10	45 mg/L

Notes:

***As of 1st Semester 2010.**

Maximum concentrations shown on figures are from 2nd Semester 2009 not 1st Semester 2010.

HSU = Hydrostratigraphic unit.
mg/L = Milligrams per liter.
NA = Not applicable.
µg/L = Micrograms per liter.

Appendix A

Ground Water Flow and Contaminant Transport Modeling and Preliminary Cleanup Time Predictions

Appendix A
Ground Water Flow and Contaminant Transport Modeling and Preliminary Cleanup Time Predictions

A-1. Objective

The primary objective of the ground water flow and contaminant transport modeling was to provide a set of decision-making tools that can be used to refine DOE/LLNS' understanding of groundwater flow and contaminant transport within the Building 832 Canyon Operable Unit. The models also serve as a framework for organizing field and laboratory data and were used to develop preliminary estimates of the time required to achieve cleanup standards within the $Tnsc_{1b}$ and Upper $Tnbs_1$ ($UTnbs_1$) hydrostratigraphic units (HSUs). When fully calibrated, the models will also be used as to aid in extraction wellfield management and design, including capture zone analysis. Each model simulates the transport of trichloroethene (TCE), the primary contaminant of concern (COC) in the Building 832 Canyon OU.

A-2. Conceptual Model

The $Tnsc_{1b}$ and $UTnbs_1$ HSUs were each modeled separately and simulate single-phase (saturated-zone) ground water flow within a single HSU. Both HSUs were modeled as confined, although actual field conditions vary from unconfined to confined. This assumption of confined conditions is common and provides a reasonable approximation of field conditions without adding unnecessary complexity in the initial stages of model development. The conceptual model of flow and transport within these HSUs is described in Section 3 (Background) of this report.

The following assumptions apply to both models:

- The models were built by discretizing a single layer into three dimensions; however, due to vertically averaged properties, the models are representative of a two-dimensional domain.
- Models solve for steady-state ground water flow and transient transport.
- HSUs are homogeneous and isotropic within distinct zones.
- TCE was the only chemical species modeled.
- Retardation effects were considered using a sensitivity analysis.
- Flow and transport occur only through porous media. Fracture flow is ignored.
- Biological effects are assumed negligible.
- Models are isothermal.

A-3. Model Description

A-3.1. Numerical Code

All modeling was conducted using FEFLOW, a finite element subsurface flow and transport simulation system developed at the Institute for Water Resources Planning and Systems

Research, Ltd. (Diersch, 1998). Version 4.8, which was used for the simulations, features an interactive graphical interface and PEST, an add-in module for automated parameter estimation. Details about the equations governing ground water flow and contaminant transport are included in FEFLOW's reference manual (Diersch, 1998).

A-3.2. Model Domain and Grid

Figures A-1 and A-2 show the domains used for the $Tnsc_{1b}$ HSU and $UTnbs_1$ HSU models, respectively. The northern, eastern, and western boundaries of the model domains were chosen to approximately outline the extent of saturation within the $Tnsc_{1b}$ and $UTnbs_1$ HSUs. The southern boundary of each model extends past the site boundary and Corral Hollow Road to include data from offsite wells. The initial model domain for the $Tnsc_{1b}$ HSU had 22,008 elements and 16,998 nodes, and covered approximately 378 acres. The initial model domain for the $UTnbs_1$ HSU had 20,634 elements and 16,008 nodes, and covered approximately 494 acres. The irregular, finite element meshes were created using FEFLOW's automated mesh generation program. The meshes were refined near the source areas to minimize problems with numerical dispersion during the transport calibration. Figure A-3 shows a three-dimensional visualization of the grid used for the $UTnbs_1$ model. In each model, the HSU of concern was modeled as a separate 3-dimensional layer. Mass balances were checked after flow and transport were calibrated to confirm that the mesh was adequately refined.

A-3.3. Boundary Conditions, Aquifer Type, Top and Bottom Layers

Boundary conditions were selected based on an analysis of expected recharge to and discharge from, the $Tnsc_{1b}$ and $UTnbs_1$ HSUs. Recharge to the $UTnbs_1$ model was primarily along the western boundary and recharge to the $Tnsc_{1b}$ model was primarily along the eastern and northern boundaries north of the Building 830 and 832 source areas. In both models, these boundaries represent inflow from the catchment area and from where narrow canyons intersect with the model boundaries. Recharge also occurs where the $Tnsc_{1b}$ or $UTnbs_1$ stratigraphic units are exposed at the surface. Because of the steep topography and high evapotranspiration rates at Site 300, areal recharge was not expected to be significant within the model domain and hence, only a small areal recharge was applied. Discharge from each model was expected to occur along the southeastern border of the model where the $Tnsc_{1b}$ and $UTnbs_1$ sub-crop beneath the Quaternary alluvium HSU and an upward gradient is present. Boundary conditions for the $Tnsc_{1b}$ HSU and the $UTnbs_1$ HSU models are shown on Figures A-1 and A-2, respectively. On each figure, boundaries with a net influx of groundwater are shown in red and discharge boundaries are shown in blue.

Recharge and discharge model boundaries were initially set as constant head based on ground water elevation data, and revised as appropriate during the flow calibration (see Section A-3.5). Recharge boundaries using 'constant head' boundary conditions were changed to 'specified flux' boundary conditions when using the models for forward simulations such as predicting the time to achieve cleanup standards. Top boundaries in both models had a small amount of areal recharge, primarily applied to the unconfined portions of each aquifer. This infiltration accounted for less than ten percent of the total recharge. Bottom boundaries of the model were no flow, and the surfaces used to create these layers were imported from a 3-dimensional (3-D) geologic model specifically developed for the southeast corner of Site 300.

A-3.4. Input Parameters

A-3.4.1. Flow Model Input Parameters

For the $Tnsc_{1b}$ HSU, hydraulic conductivity for the calibrated model was approximately 1.0 feet per day (ft/day) near the Building 830 source area and 0.25 ft/day near the Building 832 source area (Figure A-1). Hydraulic conductivity within the aquifer was calibrated as described in Section A-3.5.1. A non-uniform hydraulic conductivity (K) (uniform within discrete zones) was used to better match the observed ground water elevation data and to match the lower yields observed in the Building 832 source area. Hydraulic conductivities used to model the $Tnsc_{1b}$ HSU in the *Interim Remedial Design for the Building 832 Canyon Operable Unit* (RD) (Madrid et al., 2006) were also an order of magnitude lower in the Building 832 source area.

For the $UTnbs_1$ HSU, hydraulic conductivity for the calibrated model was 1.2 ft/day in the northern portion of the model domain and 1 ft/day in the southern portion of the model domain (Figure A-2). Hydraulic conductivity within the aquifer was calibrated as described in Section A-3.5.1. A non-uniform hydraulic conductivity (K) (uniform within discrete zones) was used to better match the observed ground water elevation data, with lower conductivities near the southern model boundary where the $UTnbs_1$ subcrops beneath the Quaternary alluvium HSU. Hydraulic conductivities used to model the $UTnbs_1$ HSU in the RD also averaged one foot per day.

A-3.4.2. Transport Model Input Parameters

For both the $Tnsc_{1b}$ and $UTnbs_1$ HSUs, a porosity value of 0.25 was chosen using average core porosity measured during laboratory testing (Madrid and Jakub, 1998). Initial concentrations of TCE used for production runs were based on second quarter 2009 data. TCE concentrations were input entered into FEFLOW at discrete points, and the program's linear interpolation scheme was used to assign values between data points. Minor adjustments were also made to ensure that the maximum concentrations in the initial concentration array matched the observed data. Values of less than 5 micrograms per liter (µg/L) TCE were set to a very low value to minimize problems with numerical dispersion during initial time steps. In the $UTnbs_1$ model, a longitudinal dispersivity of 10 meters (m) and a transverse dispersivity of 1 m, or 10% of the longitudinal dispersivity, were used for the cleanup time simulations. In the $Tnsc_{1b}$ model, a longitudinal dispersivity of 20 meters (m) and a transverse dispersivity of 5 m, or 25% of the longitudinal dispersivity, were used for the cleanup time simulations. Both the longitudinal and transverse dispersivities were calibrated as part of the transport calibration process.

A-3.5. Calibration

A-3.5.1. Flow Calibration

$Tnsc_{1b}$ Flow Calibration

The model was calibrated using FEFLOW's automated parameter estimation tool (PEST), which minimized the sum of the squared differences between measured and modeled head data at 17 observation wells located within the model domain. The initial hydraulic conductivities input entered into PEST were 1 ft/day for the Building 830 source area and 0.1 ft/day for the Building 832 source area. This range matched the values used to model the $Tnsc_{1b}$ HSU in the *Final Site-Wide Remediation Summary Report* (SWRSR) (Ferry et al., 2006). Calibrated values ranged from 1.0 to 0.25 ft/day. After initial calibration with PEST, minor (< 2 ft) adjustments in the initial specified head data used as boundary conditions were made to improve calibration results. The resulting ground water elevation map was also subject to visual inspection to confirm the direction of the flow gradient. Recharge to the model from the eastern boundary and through areal recharge [725 cubic feet per day (cfd)] was compared with independent estimates of recharge to the Neroly formation (4100 cfd) that were determined considering the size of the catchment area and assuming only 20% percentage of the total recharge to the Neroly formation is apportioned to the $Tnsc_{1b}$ HSU (Madrid et al., 2006).

The $Tnsc_{1b}$ HSU is a complex aquifer system with multiple source areas, faults, spatially variable aquifer properties, and an extent of saturation that is complex due to the localized nature of unit thickness and recharge. As part of the flow calibration, a comparison was made between measured and modeled ground water elevation data. Ground water elevation data collected in July 1996 were used for the initial calibration, and a steady-state pumping rate of 1 gallon per minute (gpm) at onsite water supply Wells 18 and 20 was assumed. Although the model was successful in matching the overall flow patterns, it was less successful in meeting more objective functions such as the average difference between measured and modeled data. In particular, modeled ground water levels in the Building 832 source area were significantly lower than measured in the field (Figure A-4). In the future, this area may be modeled separately to more accurately depict the limited recharge, low yields, and thin saturated thicknesses found in this area. As a result, all cleanup time estimates obtained from this model (particularly in the Building 832 source area) must be considered as preliminary until supported by a more robust modeling effort. Nevertheless, the model has been useful in developing a framework for organizing field and laboratory data and in refining our understanding of groundwater flow and contaminant transport within the $Tnsc_{1b}$ HSU. It will also provide a starting point for future modeling efforts.

$UTnbs_1$ Flow Calibration

The $UTnbs_1$ HSU model was calibrated using FEFLOW's automated parameter estimation tool (PEST), which minimized the sum of the squared differences between measured and modeled head data at 15 observation wells located within the model domain. The initial range of hydraulic conductivities used as input to PEST was similar to the range of values used to model cleanup time predictions for $UTnbs_1$ HSU in the SWRSR (Ferry et al., 2006). Calibrated values averaged approximately 1 ft/day. After initial calibration with PEST, minor (< 2 ft) adjustments in the initial specified head data used as boundary conditions were made to improve calibration results. The resulting ground water elevation map was also subject to visual inspection to

confirm the direction of the flow gradient. Recharge to the model from the western boundary and through areal recharge (3870 cfd) was compared with independent estimates of recharge to the Neroly formation (4100 cfd) that were determined considering the size of the catchment area and assuming that most of the total recharge to the Neroly formation is apportioned to the $UTnbs_1$ and $LTnbs_1$ HSUs (Madrid et al., 2006).

As part of the initial flow calibration, a comparison was made between measured and modeled ground water elevation data. Ground water elevation data collected in July 1996 were used for the initial calibration and a combined steady-state pumping rate of 8 gpm at onsite water supply Wells 18 and 20, and no extraction wells was assumed. R^2, which is defined as $R^2=1-\sum[(\text{measured}_i-\text{predicted}_i)^2/(\text{mean-measured}_i)^2]$, where measured_i are the measured ground water head data, predicted_i are the modeled ground water head data, and mean is the mean of measured ground water head data, was 0.99. The average difference between measured and modeled data was 1.5 feet.

After the initial flow calibration, a comparison was made between measured and modeled ground water elevation data for a second (stressed) time period. Ground water elevation data collected in January 2000 were used for this calibration (Figure A-5). For this simulation, a 25% increase in areal recharge to compensate for the 1998 El Niño infiltration, a combined pumping rate of 8 gpm at onsite water supply Wells 18 and 20, and a pumping rate of 1.4 gpm at extraction well W-830-57 were assumed. R^2 was 0.89 and the average difference between measured and modeled data was 2.5 feet.

Ground water elevation data collected in January 2004 were used for the third flow calibration. For this simulation, decreased pumping from onsite water supply Wells 18 and 20 at a rate of 5 gpm, base case (non El Niño) areal recharge, and a pumping rate of 1.4 gpm at extraction well W-830-57 were assumed. R^2 was 0.83 and the average difference between measured and modeled data was 3.5 feet.

The capability of the $UTnbs_1$ model to match observed ground water elevation data under a variety of conditions supports the robustness of this flow calibration. A final calibration step will be to observe the behavior of the model under stressed conditions by comparing drawdowns observed during long-term pumping tests at wells W-830-2215 and W-830-60 with drawdowns modeled using steady-state or transient simulations.

A-3.5.2. Transport Calibration

Both the $Tnsc_{1b}$ and $UTnbs_1$ models rely primarily on the flow calibration to ensure robustness, however some transport parameters (longitudinal and transverse dispersivity) were also calibrated. For both HSUs, the calibrated longitudinal dispersivity that best matched the observed data was 20 m and the calibrated transverse dispersivity that best matched the observed data was 5 m, or 25% of the longitudinal dispersivity. The TCE retardation coefficient used for these simulations was 1.75.

For the $Tnsc_{1b}$ transport calibration, a 1 milligram per liter (mg/L) point source was applied at the primary TCE source area, Building 830. The point source was a "step function" that was applied at a constant rate for 25 years, approximating the period between 1955 to 1980. The contaminant plume was then observed after another 30 years of transient transport and compared with present-day (second quarter 2010) TCE data.

Results of the $Tnsc_{1b}$ transport calibration found that a source term of 1 mg/L applied for 25 years was able to match the general plume shape and concentration distributions. However, more fine-tuning of input parameters and boundary conditions is needed to better match the areas of highest concentrations. Onsite water supply Wells 18 and 20, which had intermittent pumping rates of up to 30 gpm during the 1970s and 1980s, may have also influenced the historical distribution of contaminants in $Tnsc_{1b}$ aquifer. These wells were not pumped during the transport calibration simulations.

For the $UTnbs_1$ transport calibration, a 0.5 mg/L point source was applied at the primary TCE source area, Building 830. The point source was a "step function" that was applied at a constant rate for 25 years, approximating the period between 1955 to 1980. The contaminant plume was then observed after another 30 years of transient transport and compared with present-day (second quarter 2010) TCE data.

Results of the $UTnbs_1$ transport calibration found that a source term of 0.5 mg/L applied for 25 years was able to match the general plume concentration distributions. However, in the future, some adjustment of the model boundary conditions may be needed to better match the overall direction of contaminant transport and associated hydraulic capture zones. Intermittent pumping of onsite water supply Wells 18 and 20 may also have influenced the distribution of contaminants in $UTnbs_1$ HSU. Steady-state pumping from Wells 18 and 20 at a rate of 1 gpm was applied during the transport calibration to account for these intermittent pumping effects.

A-4. Model Results

The primary objective of this modeling study was to develop FEFLOW models of the $Tnsc_{1b}$ and $UTnbs_1$ HSUs that could be used to refine our understanding of groundwater flow and contaminant transport in the Building 832 Canyon OU. The models were also used for preliminary estimates of cleanup times and in the future, they may be used for extraction wellfield optimization. They also serve as a framework for organizing field and laboratory data.

Although these models can be used to evaluate a variety of pumping strategies, only the results of one case, Case A, are presented here. This case assumes that all extraction wells that are currently operating in each HSU will continue to operate at full capacity. This case also assumes that all proposed new extraction wells have also been installed and are operating at full capacity. Full capacity is defined as a long-term, steady-state pumping rate considered sustainable based on available hydrogeologic data.

For the $Tnsc_{1b}$ HSU (Case A-$Tnsc_{1b}$), twelve existing extraction wells and one proposed new extraction well were pumped at a combined rate of 4.5 gpm (Figure A-1). For the $UTnbs_1$ HSU (Case A-$UTnbs_1$), three existing extraction wells were pumped at a combined rate of 4.7 gpm (Figure A-2). No pumping was assumed from either Wells 18 or 20 during both the Case A-$Tnsc_{1b}$ and Case A-$UTnbs_1$ simulations. As discussed above, future cases may incorporate alternative flow rates or additional pumping wells to optimize mass removal and to prevent the offsite migration of contaminants. Proposed extraction wells that will be screened in other HSUs such as the $Tnsc_{1a}$ HSU were also not included in these simulations. Distributions of TCE within the model domain after 0, 25, and 75 years are shown in Figure A-6 for the $Tnsc_{1b}$ model and in Figure A-7 for the $UTnbs_1$ model. As shown on these figures and on Figures A-8 and A-9, simulations of cleanup in both the $Tnsc_{1b}$ and $UTnbs_1$ HSUs indicate that TCE plume

concentrations greater than drinking water standards persist after 25 years of cleanup. A discussion of these results is included in Section A-6 (Preliminary Cleanup Time Predictions).

A-5. Sensitivity Analysis

Although a comprehensive sensitivity analysis was not conducted for this report, the sensitivity of many input parameters was observed during calibration. In general, the flow model is most sensitive to boundary conditions. Hydraulic conductivity is also important in determining boundary fluxes, water levels, and plume migration patterns. With regard to transport, the model showed little sensitivity to the values of longitudinal and transverse dispersivities and more sensitivity to the sorption coefficient used to calculate TCE retardation. The effect of the TCE retardation coefficients on cleanup time estimates is shown on Figures A-8 and A-9. After these models are fully calibrated, further sensitivity analyses may be conducted to better understand the effect of varying flow and transport parameters on cleanup time estimates.

A-6. Preliminary Cleanup Times Predictions

FEFLOW modeling output was used to make preliminary estimates of the time required to clean up the TCE plumes in the $Tnsc_{1b}$ and $UTnbs_1$ HSUs to a cleanup standard of 5 µg/L. The predictions were made using the Case A ($Tnsc_{1b}$ and $UTnbs_1$) extraction wellfields, with constant flow rates specified at each existing and proposed extraction well.

In both models, it was assumed that the Building 830 and 832 source areas did not continue to contribute mass to each HSU beyond what was initially present. It was also assumed that extraction wellfields remained unchanged over time; however, in reality, optimization of the extraction wellfields could significantly reduce future cleanup time estimates. In the $Tnsc_{1b}$ HSU, vapor extraction should also play a significant role in mass removal, decreasing predicted cleanup times.

Figure A-8 shows the maximum TCE concentrations over time created by a 13-well Case A-$Tnsc_{1b}$ pumping scenario. The location of these extraction wells is shown on Figure A-1. The thirteen wells used for the Case A-$Tnsc_{1b}$ pumping scenario included nine existing $Tnsc_{1b}$ wells W-832-01, W-832-10, W-832-11, W-830-19, W-830-49, W-830-59, W-830-51, W-830-52, and W-830-53; one proposed new $Tnsc_{1b}$ well (W-832-2702); and three Qal/WBR-$Tnsc_{1b}$ wells W-832-12, W-832-15 and W-830-1807. Extraction wells W-832-12 and W-832-15 were co-located at a single node. Figure A-9 shows the maximum concentration over time created by a 3-well Case A-$UTnbs_1$ pumping scenario. The three wells used for the Case A-$UTnbs_1$ pumping scenario included three existing extraction wells: W-830-57, W-830-2215 and W-830-60. The location of these wells is shown on Figure A-2. No new extraction wells are proposed for the $UTnbs_1$ HSU.

To better show model sensitivity to retardation, cleanup time predictions have been simulated using two different TCE retardation coefficients (1 and 1.75). Cleanup time estimates for the $Tnsc_{1b}$ model are generally higher than the cleanup times predicted using the WINFLOW analytical model for the SWRSR (Ferry, et al., 2006). Because WINFLOW assumes an infinite aquifer, the SWRSR cleanup time estimates predicted using WINFLOW may be optimistic. In an area with low yields and limited recharge such as in the Building 832 Canyon OU, the amount of water available for extraction plays an important role in determining cleanup time estimates.

It is also likely that the complexity of the $Tnsc_{1b}$ HSU is not adequately captured by this FEFLOW model, and that more effort is needed to obtain a robust and calibrated FEFLOW model especially near the Building 832 source area where saturated thicknesses are particularly thin.

The time required to cleanup the $UTnbs_1$ HSU to the 5 µg/L cleanup standard ranged from 75 to 125 years. Specific cleanup time estimates for the $UTnbs_1$ HSU were not included in the SWRSR, but were assumed to be less than the $Tnsc_{1b}$ HSU cleanup time estimates. The dashed portions of the curves shown on Figures A-8 and A-9 indicate the increasing uncertainty that exists in all model predictions as the estimated time period moves farther from the initial conditions. All results obtained from the $Tnsc_{1b}$ FEFLOW model should be considered preliminary until more robust flow calibrations can be performed.

A-7. Conclusions

This appendix provides an overview of the FEFLOW models developed for the Building 832 Canyon OU.

The following conclusions were derived from the $Tnsc_{1b}$ HSU modeling:

- The $Tnsc_{1b}$ model shows a fair calibration to field data with respect to ground water flow and plume migration patterns (Figure A-4). Nevertheless, additional calibration and fine-tuning of the input parameters may be needed to better minimize the discrepancy between measured and modeled ground water levels, especially near the Building 832 source area where saturated thicknesses are thin. As a result, all interpretations and predictions made using this model should be considered preliminary until verified by a more robust model that adequately captures the complexity of this system.
- Results of the $Tnsc_{1b}$ transport calibration suggest that a "step function" source term of 1 mg/L applied for 25 years was able to match the general size and pattern of the current TCE plume in the $Tnsc_{1b}$ HSU. However, more fine-tuning of input parameters and boundary conditions may be needed to match the areas of highest TCE concentrations. Onsite water supply Wells 18 and 20, which had intermittent pumping rates of up to 30 gpm during the 1970s and 1980s, may have also influenced the historical distribution of contaminants in $Tnsc_{1b}$ aquifer. The effect of pumping these wells was not considered during the transport calibration.
- As shown on Figures A-6 and A-8, simulations of cleanup in the $Tnsc_{1b}$ HSU using the 13-well Case A-$Tnsc_{1b}$ pumping scenario indicate that TCE plume concentrations greater than drinking water standards persist after 25 years. Cleanup time estimates were generally higher than previous modeling efforts (Ferry, et al. 2006) and should be considered preliminary until more robust flow calibrations can be obtained. The spatial distributions of TCE after 0, 25, and 75 years are shown in Figure A-6.
- After additional calibration, this $Tnsc_{1b}$ model may be used to evaluate the capability of the extraction wellfield to adequately capture the contaminants of concern to drinking water standards. It will also be used to optimize the extraction wellfield to achieve cleanup levels.

The following conclusions were derived from the $UTnbs_1$ modeling:

- The $UTnbs_1$ model shows a good calibration to field data with respect to ground water levels, ground water gradients and pumping rates (Figure A-5). The capability of the model to match observed ground water elevation data under a variety of conditions and the high objective function (R^2=0.99) supports the robustness of this flow calibration. In the future, this model may be improved by modifying the boundary conditions to better match plume migration patterns and observed hydraulic capture zones.
- Results of the $UTnbs_1$ transport calibration show that a source term of 0.5 mg/L applied for 25 years is needed to match the current TCE plume in the $UTnbs_1$ HSU. Further fine-tuning of input parameters and boundary conditions may be needed to match the areas of highest TCE concentrations. Onsite water supply Wells 18 and 20, which had intermittent pumping rates of up to 30 gpm during the 1970s and 1980s, may have also influenced the historical distribution of contaminants in $UTnbs_1$ HSU. A steady state pumping rate of one gallon-per-minute was assumed.
- The spatial distributions of TCE after 0, 25 and 75 years are shown in Figure A-7. As shown on this figure and on Figure A-9, simulations of cleanup in the $UTnbs_1$ HSU using the 3-well Case A-$UTnbs_1$ pumping scenario indicate that TCE plume concentrations greater than drinking water standards persist after 25 years. This HSU is expected to achieve the TCE cleanup standard of 5 µg/L before the $Tnsc_{1b}$ HSU. In the future, the $UTnbs_1$ model will be used to evaluate the capability of the extraction wellfield to adequately capture the contaminants of concern to drinking water standards. It will also be used to optimize the extraction wellfield to achieve cleanup levels.

A-8. References

Diersch, H. G. (1998), Reference Manual, "FEFLOW- Interactive, Graphics-based Finite-Element Simulation System for Modeling Ground water Flow, Contaminant Mass and Head Transport Processes," WASY Institute for Water Resources Planning and Systems Research Ltd., Berlin, Germany.

Ferry, L., M. Dresen, Z. Demir, V. Dibley, V. Madrid, M. Taffet, S. Gregory, J. Valett, M. Denton (2006), *Final Site-Wide Remediation Evaluation Summary Report for Lawrence Livermore National Laboratory Site 300,* Lawrence Livermore National Laboratory, Livermore, Calif. (UCRL-AR-220391).

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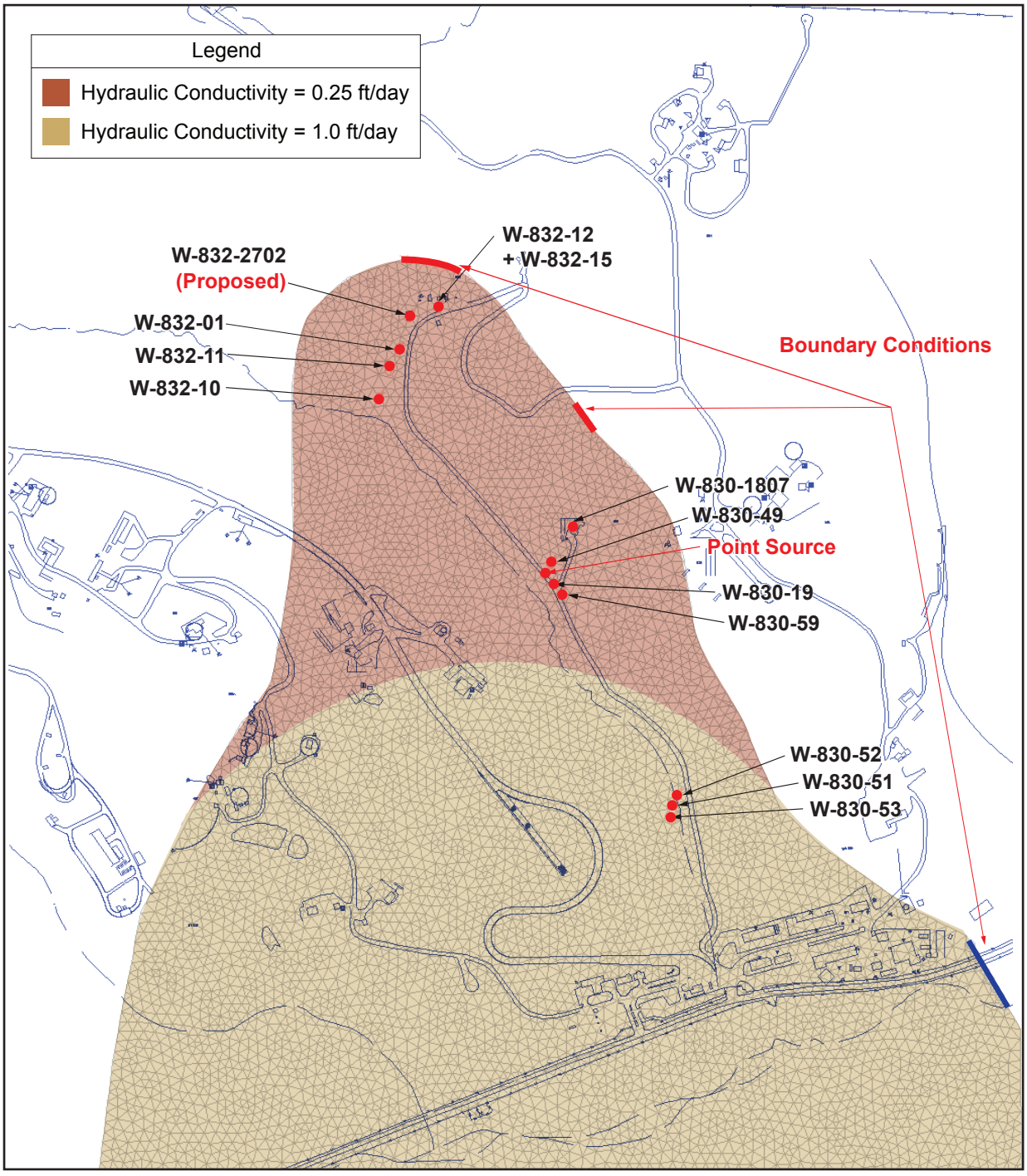
Madrid, V., J. Valett, M. Denton, Z. Demir, M. Dresen, and W. Daily (2006), *Interim Remedial Design for the Building 832 Canyon Operable Unit at Lawrence Livermore National Laboratory Site 300*, Lawrence Livermore National Laboratory Livermore, Calif. (UCRL-AR-214990).

Appendix A

Figures

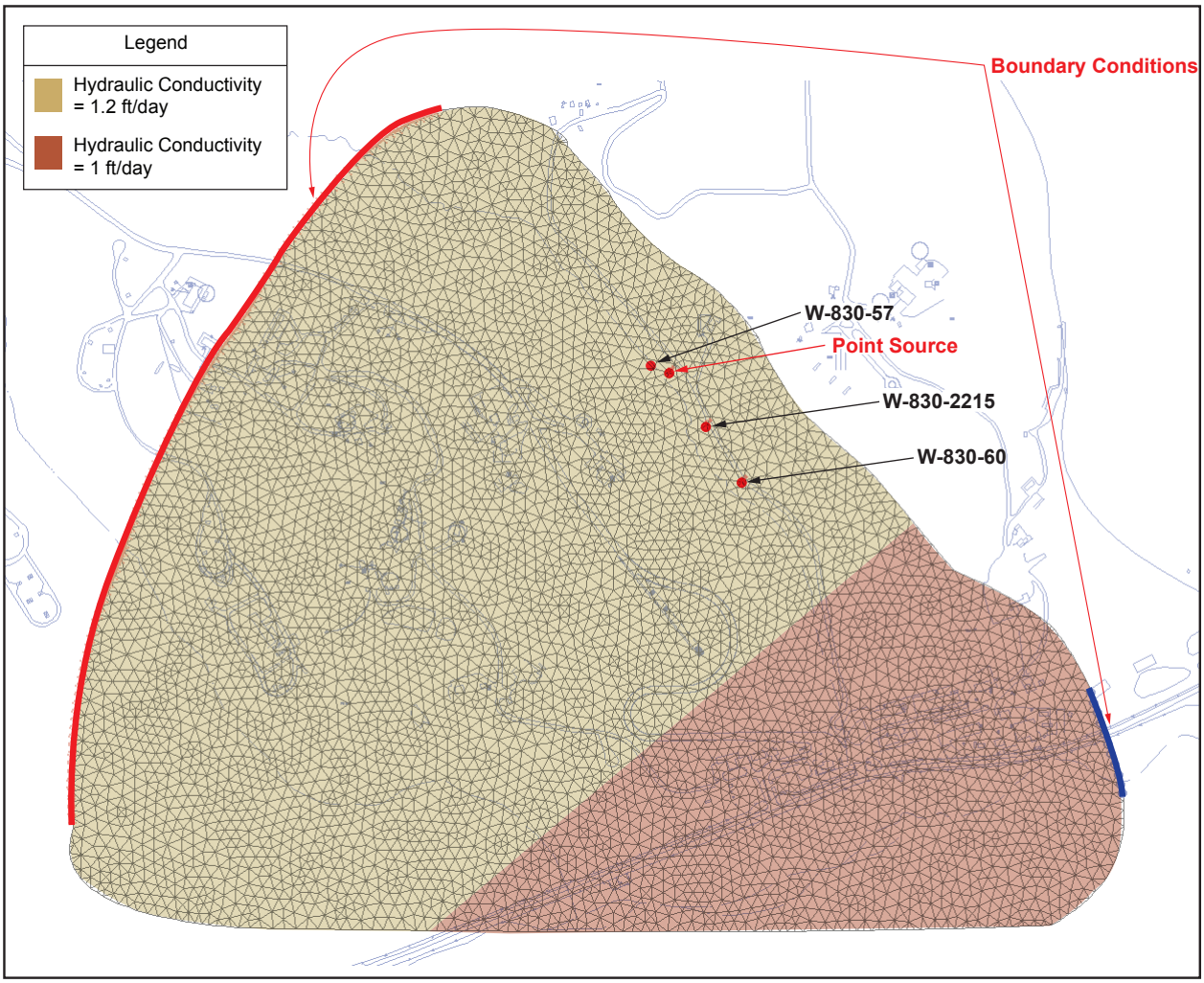
Appendix A

List of Figures



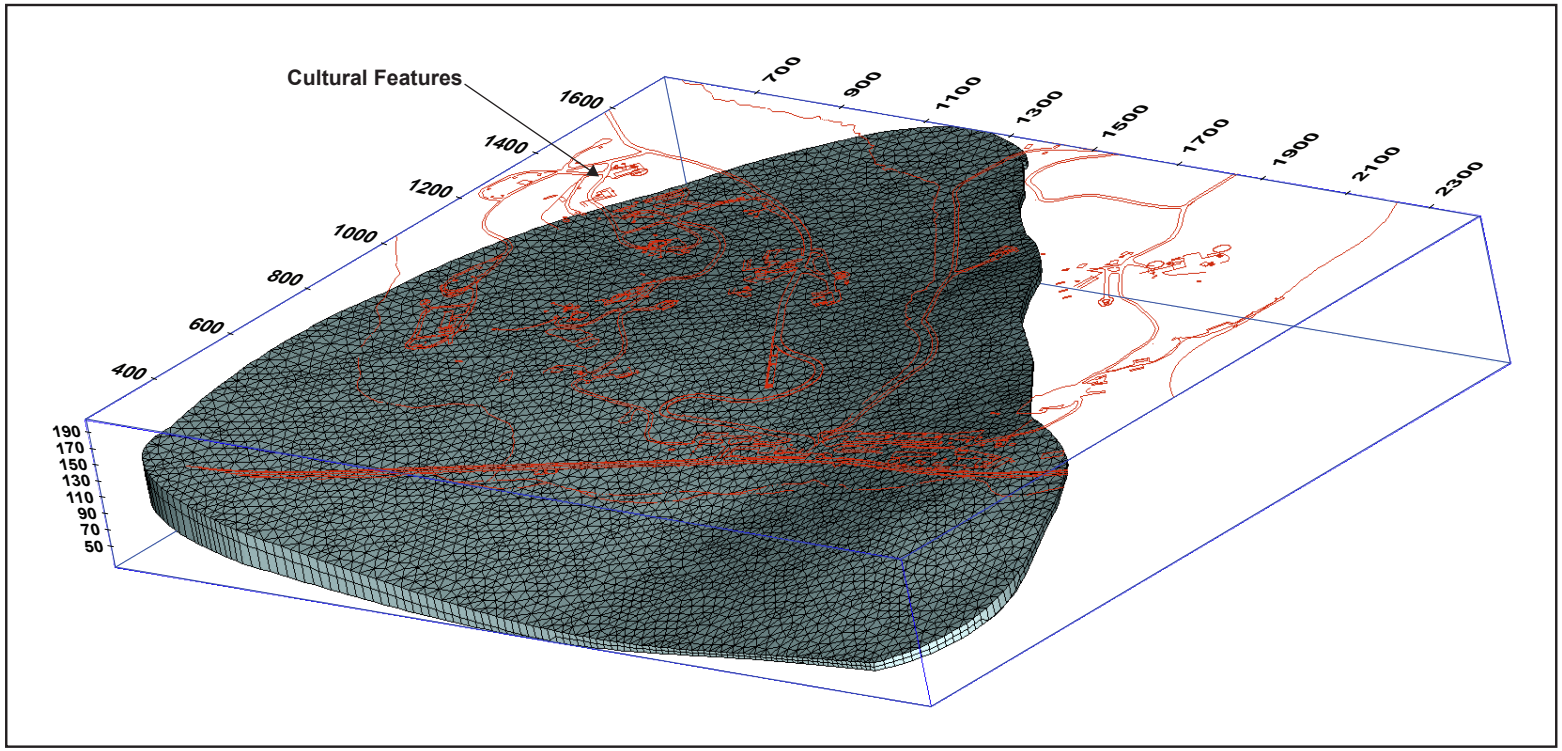
ERD_S3R_11_0062

Figure A-1. Map showing the $Tnsc_{1b}$ FEFLOW model domain, grid, boundary conditions, point source location, hydraulic conductivity field, cultural features, and location of existing and proposed extraction wells included in the Case A-$Tnsc_{1b}$ Simulation.



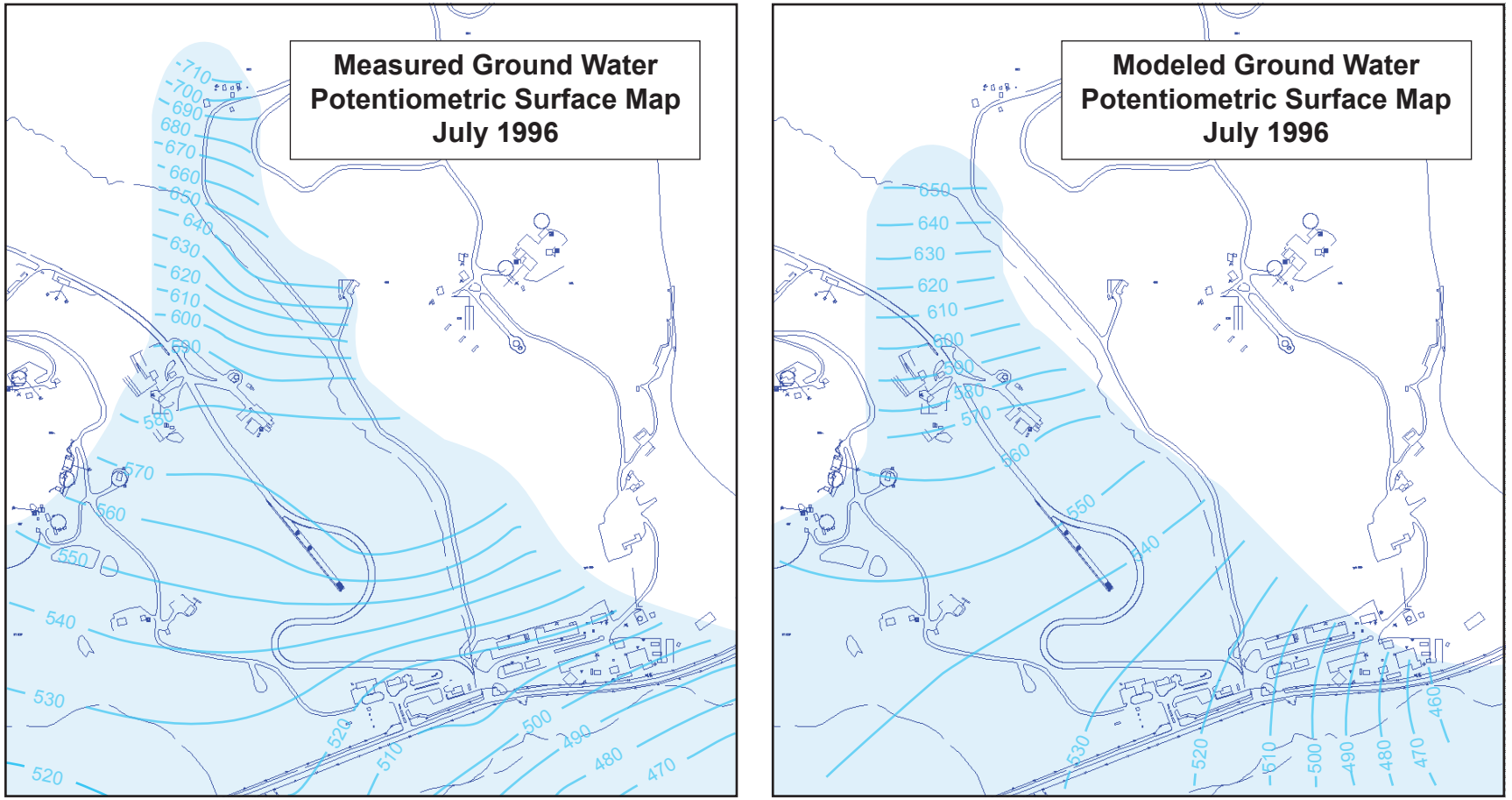
ERD_S3R_11_0061

Figure A-2. Map showing the Upper Tnbs$_1$ FEFLOW model domain, grid, boundary conditions, point source location, hydraulic conductivity field, cultural features, and location of existing extraction wells included in the Case A-UTnbs$_1$ Simulation.



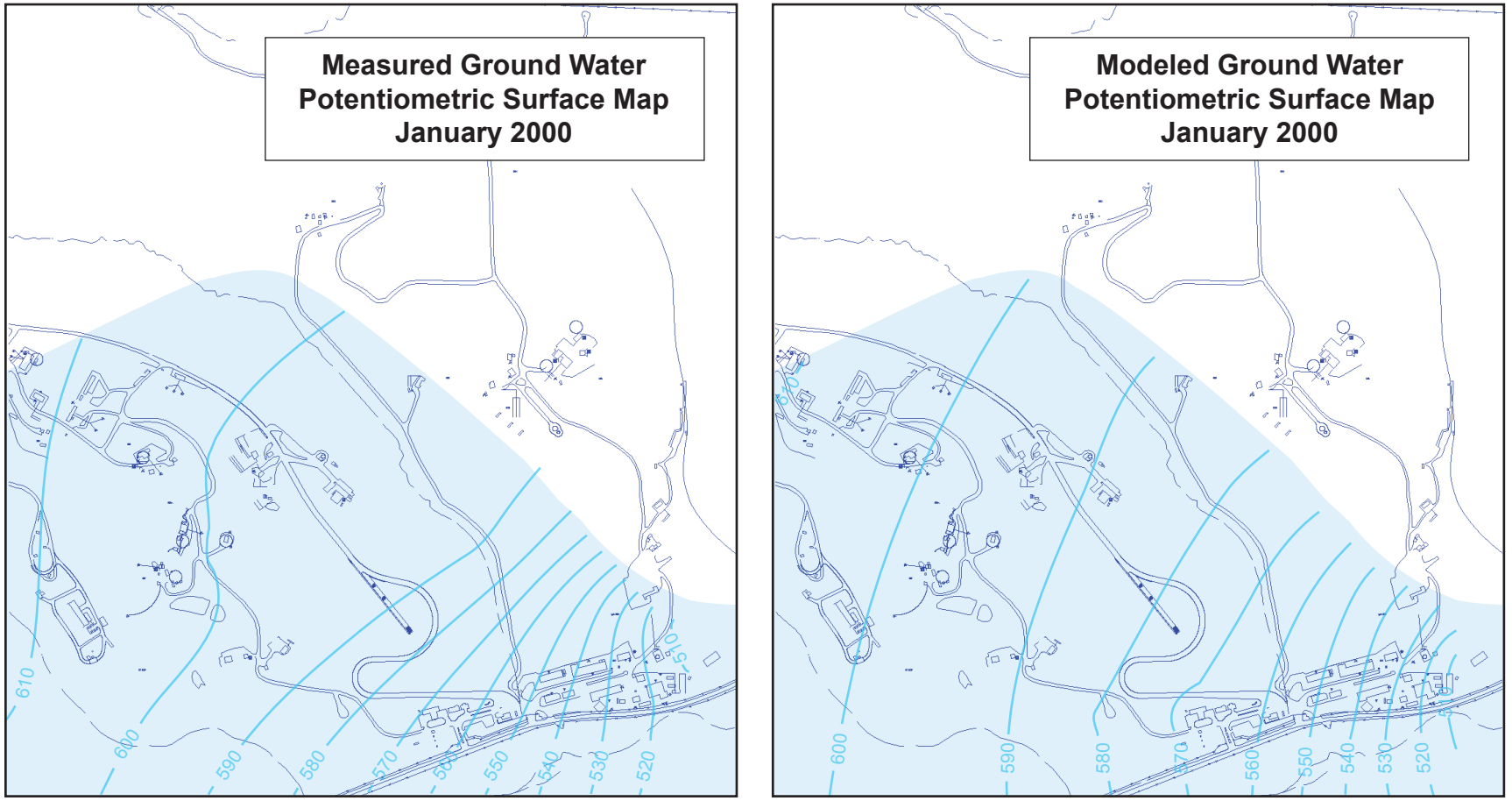
ERD_S3R_11_0060

Figure A-3. Figure showing a three-dimensional visualization of the grid used for the Upper $Tnbs_1$ FEFLOW model.



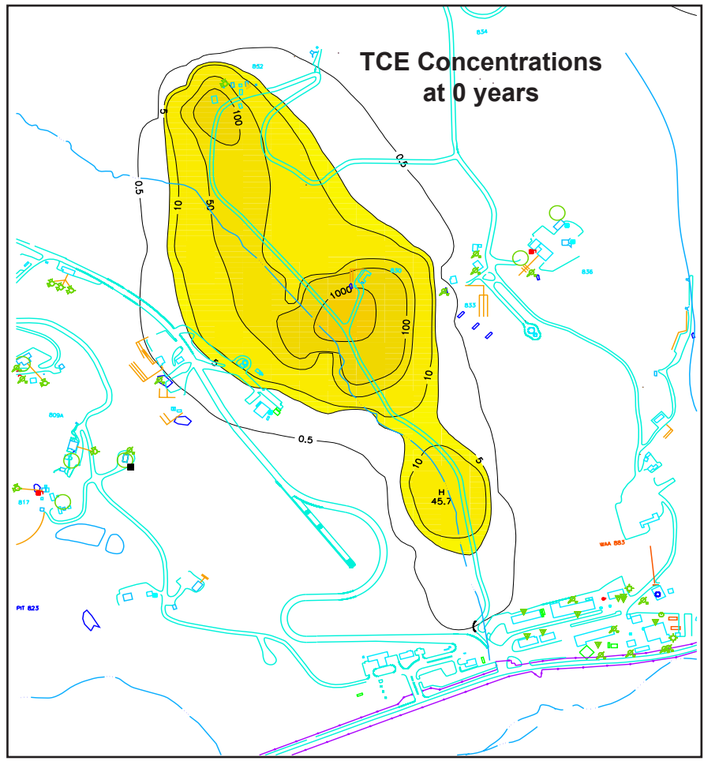
ERD_S3R_11_0064

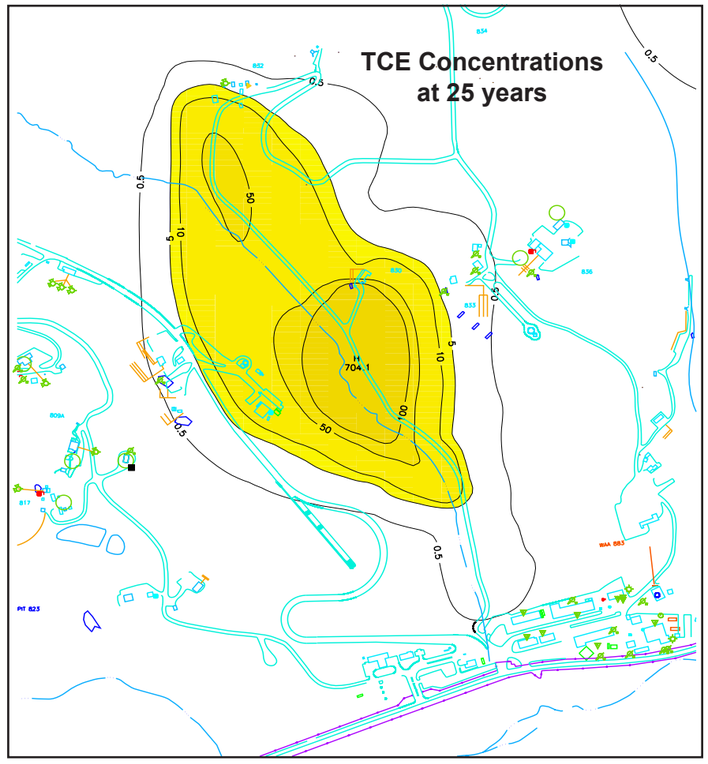
Figure A-4. Measured and modeled ground water potentiometric surface maps used for and resulting from the $Tnsc_{1b}$ FEFLOW model calibration.



ERD_S3R_11_0063

Figure A-5. Measured and modeled ground water potentiometric surface maps used for and resulting from the Upper Tnbs1 FEFLOW model calibration.





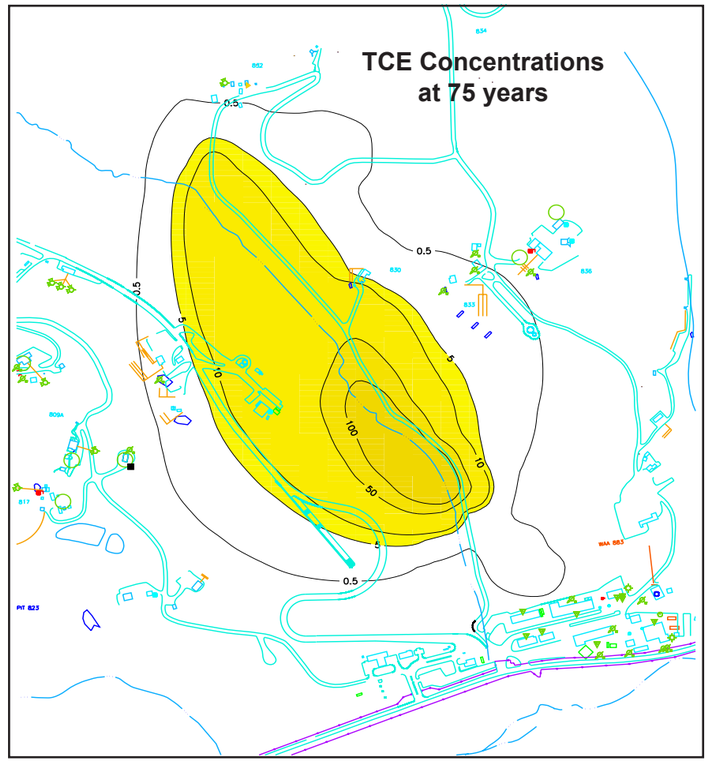


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Figure A-6. TCE concentrations simulated using the $Tnsc_{1b}$ FEFLOW model after 0, 25 and 75 years.

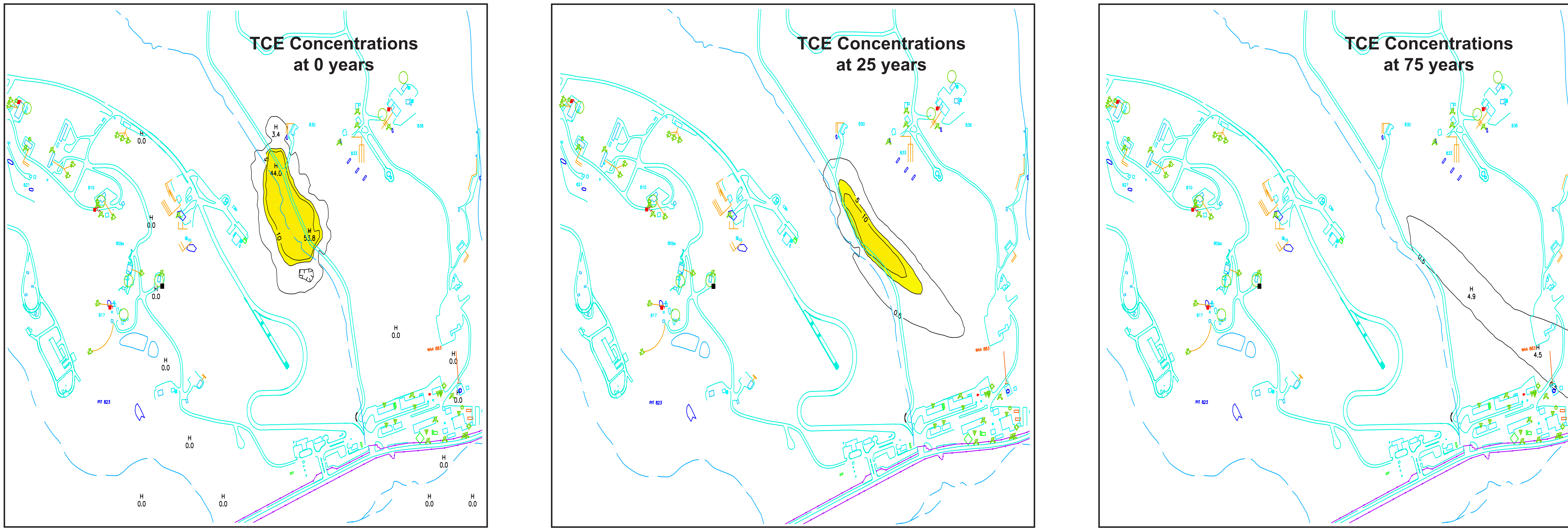

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Figure A-7. TCE concentrations simulated using the Upper $Tnbs_1$ FEFLOW model after 0, 25 and 75 years.

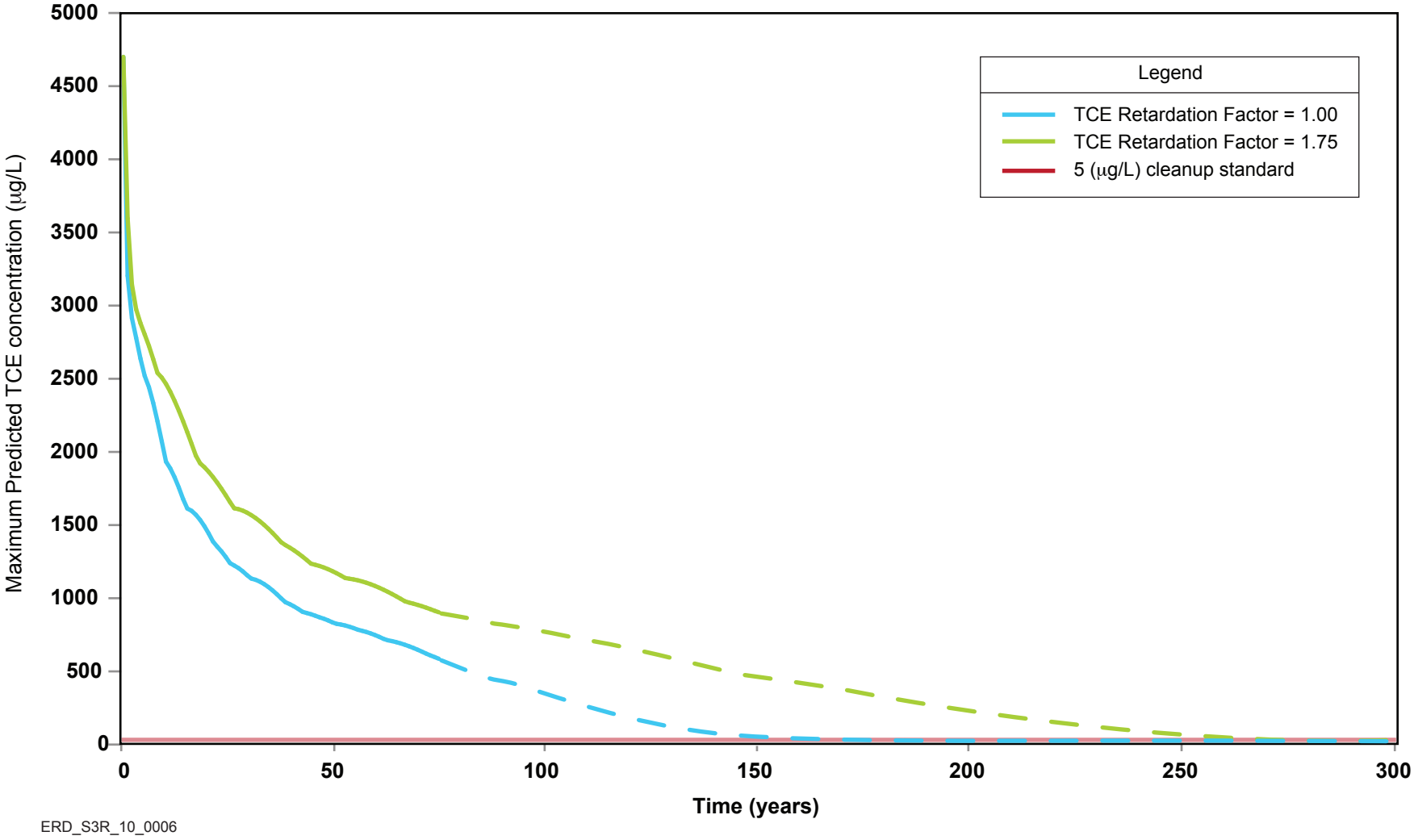

Figure A-8. Preliminary maximum TCE concentrations (µg/L) predicted over time in the $Tnsc_{1b}$ HSU.

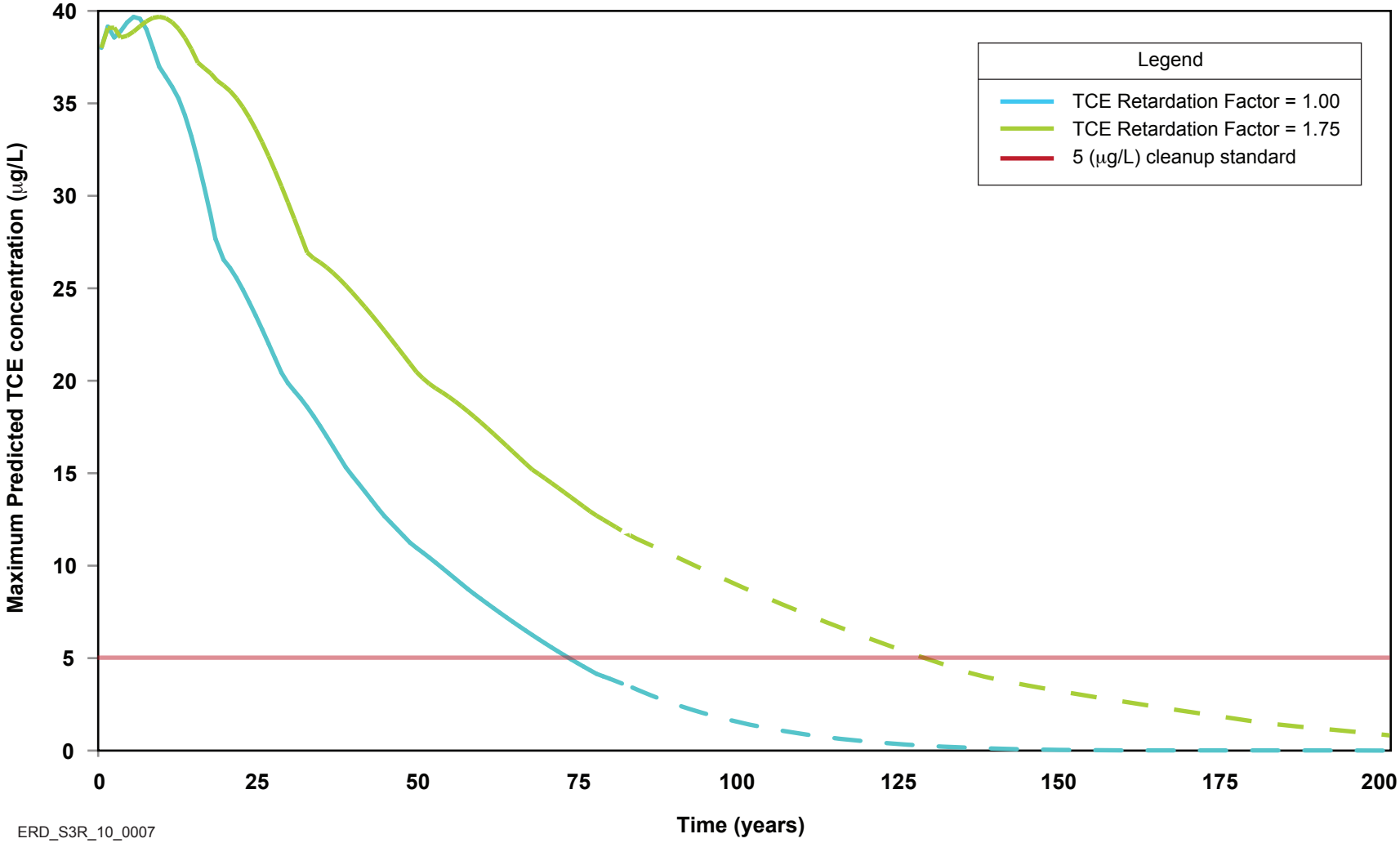

Figure A-9. Preliminary maximum TCE concentrations (μg/L) predicted over time in the Upper $Tnbs_1$ HSU.

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