U.S. Department of Energy
Oakland Operations Office, Oakland, California 94612

Lawrence Livermore National Laboratory
University of California, Livermore, California 94550

UCRL-AR-144744

Five-Year Review Report for the Building 834 Operable Unit at Lawrence Livermore National Laboratory Site 300

Authors:

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February 2002

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Environmental Protection Department
Environmental Restoration Division

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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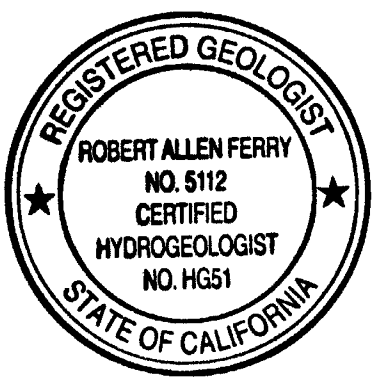
Certification

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.



3/4/02

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Approval and Concurrence for the Five-Year Review for the Building 834 Operable Unit at Lawrence Livermore National Laboratory Site 300

Prepared by:

The United States Department of Energy
Oakland Operations Office
Oakland, California

Approved:

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U.S. Department of Energy
Oakland Operations Office

Concurrence:

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Chief, Federal Facilities Cleanup Branch
Superfund Division
U.S. Environmental Protection Agency, Region IX

Five-Year Review Summary Form

Site Identification		
Site name: Lawrence Livermore National Laboratory Site 300, Building 834 Operable Unit		
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: To be determined	
Has the site been put into reuse: No		
Review Status		
Reviewing agency: U.S. Department of Energy		
Author name: Robert A. Ferry		
Author title: Principal	Author affiliation: Stantec Consulting	
Review period: June 2001 to August 2001		
Date(s) of site inspection: Not applicable		
Type of review: Statutory		
Review number: 1		
Triggering action: Interim Record of Decision for the Building 834 OU		
Triggering action date: September 26, 1995		
Due date: September 26, 2000		

Five-Year Review Summary Form (continued)

Deficiencies:

No deficiencies in the interim remedy were identified during the five-year review process.

Recommendations and Follow-up Actions:

This five-year review does not identify a need for reassessing the overall approach to cleanup. DOE should implement the following actions according to the schedules included in the Remedial Design Work Plan for the Interim Remedies and the Interim Remedial Design document for the Building 834 OU:

- Modify the ground water and soil vapor extraction wellfield configurations to optimize contaminant mass removal and prevent stagnant zones from forming.
- Operate the Core Area extraction wells cyclically to maximize *in situ* biodegradation of TCE.

In addition:

- DOE should continue to evaluate other remedial technologies that could shorten cleanup time, especially those that will facilitate remediation of the low-permeability sediments.
- Due to the limited amount of recharge, installing additional ground water extraction wells may not result in a significant increase in contaminant mass removal or a decrease in cleanup time. Any additional ground water extraction wells should be installed only in areas where the wells will yield significant quantities of ground water. Soil vapor extraction appears to be a much more efficient mass removal technology given the nature of the subsurface materials at Building 834.

No other follow-up actions were identified related to this five-year review.

Protectiveness Statement:

The interim remedy for the Building 834 OU is expected to be protective of human health and the environment upon completion, and in the interim: (1) the Health and Safety Plan is in place, sufficient to control risks, and properly implemented, (2) ground water and soil vapor extraction and treatment are reducing contaminant concentrations in the subsurface, and (3) institutional controls to minimize heath risks and prevent use of contaminated ground water are in place or are scheduled to be implemented.

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1. Introduction

The United States Department of Energy (DOE) has conducted a five-year review of the interim remedial actions being implemented at the Building 834 operable unit (OU) at Lawrence Livermore National Laboratory (LLNL) Site 300. DOE is the lead agency for environmental restoration at LLNL. The review documented in this report was conducted from June 2001 through August 2001. Parties providing analyses in support of the review include the DOE Oakland Operations Office; LLNL Environmental Restoration Division; Stantec Consulting; and Weiss Associates.

The purpose of five-year reviews is to determine whether the remedy at the site is, or is expected to be, protective of human health and the environment. The methods, findings, and conclusions of the reviews are documented in five-year review reports. In addition, the five-year review reports identify deficiencies found during the review, if any, and present recommendations to address them. The format and content of this document is consistent with guidance issued by DOE (DOE, 2001) and the U.S. Environmental Protection Agency (EPA) (EPA, 2001).

This is the first five-year review for the Building 834 OU and is required by statute because the interim remedy will result in contaminants remaining at the site above concentrations that allow for unlimited use and unrestricted exposure (i.e., ground water cleanup standards have not yet been established). Since cleanup was initiated at this OU as a treatability study, the triggering action for this review is the signature date, September 26, 1995 of the Interim Record of Decision (ROD) for the Building 834 OU (DOE, 1995).

DOE is preparing this five-year review pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) §121 and the National Contingency Plan (NCP). This requirement is interpreted further in 40 Code of Federal Regulations (CFR) §300.430(f)(4)(ii).

DOE and EPA have agreed to perform separate five-year reviews for each OU at Site 300 to enhance project management focus in evaluating cleanup progress after construction in each discrete area of contamination and to smooth workload and staffing resources throughout each five-year cycle.

The following paragraphs include descriptions and status of other environmental restoration activities at Site 300. Many of these areas and OUs were included in the Interim Site-Wide ROD for Site 300 (DOE, 2001).

General Services Area OU - Solvents containing volatile organic compounds (VOCs) were commonly used as degreasing agents in craft shops in this OU. In the 1960s and 1970s, rinse water from these operations was disposed of in dry wells and VOC-contaminated debris was buried in trenches. Ground water cleanup began in 1991 and soil vapor extraction started in 1994. In 1995, a Final ROD for this OU was signed. Ground water and soil vapor extraction have been very successful in decreasing the concentration and mass of subsurface contaminants and in reducing the offsite extent of contamination. DOE has previously performed a five-year review for the General Services Area OU (Ferry et al., 2001a).

Pit 6 Landfill OU - From 1964 to 1973, waste was buried in nine unlined trenches and animal pits at the Pit 6 Landfill. Contaminants in the subsurface include VOCs, tritium, nitrate, and perchlorate. In 1971, DOE excavated portions of the waste contaminated with depleted uranium. In 1997, a landfill cap was installed as a removal action to prevent infiltrating precipitation from further leaching contaminants from the waste. Because of decreasing trichloroethylene (TCE) concentrations in ground water, the presence of TCE degradation products, and the short half-life of tritium (12.3 years), the selected interim remedy for TCE and tritium at the Pit 6 Landfill is monitored natural attenuation. DOE is evaluating the source, extent, and natural degradation of perchlorate and nitrate. The interim remedy for these contaminants in ground water is continued monitoring.

High Explosives Process Area OU - Surface spills from 1958 to 1986 resulted in the release of VOCs at the former Building 815 steam plant. High-explosive compounds, nitrate, and perchlorate are present in the subsurface and are attributed to wastewater discharges to former unlined rinsewater lagoons. The High Explosives Burn Pits were capped in 1998. In 1999, DOE implemented a removal action to perform ground water extraction at the site boundary to prevent the TCE plume from migrating offsite. Treatability studies are underway near Building 815 to assess high explosive, nitrate, and perchlorate treatment technologies. The selected interim remedy for this OU includes continued ground water extraction and treatment.

Building 850 Firing Table - High-explosives experiments have been conducted at the Building 850 Firing Table since 1958. Tritium was used in these experiments, primarily between 1963 and 1978. As a result of the dispersal of test assembly debris during explosions, surface soil was contaminated with metals, polychlorinated biphenyls (PCBs), dioxins, furans, high-explosive compounds, and depleted uranium. Leaching from firing table debris has resulted in tritium and depleted uranium contamination in subsurface soil and ground water. Nitrate has also been identified in ground water. PCB-contaminated shrapnel and debris was removed from the area around the firing table in 1998. The selected remedy for the Building 850 area includes excavation of the contaminated surface soil and a nearby sand pile as a final remedy and monitored natural attenuation of tritium in ground water as an interim remedy.

Pit 7 Landfill Complex - 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. Ongoing releases of contaminants to ground water are occurring. DOE is continuing to characterize the area and is preparing an area-specific Remedial Investigation/Feasibility Study.

Pit 2 Landfill - The Pit 2 Landfill was used from 1956 to 1960 to dispose of firing table debris and gravel. No unacceptable risk or hazard to human health or ecological receptors has been associated with the Pit 2 Landfill, and there is no evidence of any release from the landfill. The selected interim remedy for the Pit 2 Landfill is enhanced vadose zone and ground water monitoring to detect any future releases from the landfill.

Building 854 OU - TCE was released to soil and ground water through leaks and discharges of heat-exchange fluid, primarily between 1967 and 1984. Other contaminants in ground water include nitrate and perchlorate. Some TCE-contaminated soil was excavated in 1983. Treatability studies to assess VOC, nitrate, and perchlorate extraction and treatment are underway. The selected interim remedy for this OU includes ground water and soil vapor extraction and treatment.

Building 832 Canyon OU - TCE was released to soil and ground water through leaks and discharges of heat-exchange fluid at Buildings 830 and 832 between the late 1950s and 1985. Nitrate and perchlorate are also present in ground water. In 1999, DOE began a treatability study to evaluate ground water and soil vapor extraction. Another treatability study is underway in the downgradient portion of the VOC plume to test the effectiveness of iron filings (zero-valent iron) in removing VOCs from ground water. The selected interim remedy for this OU includes continued soil vapor and ground water extraction and treatment.

Building 801 Dry Well and the Pit 8 Landfill - Waste fluid was discharged to a dry well located adjacent to Building 801D from the late 1950s to 1984, resulting in minor subsurface VOC contamination. The Pit 8 Landfill was used to dispose of debris from the Building 801 Firing Table until an earthen cover was installed in 1974. There is no evidence of a contaminant release from the landfill. The selected interim remedy for this area is enhanced vadose zone and ground water monitoring to detect any future releases from the landfill.

Building 833 - 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 minor VOC contamination of the shallow soil/bedrock and perched ground water. The selected interim remedy for this area is continued monitoring.

Building 845 Firing Table and Pit 9 Landfill - High-explosives experiments were conducted at the Building 845 Firing Table from 1958 to 1963. Leaching from firing table debris resulted in minor contamination of subsurface soil with depleted uranium and high-explosive compounds. No ground water contamination has been detected. The Pit 9 Landfill was used to dispose of firing table debris generated at the Building 845 Firing Table. The debris buried in the pit may contain tritium, uranium, and/or high-explosive compounds. However, there is no evidence of a contaminant release from the Pit 9 Landfill. The selected interim remedy for this area is enhanced vadose zone and ground water monitoring to detect any future releases from the landfill.

Building 851 Firing Table - The Building 851 Firing Table has been used for high-explosives research since 1982. These experiments resulted in minor VOC, depleted uranium, metals, and high-explosives contamination in soil and ground water. No unacceptable risk or hazard was identified in this area. The selected interim remedy for this area is continued monitoring.

Advanced Test Accelerator (Building 865) - Solvents were used at this facility, and Freon-113 has been detected in the subsurface. DOE is planning to conduct site characterization in this area.

Building 812 - This facility has been in use since the 1960s. Gravel from the firing table was pushed into an adjacent ravine or to the side of the table. Depleted uranium has been detected in soil and further characterization is planned.

Sandia Test Facility - From about 1959 to 1960, Sandia National Laboratories (Livermore) operated a small, temporary firing table at Site 300. The facility consisted of a portable building with other structures built into the hillside and surrounded by sandbags. The facility may have been used to test or store high explosives. DOE is planning to investigate this area.

2. Site Chronology

The following is a chronological listing of important environmental restoration events at the Building 834 OU:

1955

- LLNL Site 300 was established as a DOE high-explosives test facility.

1962–1978

- During the course of experiments involving thermal cycling (i.e., repeated heating and cooling) of weapons components at Building 834, VOCs, primarily TCE, were released through spills and piping leaks. TCE was used as the primary heat-transfer fluid during these experiments and was sometimes mixed with the silicone oils tetra-butyl-orthosilicate (TBOS) and tetra-kis-2-ethylbutyl silane (TKEBS) to prevent degradation of pump seals and gaskets.

1982–1983

- DOE excavated approximately 100 cubic yards of TCE-contaminated soil resulting from spills and piping leaks.
- Site investigations began at Building 834.

1986

- Ground water and soil vapor extraction began as treatability tests.

1989

- Ground water and soil vapor extraction treatability testing ended and construction of a full-scale facility began at Building 834.

1990

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

1991

- DOE conducted a demonstration of an electron accelerator to treat VOCs in extracted vapor. This technology was subsequently screened out in the Site-Wide Feasibility Study due to the production of undesirable byproducts, including phosgene.

1992

- A Federal Facility Agreement for Site 300 was signed. The parties to the Agreement included DOE, the California Department of Toxic Substances Control, and the California Regional Water Quality Control Board.
- DOE conducted an evaluation of a technology to treat extracted soil vapor using ultraviolet light and hydrogen peroxide. This technology was subsequently screened out in the Site-Wide Feasibility Study due to the high energy and operation costs.

- An electrical soil heating (Joule heating) pilot test was performed. This technology was subsequently screened out in the Site-Wide Feasibility Study due to limited applicability at Building 834.

<u>1994</u>

- The Site-Wide Remedial Investigation report for Site 300 was issued.
- A Feasibility Study for the Building 834 OU was issued.

<u>1995</u>

- An Interim ROD for the Building 834 OU was signed. Ground water and soil vapor extraction began as an interim remedial action. DOE also agreed to test innovative cleanup technologies at Building 834.

<u>1998</u>

- DOE began treatability tests to evaluate the role of intrinsic *in situ* biodegradation in reducing TCE mass and concentration. This process was found to be important in removing TCE from the subsurface and measures to maximize biodegradation are being incorporated into the cleanup.
- A surfactant "push-pull" treatability test was performed. This technology was subsequently screened out in the Site-Wide Feasibility Study due to difficulty in ensuring complete capture of mobilized contaminants and resulting risk of enhanced migration.
- Soil from Building 834 was used in laboratory experiments to test the capability of potassium permanganate injection to destroy VOCs *in situ*. These tests indicated potential problems with injection and coverage and this technology was subsequently screened out in the Site-Wide Feasibility Study.
- Surface water drainage was diverted to prevent infiltration of precipitation in the Building 834 contaminant source area.

<u>1999</u>

- The Site-Wide Feasibility Study for Site 300 was issued.

<u>2000</u>

- Additional extraction well configuration testing was conducted at Building 834 to optimize interim remedial action performance.

<u>2001</u>

- An Interim Site-Wide ROD for Site 300 was signed that superceded the 1995 Interim ROD for the Building 834 OU. The Interim Site-Wide ROD specified continued ground water and soil vapor extraction, administrative controls (e.g., risk and hazard management), and monitoring as the components of the selected interim remedy for the Building 834 OU. The Interim Site-Wide ROD did not contain ground water cleanup standards. These standards will be established in a future Final ROD for Site 300.
- A Remedial Design Work Plan was issued that contained the strategic approach and schedule to implement the remedies in the Interim Site-Wide ROD.

- DOE performed treatability tests at the Building 834 OU that indicated that the existing air-sparging ground water treatment system could be replaced by an aqueous-phase granular activated carbon (GAC) system.

2002

- The Interim Remedial Design document for the Building 834 OU was issued.

3. Background

3.1. Physical Characteristics

3.1.1. Site Description

LLNL Site 300 is a remote DOE experimental test facility operated by the University of California. The site is located in the eastern Altamont Hills, 17 miles east of Livermore, California (Figure 1). At Site 300, DOE conducts research, development, and testing associated with high-explosive materials. During previous Site 300 operations, a number of contaminants were released to the environment. These releases occurred primarily from spills, leaking pipes, leaching from unlined landfills and pits, high-explosive test detonations, and disposal of waste fluids in lagoons and dry wells (sumps). The climate at Site 300 is semi-arid; approximately 10 to 15 inches of precipitation falls each year, mostly in the winter.

The Building 834 Complex is located on an isolated hilltop in the southeast portion of Site 300 (Figure 2). The facilities at Building 834 have been used since the late 1950s to conduct thermal-cycling experiments on weapons components. These experiments were performed in four main buildings surrounded by a ring of eight smaller test cells. Aboveground pipes carried TCE-based heat-exchange fluid from the main buildings to and from the test cells. The heat-exchange system was dismantled in 1993–1994.

The Building 834 OU is informally divided into the Core and Distal Areas. The Core Area generally refers to the vicinity of the buildings and test cells in the center of the Building 834 Complex where the majority of contaminant releases occurred. The Distal Area refers to the dissolved contaminant plumes downgradient from the Core Area.

3.1.2. Hydrogeologic Setting

The primary hydrogeologic units in the Building 834 area are described below, from shallow to deep. A conceptual hydrostratigraphic column is shown on Figure 3.

Vadose (Unsaturated) Zone - Unconsolidated sand, silt, and clay sediments beneath the Complex are unsaturated to a depth of approximately 30 feet below ground surface (bgs). The vadose zone is highly contaminated with VOCs, TBOS, and TKEBS beneath the Complex.

Perched Water-Bearing Zone - A variably saturated, discontinuous perched water-bearing zone occurs in sand and gravel lenses below the vadose zone. The perched zone can be up to 8 feet thick. Ground water in the perched aquifer generally flows toward the south. Figure 4 shows potentiometric surface elevation contours of the perched water-bearing zone. Perched ground water is not laterally continuous except for short periods of time following heavy rainfall events. The lateral extent of the perched zone is limited by the steep slopes to the north, east, and west of the Complex. The perched water-bearing zone is highly contaminated below the Core Area and discontinuous plumes of contaminants extend into the Distal Area.

Perching Horizon - Downward ground water and contaminant movement from the perched zone is inhibited by an underlying low-permeability clay and claystone perching horizon. The thickness of the perching horizon ranges from 10 to 40 feet. Some contamination is present in the upper portion of the perching horizon.

Regional Aquifer - Approximately 280 feet of unsaturated, interbedded claystone and sandstone lies below the perching horizon. A laterally-extensive regional aquifer occurs at a depth of about 340 feet bgs. No contamination from releases at the Building 834 Complex has been detected below the perching horizon nor in the regional aquifer.

3.2. Land and Resource Use

Before DOE established Site 300 as a remote testing facility, the area was used for cattle grazing. Site 300 is currently an operating facility and will remain under DOE control for the reasonably anticipated future. Current offsite land use near the OU includes agriculture, private residences, and an ecological preserve. 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 land adjacent to the OU.

Ground water from the perched zone is not currently used due to extremely low well yields, limited extent of saturation, and naturally poor water quality. At Site 300, the regional aquifer is a source of water for drinking, processing of explosives, and fire suppression. Offsite, the regional aquifer supplies water for domestic and agricultural uses. There are no offsite private water-supply wells in use near the OU.

There are no environmentally-sensitive areas on Site 300 property within the Building 834 OU. However, the American badger (a California Department of Fish and Game species of special concern) and the big tarplant (an annual plant on the California Native Plant Society’s List 1B) do occur in the area. Although the Building 834 OU is within the general area of Site 300 proposed as Critical Habitat for the California Red-Legged Frog by the U.S. Fish and Wildlife Service, the Building 834 OU does not contain critical habitat for this species. The California Department of Fish and Game operates an ecological preserve east of the OU along Corral Hollow Creek, but contaminant releases from the OU are not anticipated to affect the preserve.

3.3. History of Contamination

The Building 834 facilities have been in use since the late 1950s for experiments involving thermal cycling of weapons components. From 1962 to 1978, intermittent spills and piping leaks resulted in contamination of the subsurface with TCE and silicone oils (TBOS and TKEBS) at eight release points. DOE estimates that approximately 550 gallons (3,038 kilograms [kg]) of

TCE were released, either directly to the ground surface and/or to floor drains leading to a nearby septic system leach field, but it is likely that a significant fraction of the total amount of TCE released volatilized without infiltrating into the subsurface. Nitrate contamination in ground water results from septic-system effluent but may also have natural sources. DOE has not determined the amount of silicone oil and nitrate released. Diesel, benzene, toluene, and ethylbenzene have been detected sporadically in ground water in the Core Area. The source of these contaminants is an underground fuel storage tank that was excavated in 1994 and closed with the concurrence of State of California regulatory agencies; no further action is required.

3.4. Initial Response

DOE began environmental investigations in the Building 834 area in 1983. Since then, 75 boreholes have been drilled in the Building 834 OU; 55 of these boreholes were completed as ground water monitor wells. The geologic and chemical data from these wells and boreholes are used to characterize the site hydrogeology and to monitor temporal and spatial changes in saturation and dissolved contaminants. Site characterization also included soil vapor surveys, test pits, hydraulic testing, and geophysical surveys.

Remediation activities at the Building 834 OU conducted prior to the Interim Site-Wide ROD (i.e., before 2001) included soil excavation, numerous treatability studies, soil vapor and ground water extraction, and diverting surface water drainage from contaminant source areas. These activities are described in Sections 2 and 4.2.

3.5. Contaminants

Three primary types of contaminants have been detected in the subsurface in the Building 834 OU: (1) VOCs, (2) silicone oils, and (3) nitrate. Historic and current concentrations of these contaminants are discussed in Section 6.4.

The predominant contaminant in the vadose zone and ground water is TCE, a suspected human carcinogen. Due to the high concentrations detected, TCE is suspected to occur as discontinuous Dense Non-Aqueous Phase Liquid but has never been directly observed in this phase. The baseline human health risk assessment estimated a maximum excess carcinogenic risk of 1×10^{-5} to site workers, assuming continuous inhalation of TCE vapors volatilizing from the subsurface and migrating into indoor air over a 30-year period.

Significant concentrations of cis-1,2-dichloroethylene (cis-1,2-DCE) also occur, primarily as a breakdown product of TCE through *in situ* biodegradation. Low concentrations of tetrachloroethylene, vinyl chloride, ethene, and ethane are also present.

Silicone oils (TBOS and TKEBS) occur as a Light Non-Aqueous Phase Liquid floating on the perched ground water. Silicone oils are relatively non-toxic, and no health risks have been identified for these compounds. No regulatory limits have been established for these compounds.

Nitrate contamination in ground water results from septic-system effluent but may also have natural sources. DOE is currently studying the relative contributions of these nitrate sources. Nitrate can cause non-carcinogenic health effects if ingested at elevated concentrations.

4. Interim Remedial Actions

4.1. Interim Remedy Selection

Remedial Action Objectives for Site 300 were established in the Interim Site-Wide ROD, of which the following are applicable to the Building 834 OU:

For Human Health Protection:

- Restore ground water containing contaminant concentrations above cleanup standards. The Interim Site-Wide ROD established that the ground water cleanup standards that will be set in the Final ROD for Site 300 will be at least as protective as achieving Maximum Contaminant Levels (MCLs).
- Prevent human inhalation of VOCs volatilizing from subsurface soil to air that pose an excess cancer risk greater than 1×10^{-6} or hazard quotient greater than 1, a cumulative excess cancer risk (all carcinogens) in excess of 1×10^{-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 1×10^{-4} and/or a cumulative hazard index greater than 1 (all noncarcinogens).

For Environmental Protection:

- Restore water quality, at a minimum, to protect beneficial uses within a reasonable timeframe. Prevent migration of contaminants into pristine waters. This will apply to both individual and multiple constituents that have additive toxic or carcinogenic effects.
- Ensure that ecological receptors important at the individual level of ecological organization (State of California or federally listed or endangered species or State of California species of special concern) do not reside in areas where relevant hazard indices exceed 1.
- Ensure that existing contaminant conditions do not change so as to threaten wildlife populations and vegetation communities.

DOE has agreed to remediate VOCs in the vadose zone to the extent technically and economically feasible to minimize further degradation of the ground water. DOE will also mitigate the excess cancer risk from inhalation of indoor air within Building 834D caused by TCE migrating into the building from the subsurface.

In the Interim Site-Wide ROD, the remedies for the Building 834 OU were selected based on their ability to contain contaminant sources, prevent further plume migration, remove contaminant mass from the subsurface, and protect human health and the environment. The selected interim remedy for the Building 834 OU consists of:

- Continuing ground water and soil vapor extraction and treatment in the Core Area.
- Expanding the existing wellfield to extract soil vapor and ground water from wells in the Distal Area.

- Performing regular ground water and soil vapor monitoring.
- Establishing or maintaining administrative controls, such as building access, risk and hazard management, and land-use restrictions, and measures to prevent use of contaminated ground water.

4.2. Interim Remedy Implementation

Ground water and soil vapor extraction and treatment began in 1986 as treatability studies. Cleanup continued under the Interim ROD for the Building 834 OU (DOE, 1995) and later under the Interim Site-Wide ROD for Site 300 (DOE, 2001). DOE has periodically modified and expanded the extraction wellfield and upgraded the treatment facilities.

- The interim remedy is now being performed as described in the Interim Remedial Design for the Building 834 OU (Gregory et al., 2002). Although the designs differ slightly from the conceptual plans included in the Interim Site-Wide ROD, the regulatory agencies have agreed that the modifications to the remedy do not require documentation through a ROD amendment or Explanation of Significant Differences. The schedules to implement the interim remedy are included in the Interim Remedial Design document and the Remedial Design Work Plan for the interim remedies (Ferry et al., 2001b). The interim remedy includes:
- Extracting ground water from twelve wells in the Core Area, each producing 0.003 to 0.02 gallons per minute (gpm). Soil vapor also is being extracted from these wells and from three other wells not used for ground water extraction. The extraction and monitor wellfield in the Core Area is shown on Figure 5.
- Cyclic operation of selected extraction wells in the Core Area to maximize *in situ* biodegradation of TCE. Passive microbial degradation (intrinsic bioremediation) of TCE occurs in the Core Area where silicone oils are present. Intrinsic bioremediation is facilitated by the presence these oils, whose fermentation yields the hydrogen required for microbial dechlorination of TCE to cis-1,2-DCE. This process occurs only under oxygen-depleted conditions, and operating the soil vapor extraction system introduces oxygen into the subsurface that inhibits TCE biodegradation. The cis-1,2-DCE concentration declines dramatically after soil vapor extraction has begun. Preliminary estimates indicate that a cyclic extraction schedule of two weeks on/two weeks off may result in optimum VOC mass removal and biodegradation.
- Expanding ground water and soil vapor extraction into the Distal Area. Six existing monitor wells will be converted to extraction wells. The extraction and monitor wellfield in the Distal Area is shown on Figure 6. Although the vadose zone is not contaminated in the Distal Area, ground water extraction will be used to dewater the perched zone, allowing remaining VOC contaminants to be removed by the more efficient soil vapor extraction process.
- Continuing treatability studies to evaluate the possible application of enhanced *in situ* bioremediation through the addition of nutrients.

The ground water treatment system consists of:

- An oil skimmer/phase separator.
- A pre-treatment storage tank.
- Primary and secondary air-sparging units. Based on the results of recent treatability studies, these air-sparging units will be replaced by an aqueous-phase GAC system. In these studies, aqueous-phase GAC was found to perform comparably to air sparging in removing VOCs from extracted ground water, but with lower operation costs. However, aqueous-phase GAC does not reduce the concentration of silicone oils as efficiently as the air sparging units and DOE will monitor the discharge area to determine if an oily residue develops and/or if there are indications that the silicone oils in the treated ground water are having a negative impact on plant life. The air-sparging units will remain in place and will be restarted if a problem arises with the discharge of silicone oils.
- A particulate filter.
- Three vapor-phase GAC units and an emissions stack.
- Two post-treatment storage tanks.
- Six misting towers to discharge treated water. The discharge area is monitored regularly to identify conditions indicative of wetland formation. If such conditions are observed, the discharge will be reduced or relocated.

The soil vapor treatment system consists of:

- A water knock-out drum.
- Four vapor-phase GAC units.
- An emissions stack to discharge the treated vapor stream to the atmosphere.

Photographs of the treatment system are shown in Figure 7.

4.3. System Operations/Operation and Maintenance

In general, the Building 834 OU extraction and treatment system is operating as designed and no significant operations, performance, maintenance, or cost issues were identified during this review. All required documentation is in place (or is scheduled to be produced), and treatment system operations and maintenance (O&M) activities are consistent with established procedures and protocols.

O&M procedures are contained in the following documents:

- Health and Safety Plan and Quality Assurance/Quality Control Plan for the O&M of the Building 834 Treatment Facilities, contained within the Interim Remedial Design document (Gregory et al., 2002).
- Building 834 Treatment Facility Operations and Maintenance Manual (LLNL, in progress).
- Operations and Maintenance Manual, Volume 1: Treatment Facility Quality Assurance and Documentation (LLNL, 2000a).

- Integration Work Sheet Safety Procedure #552: Ground Water and Soil Vapor Extraction at Building 834 (LLNL, 2000b).
- Building 834 Substantive Requirements and the Monitoring and Reporting Program issued by the California Regional Water Quality Control Board.
- Building 834 Permit to Operate issued by the San Joaquin Valley Unified Air Pollution Control District.
- LLNL Livermore Site and Site 300 Environmental Restoration Project Standard Operating Procedures (Dibley and Depue, 2000).

Monitoring and optimizing the performance and efficiency of the extraction and treatment system comprises a large portion of the O&M activities. Extracted ground water is sampled throughout the treatment process to ensure compliance with discharge requirements. Vapor effluent from the treatment system is monitored to ensure compliance with air permit discharge limits. Treatment system parameters such as pressure, flow, and temperature are recorded to anticipate potential mechanical problems and monitor system performance. Monitor and extraction wells are sampled regularly. Quarterly reports are submitted to the regulatory agencies that include analytic results, descriptions of O&M activities, and treatment system performance data.

The major O&M activities for the Building 834 ground water treatment system include:

- Collection and offsite disposal of TBOS and TKEBS from the oil skimmer/phase separator.
- Maintaining the particulate filters, blower, and compressor for the air-sparging unit.
- Injecting carbon dioxide into the treated ground water stream to reduce precipitation of minerals in the discharge lines.
- Maintaining the misting towers used to discharge treated ground water.
- Protecting the unit from freezing in cold weather.
- Replacing spent vapor-phase GAC.
- Routinely inspecting and maintaining extraction well pumps, pipelines, and temperature and air flow sensors.

The major O&M activities for the soil vapor treatment system include:

- Replacing spent vapor-phase GAC.
- Ensuring the temperature within the GAC units remains within the optimal range.

The treatment systems at Building 834 have consistently operated in compliance with all permits and requirements.

The budgeted and actual environmental restoration costs for the Building 834 OU are tracked closely and are consistently within the allocated budget. The O&M cost of the extraction and treatment facility is approximately $460,000 per year. The estimated capital cost of replacing the existing air-sparging ground water treatment facility with an aqueous-phase GAC system and expanding the extraction wellfield is approximately $127,000.

5. Five-Year Review Process

The five-year review of the Building 834 OU at LLNL Site 300 was led by Mr. Roy Kearns, Site 300 Remedial Project Manager for the DOE-Oakland Operations Office. The following team members assisted in the review:

- Robert Ferry, Stantec Consulting.
- Leslie Ferry, LLNL.
- Steven Gregory, LLNL.
- Victor Madrid, LLNL.
- Zafer Demir, LLNL
- John Valett, Weiss Associates.

This review consisted of examining relevant project documents and site data, including:

- Final Site-Wide Remedial Investigation for Lawrence Livermore National Laboratory Site 300 (Webster-Scholten et al., 1994).
- Interim Record of Decision for the Building 834 Operable Unit at Lawrence Livermore National Laboratory Site 300 (DOE, 1995).
- Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300 (Ferry et al., 1999).
- Interim Site-Wide Record of Decision for Lawrence Livermore National Laboratory Site 300 (DOE, 2001).
- Remedial Design Work Plan for Interim Remedies at Lawrence Livermore National Laboratory Site 300 (Ferry et al., 2001b).
- Interim Remedial Design for the Building 834 Operable Unit at Lawrence Livermore National Laboratory Site 300 (Gregory et al., 2002).

This five-year review evaluated subsurface contaminant concentration and remediation system performance data collected through calendar year 2000.

DOE informed the public that this five-year review was in progress by placing a notice in the Tracy Press on September 5, 2001. The completed report is available in the information repositories in the Visitor's Center at the LLNL Livermore Site and the Tracy Public Library. Notice of the completion of the review will be placed in the Tracy Press and local contacts and members of the community will be notified by letter. The letter will contain a brief summary of this report.

6. Five-Year Review Findings

6.1. Interviews and Site Inspection

Interviews or a site inspection are not required for sites with an ongoing presence. “Ongoing presence” means that either the U.S. EPA, the State, or another government entity is the lead agency for the site and that this agency is involved in and knowledgeable of site activities, issues, concerns, and status. Specifically, there should be regular activity at the site, evidenced by continuing response work that is overseen by the continued presence of (or regular inspections by) the lead agency.

Because the cleanup at the Building 834 OU falls within the definition of “ongoing presence,” neither interviews nor a site inspection were required.

6.2. Changes in Cleanup Standards and To Be Considered Requirements

There have been no changes in location-, chemical-, or action-specific requirements since the Interim ROD for the Building 834 OU was signed in 1995.

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

There have been no changes in exposure pathways, toxicity, and other contaminant characteristics since the Interim ROD for the Building 834 OU was signed in 1995.

6.4. Data Review

The effectiveness and protectiveness of the interim remedy for the Building 834 OU was assessed primarily by reviewing contaminant concentration reduction and mass removal data. In the following sections, DOE has included estimates of the pre-remediation mass of contaminants in the subsurface, and compared these values to the mass of contaminants removed by ground water and soil vapor extraction. The estimates of VOC mass removal by the extraction and treatment system are considered to be relatively accurate. The estimates of the pre-remediation mass of contaminants in the subsurface have a much greater degree of uncertainty and are given as a range of values, assuming an uncertainty of ±30% as calculated from sensitivity analyses. The comparison of pre-remediation mass to that removed through extraction should not be used as the basis for decision-making regarding the performance of the interim remedy. The cleanup standards that will be established in the Final ROD for Site 300 will be defined solely on the basis of the concentrations of contaminants in the subsurface.

6.4.1. Ground Water

The mass of VOCs estimated to have been present in the ground water in the Building 834 OU prior to the beginning of remediation was 65–121 kg. Since then, 34 kg of VOCs have been removed by ground water extraction, representing 28–52% of the original mass. Over

174,000 gallons of contaminated ground water have been extracted and treated. TCE and cis-1,2-DCE are the predominant VOCs in extracted ground water. The cumulative mass of VOCs extracted over time is shown on Figure 8. Future mass removal rates are extremely difficult to predict because: (1) removal efficiency varies as a result of fluctuating ground water elevation and contaminant concentration, (2) changes in extraction well configuration affect removal rate, and (3) the mass removal rate will continue to decline as VOCs are removed from high-permeability sediments and diffuse slowly out of fine-grained materials.

A comparison of the distribution of total VOCs in perched ground water in 1995 and 2000 is shown on Figure 9. The maximum total VOC concentration in ground water in the perched aquifer has declined from a pre-remediation (1993) value of 1,060,000 micrograms per liter (µg/L) to 34,000 µg/L in late 2000, although significantly higher concentrations (up to 210,000 µg/L) are currently present in the low-permeability sediments of the upper part of the perching horizon. Time-series plots of total VOC concentration in ground water for selected wells are shown on Figure 10. TCE is typically the predominant VOC present in extracted soil vapor and ground water, but in areas where *in situ* intrinsic biodegradation is taking place the concentration of cis-1-2-DCE in ground water rises dramatically when the soil vapor extraction is not operating, as shown on Figure 11.

The silicone oils (TBOS and TKEBS) float on the ground water in a layer up to 4 inches thick. The highest historical concentration of these compounds dissolved in ground water was 7,300,000 µg/L (1995). The current maximum concentration is 250,000 µg/L. Since 1995, approximately 7 kg of silicone oils have been extracted. There is no consistent temporal trend in the thickness of the silicone oils nor in the concentration of these compounds dissolved in ground water. The silicone oil contamination in the subsurface is contained within the lateral and vertical distribution of VOCs. DOE's remediation strategy for these compounds does not include installing specific TBOS/TKEBS extraction wells, but the VOC extraction wellfield should also be effective to extract the silicone oils.

The highest historical concentration of nitrate in ground water was detected near the septic system leach field in 2000 (750 milligrams per liter [mg/L]). Approximately 33 kg of nitrate has been extracted since 1995. There is no consistent temporal trend in nitrate concentration in ground water. The highest concentrations of nitrate are found in areas with relatively low concentrations of VOCs. DOE has not yet developed a specific remediation strategy for the nitrate contamination, and is investigating the relative contributions of natural and anthropogenic sources.

A ground water capture zone analysis was included in the Interim Remedial Design document for the OU (Gregory et al., 2002). Estimated capture zones for the Core and Distal Areas are shown on Figures 12 and 13, respectively. The capture zones were calculated using an analytical-element flow model that conservatively assumed a constant recharge to the area and constant extraction rates from the wells. Due to the limited recharge in the Building 834 area, the actual capture zones may be larger than estimated. However, dewatering of the extraction wells may ultimately limit the extent of the capture zones. The size of the actual capture zones of the extraction wells will be verified using ground water elevation measurements.

DOE estimates that achieving MCLs for VOCs in ground water in the perched aquifer could require 140–220 years, due to: (1) low well yields, (2) limited amount of ground water available for extraction, and (3) the difficulty in removing VOCs that have diffused into low-permeability sediments. To shorten cleanup time using only ground water extraction would require installing a large number of additional extraction wells (possibly more than 25), but the limited amount of recharge to the perched aquifer may not make this approach viable. However, since the perched aquifer at Building 834 is not used as a source of water, is isolated from the underlying regional water-supply, and is not significantly migrating, ground water extraction is a viable strategy for reducing the mass of contaminants in the subsurface. An important aspect of DOE's cleanup strategy for the Building 834 OU is the application of other technologies (e.g., bioremediation) to supplement ground water extraction and reduce the time required to restore beneficial uses of ground water.

6.4.2. Vadose Zone

The original mass of VOCs estimated to have been present in the vadose zone was 602–1,118 kg. Since then, 275 kg of VOCs have been removed by soil vapor extraction, representing 25–46% of the original mass. The extracted vapor-phase VOCs are comprised almost exclusively of TCE and cis-1,2-DCE. The cumulative mass of VOCs removed from the subsurface over time is shown on Figure 8. The rate of mass removal is extremely variable, possibly as a result of: (1) temporal permeability variations in the subsurface caused by changes in vadose zone moisture content, (2) seasonal changes in the thickness of the vadose zone from fluctuating ground water levels, and/or (3) changes in the VOC concentration in extracted soil vapor as the extraction and air injection well configuration is changed.

Since full-scale soil vapor extraction began in 1998, the TCE concentration in the soil vapor treatment system influent has been extremely variable, with a maximum of 135 parts per million by volume ($ppm_{v/v}$). This variability is due to changes in extraction well configuration and intermittent operation of the extraction system. A time-series plot of TCE concentration in soil vapor treatment system influent is shown on Figure 14.

In 1982–83, DOE excavated approximately 100 cubic yards of TCE-contaminated soil at five locations within the Building 834 Core Area where heat-exchange fluid had been spilled or released from leaking pipes. The depths of the excavations ranged from 1 to 6 feet bgs. The excavated soil contained approximately 96 kg of VOCs, representing 8–16% of the pre-remediation mass of VOCs in the vadose zone. DOE has not identified any other areas at Building 834 where excavation would be a cost-effective remedial technology.

6.4.3. Institutional Controls

This five-year review evaluated the implementation of the institutional controls that were specified in the Interim Site-Wide ROD for Site 300 (DOE, 2001).

- **Maintaining access restrictions to Site 300 -** Access restrictions continue to be maintained by the LLNL Safeguards and Security organization.
- **Preventing ingestion of ground water where contaminated above concentrations protective of human health -** There are no existing water-supply wells in the Building 834 OU. LLNL environmental restoration staff routinely meet with site planning personnel and ensure that any new water-supply wells are sited in uncontaminated areas. There is no offsite ground water contamination resulting from releases at the Building 834 OU, and no offsite water-supply wells are in use near the OU.
- **Preventing installation of water-supply wells where ground water is contaminated above concentrations protective of human health -** DOE has no plans to install onsite water-supply wells near the Building 834 OU and is not aware of any proposed offsite wells near the OU.
- **Briefing all personnel working onsite on areas of contamination and possible hazards -** LLNL environmental restoration staff coordinate with Site 300 management to ensure that all facility managers and site workers are aware of potential hazards that may be encountered in contaminated areas.
- **Preventing excavation within areas of contamination except for approved remedial actions -** LLNL environmental restoration staff coordinate with Site 300 management to ensure that no excavation occurs in contaminated areas except under the supervision of hazards control staff. Onsite staff indicate that no excavation has occurred in the Building 834 area and none is planned for the future.
- **Maintaining building occupancy and land use restrictions in the vicinity of Building 834D -** Building occupancy and land use restrictions have been implemented by the Facility Coordinator for Building 834.
- **Installing warning signs in the vicinity of Building 834D -** Warning signs have been installed stating that full-time occupancy of Building 834D is prohibited.
- **Sampling indoor and outdoor air annually for VOCs within and adjacent to Building 834D until risk is less than 10^{-6} and the hazard index is less than 1 for two years -** An air sampling program will be included in the Compliance Monitoring Plan for Site 300 which is scheduled to be submitted in March 2002.
- **Conducting annual wildlife surveys to evaluate the presence of the San Joaquin kit fox and other burrowing species of special concern -** An ecological survey program will be included in the Compliance Monitoring Plan.
- **Integrating the sampling and survey data and risk assessment calculations to determine any changes in risks and hazards -** The approach that will be used to

determine changes in risks and hazards will be included in the Compliance Monitoring Plan for Site 300.

- **Reviewing human health and ecological data to evaluate compliance with the Remedial Action Objectives -** Provisions for reviewing these data are included in the Compliance Monitoring Plan for Site 300.
- **Developing and implementing Operational Safety Procedures for all remedial actions where risks can be foreseen -** All required Operation Safety Procedures are in place, and new procedures are created as needed.

7. Assessment

The protectiveness of the interim remedy was assessed by determining if:

1. The interim 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 interim remedy into question.

This five-year review determined that the interim remedy for the Building 834 OU was indeed protective, based on the following:

- The interim remedy is functioning as intended. Ground water and soil vapor extraction are reducing contaminant concentrations in the subsurface. The maximum VOC concentrations in ground water in the perched aquifer have decreased by approximately two orders of magnitude, although high concentrations remain in the upper part of the underlying low-permeability perching horizon. DOE has removed approximately 405 kg of VOCs from the subsurface, representing 33–61% of the mass of total VOCs that were present prior to remediation. Of the total mass removed from the subsurface, 68% has been through soil vapor extraction, 24% through excavation, and 8% through ground water extraction. These data indicate that soil vapor extraction is much more effective than ground water extraction in removing contaminants from the subsurface. Mass removal rates are declining for both ground water and soil vapor as contaminants are removed from more permeable subsurface sediments and diffuse slowly from lower-permeability materials. DOE currently estimates that it will require approximately 140–220 more years to achieve MCLs for VOCs in ground water at the Building 834 OU, but ground water cleanup standards will ultimately be established in the Final ROD for Site 300.
- The treatment systems are performing as designed and will continue to be operated and optimized.
- System operation procedures are consistent with requirements.
- Costs have been consistently within budget.
- No early indicators of potential interim remedy failure were identified.

- All required institutional controls are in place or scheduled to be implemented, and no current or planned changes in land use at the site suggest that they are not or would not be effective.
- The Health and Safety Plan is in place, sufficient to control risks, and properly implemented. The contingency plan for the Building 834 OU will be included in the Site-Wide Contingency Plan document to be completed in 2002.
- There have been no changes in location-, chemical-, or action-specific requirements since the Interim ROD for the Building 834 OU (1995) or the Interim ROD for Site 300 (2001) were signed, nor have there been changes in exposure pathways, toxicity, and other contaminant characteristics.
- There have been no changes in risk assessment methodologies that could call the protectiveness of the interim remedy into question.
- No additional information has been identified that would call the protectiveness of the interim remedy into question.

8. Deficiencies

No deficiencies in the interim remedy were identified during the five-year review process.

9. Recommendations and Follow-Up Actions

This five-year review does not identify a need for reassessing the overall approach to cleanup. DOE should implement the following actions according to the schedules included in the Remedial Design Work Plan for the Interim Remedies (Ferry et al., 2001b) and the Interim Remedial Design document for the Building 834 OU (Gregory et al., 2002):

- Modify the ground water and soil vapor extraction wellfield configurations to optimize contaminant mass removal and prevent stagnant zones from forming.
- Operate the Core Area extraction wells cyclically to maximize *in situ* biodegradation of TCE.

In addition:

- DOE should continue to evaluate other remedial technologies that could shorten cleanup time, especially those that will facilitate remediation of the low-permeability sediments.
- Due to the limited amount of recharge, installing additional ground water extraction wells may not result in a significant increase in contaminant mass removal or a decrease in cleanup time. Any additional ground water extraction wells should be installed only in areas where the wells will yield significant quantities of ground water. Soil vapor extraction appears to be a much more efficient mass removal technology given the nature of the subsurface materials at Building 834.

No other follow-up actions were identified related to this five-year review.

10. Protectiveness Statement

The interim remedy for the Building 834 OU is expected to be protective of human health and the environment upon completion, and in the interim: (1) the Health and Safety Plan is in place, sufficient to control risks, and properly implemented, (2) ground water and soil vapor extraction and treatment are reducing contaminant concentrations in the subsurface, and (3) institutional controls to minimize heath risks and prevent use of contaminated ground water are in place or are scheduled to be implemented.

11. Next Review

The next review will be completed within five years of the signature date of this document. The schedule and milestones for the next five-year review process are included in the Remedial Action Work Plan, contained within the Interim Remedial Design document for the Building 834 OU (Gregory et al., 2002).

12. References

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Acronyms and Abbreviations

bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cis-1,2-DCE	cis-1,2-dichloroethylene
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
GAC	granular activated carbon
gpm	gallons per minute
kg	kilograms
LLNL	Lawrence Livermore National Laboratory
MCL	Maximum Contaminant Level
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
O&M	operations and maintenance
OU	operable unit
PCB	polychlorinated biphenyl
$ppm_{v/v}$	parts per million on a volumetric basis
ROD	record of decision
TBOS	tetra-butyl-ortho silicate
TCE	trichloroethylene
TKEBS	tetra-kis-2-ethylbutyl silane
VOC	volatile organic compound

Figures

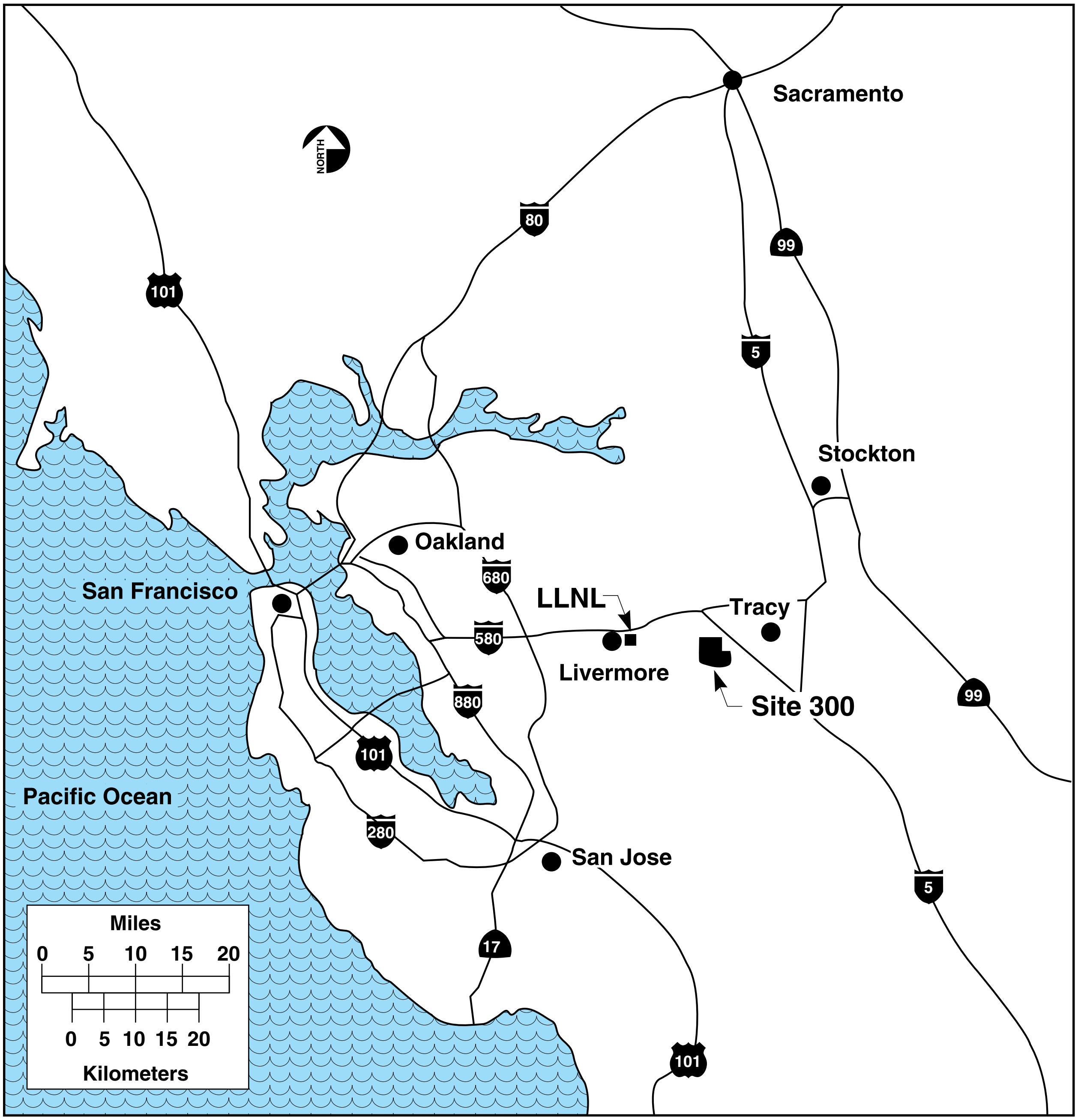

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Figure 1. Locations of LLNL Livermore Site and Site 300.

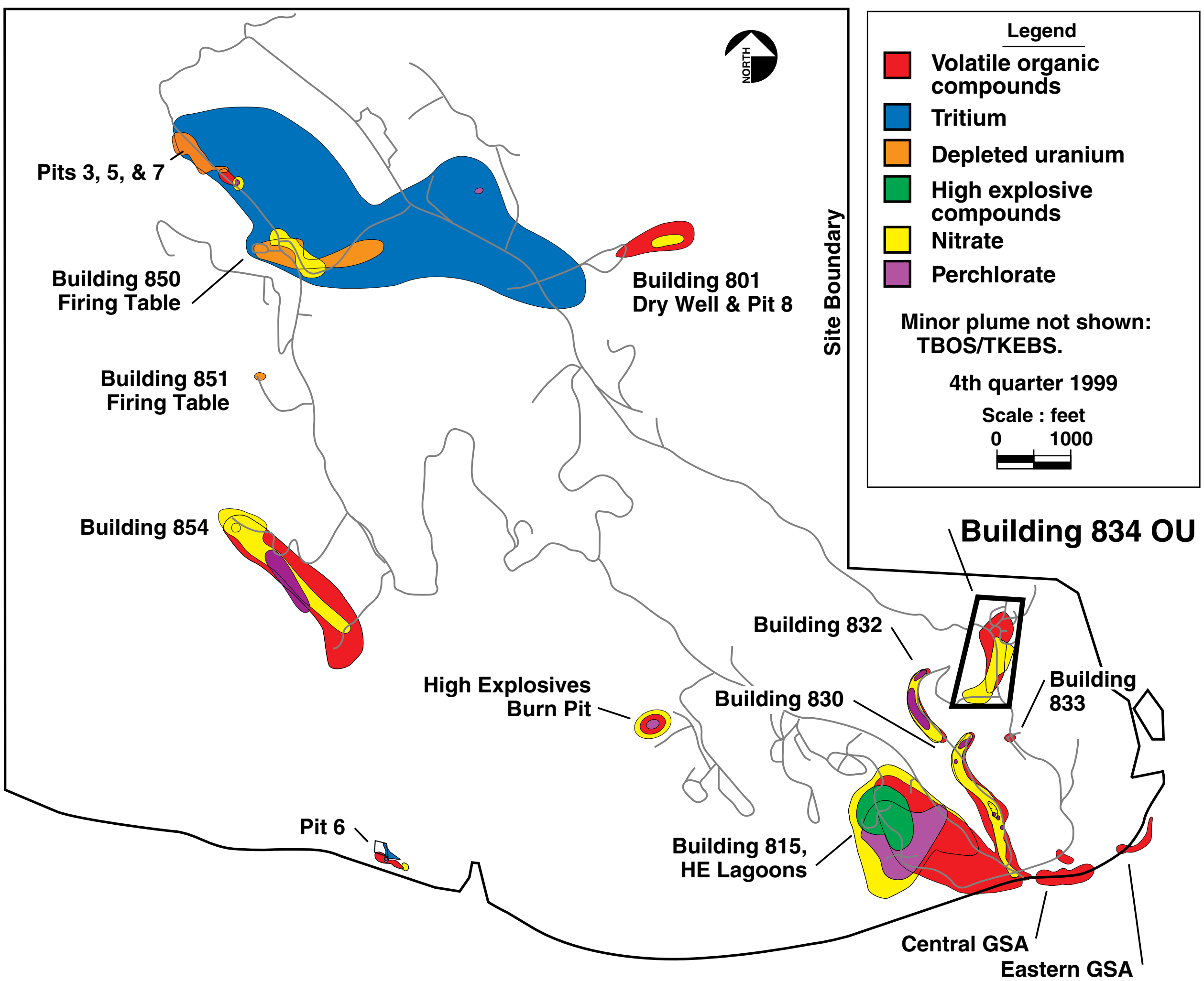

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Figure 2. Location of the Building 834 OU.

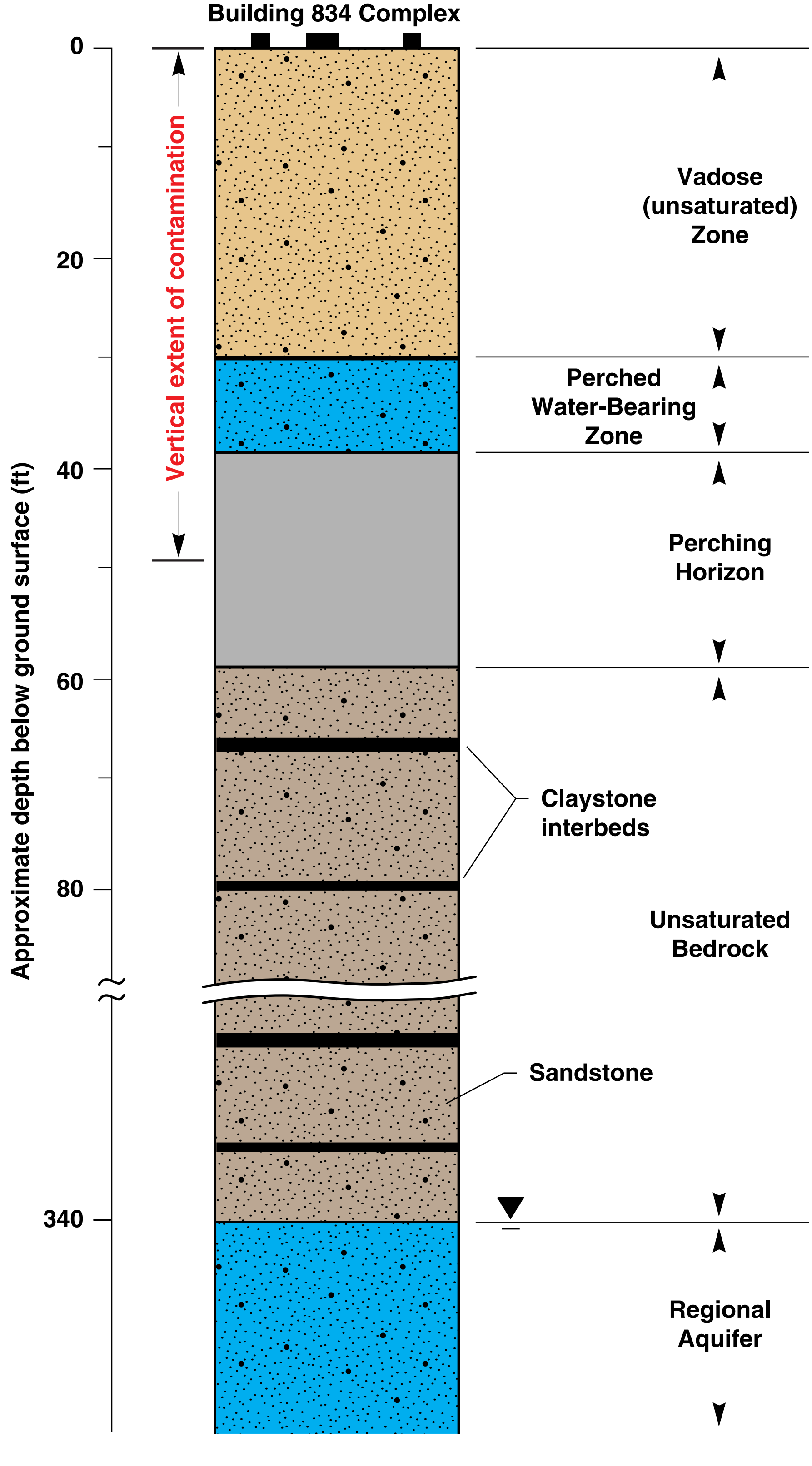

Figure 3. Conceptual hydrostratigraphic column for the Building 834 OU.

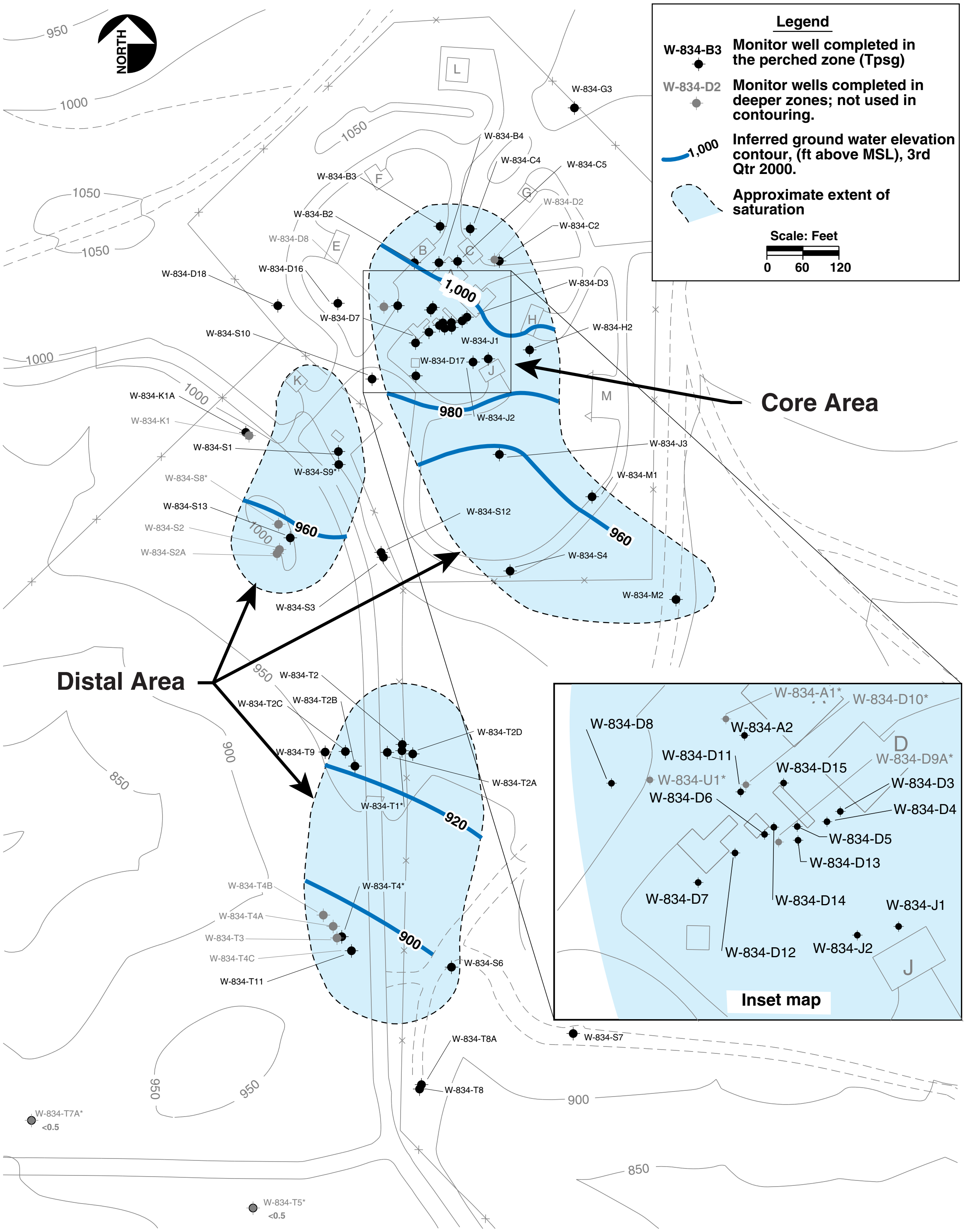

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Figure 4. Potentiometric surface elevation contour map of the perched water-bearing zone.

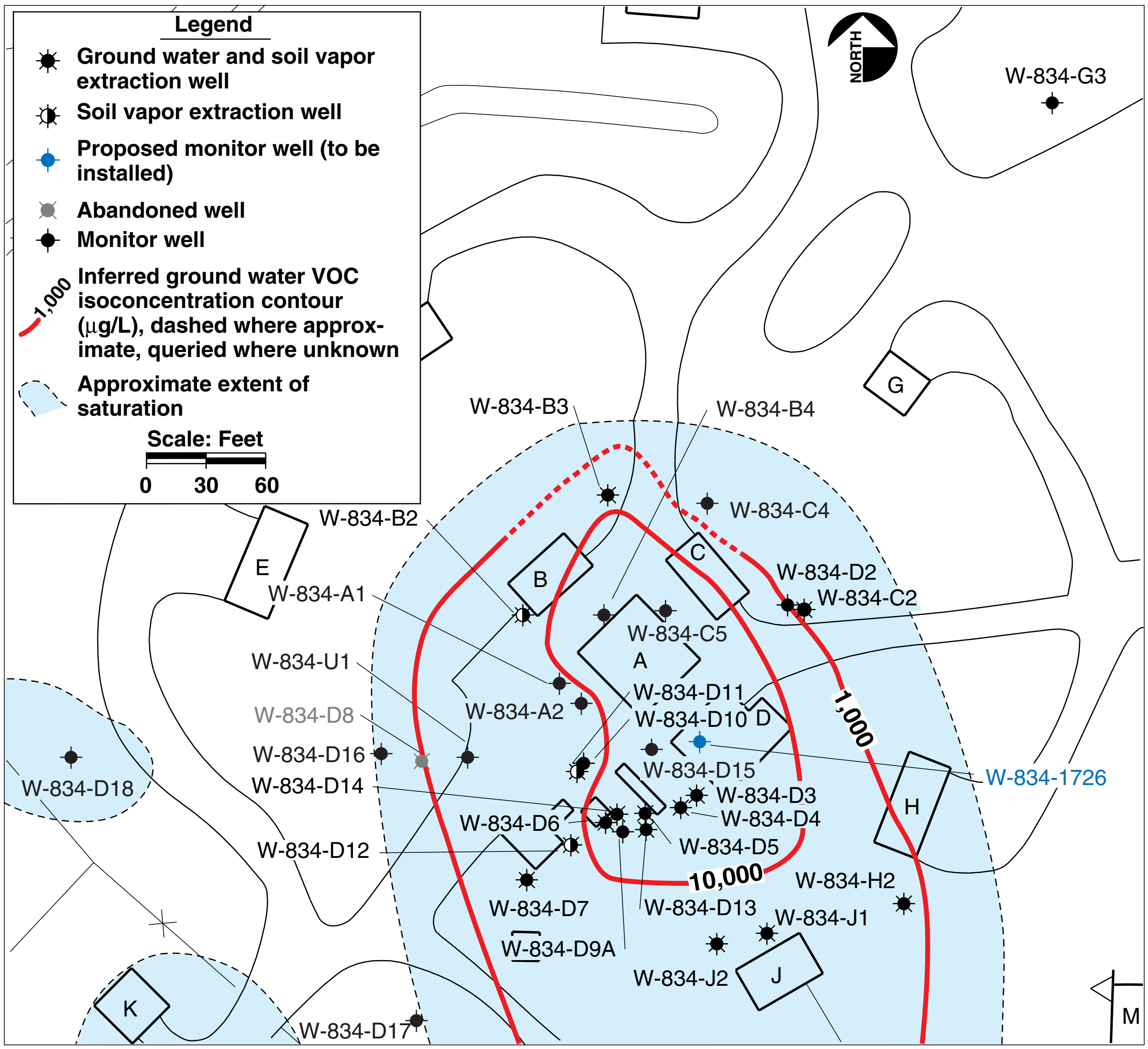

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Figure 5. Extraction and monitor wellfield in the Building 834 Core Area.

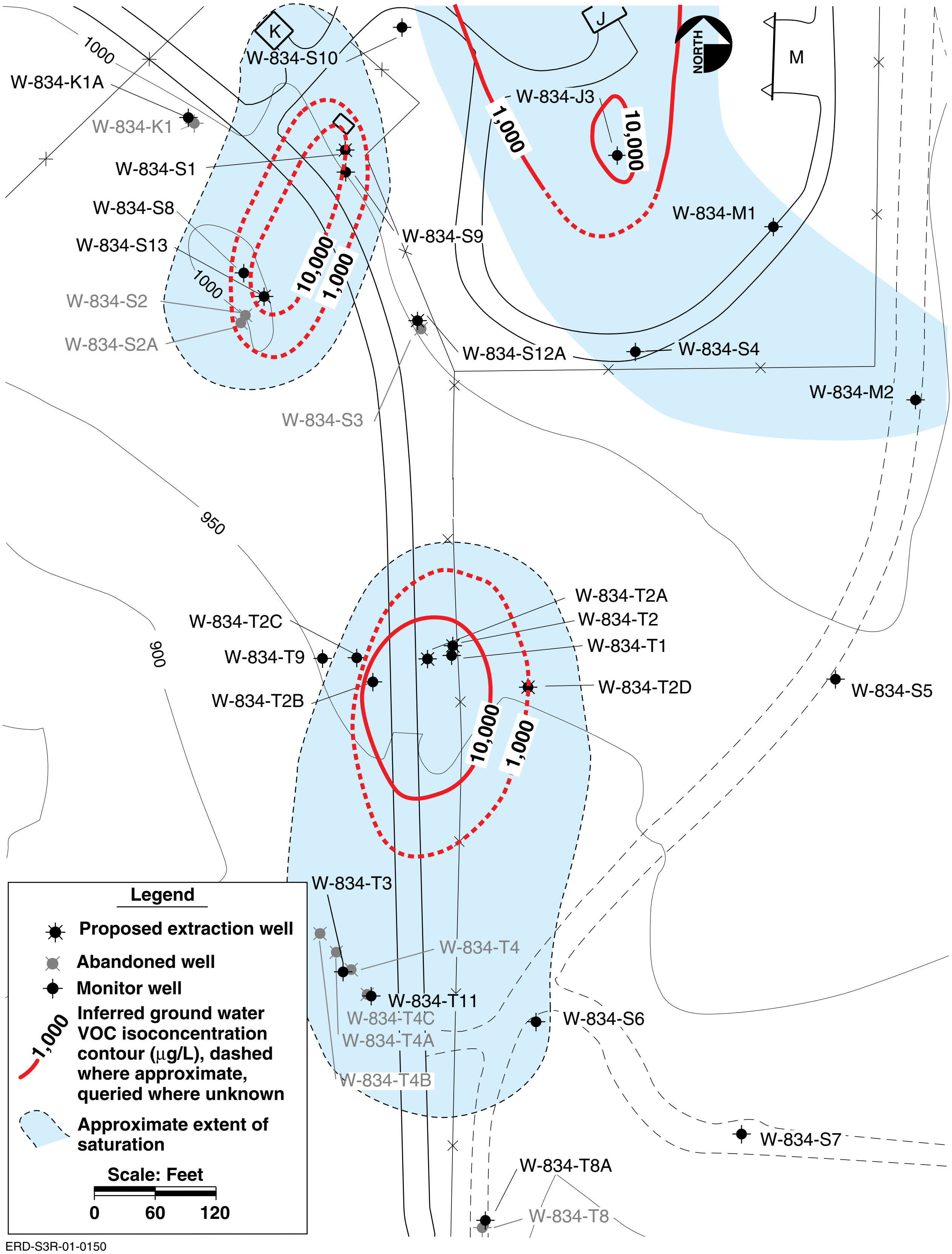
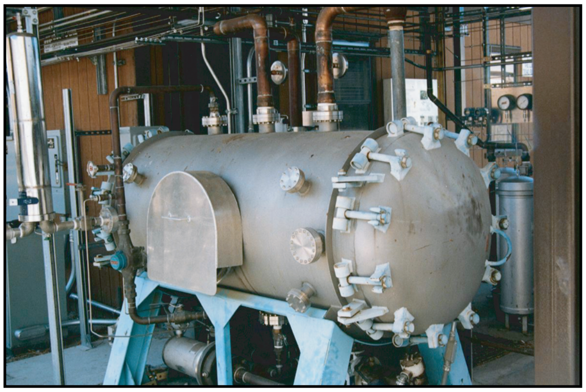


Figure 6. Extraction and monitor wellfield in the Building 834 Distal Area.

Primary air-sparging unit



GAC treatment systems

Misting towers to discharge treated ground water

Extracted silicone oil

ERD-S3R-01-0151

Figure 7. Photographs of the Building 834 treatment system.

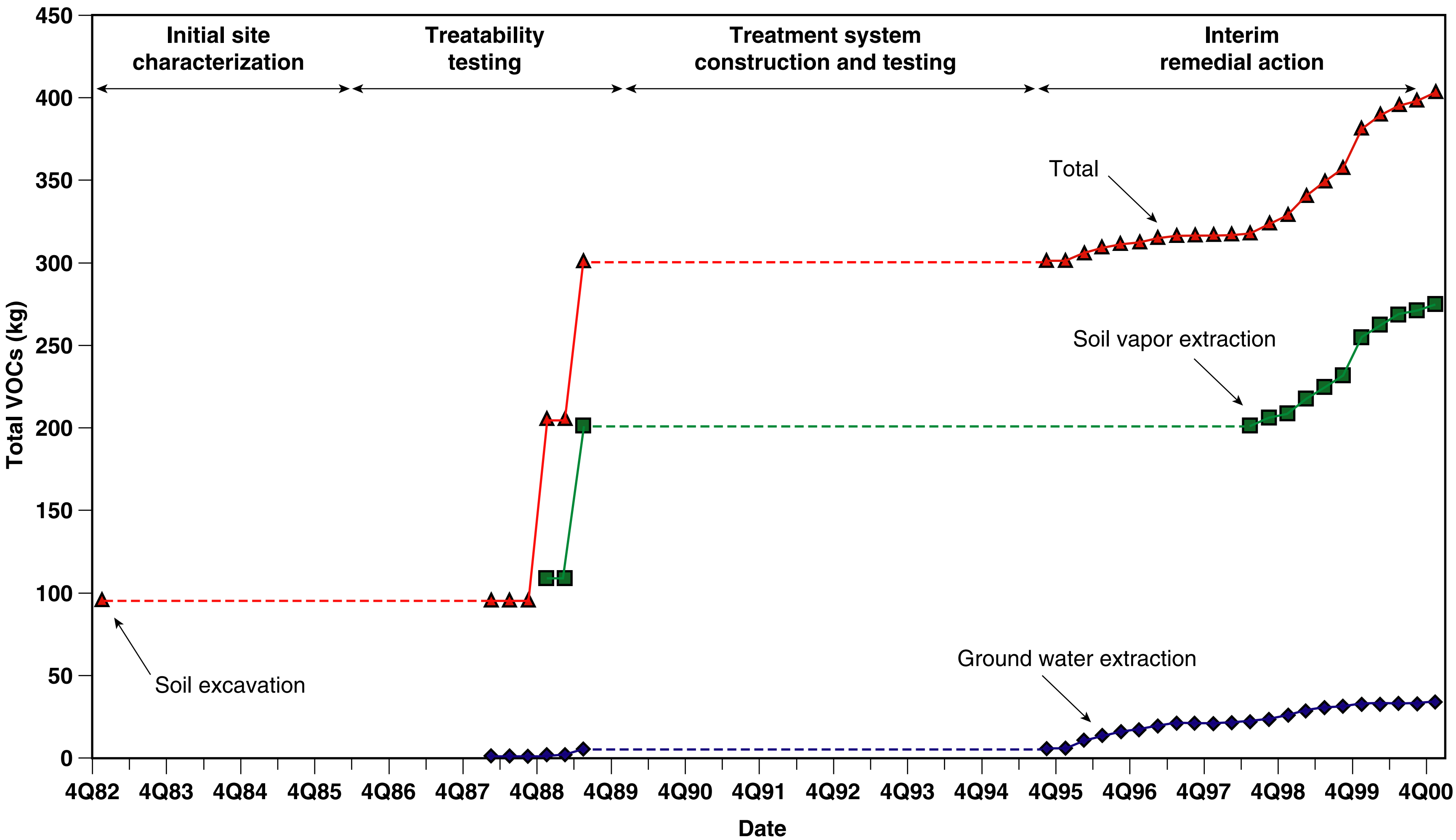


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Figure 8. Time-series plot of cumulative mass of total VOCs removed from the subsurface.

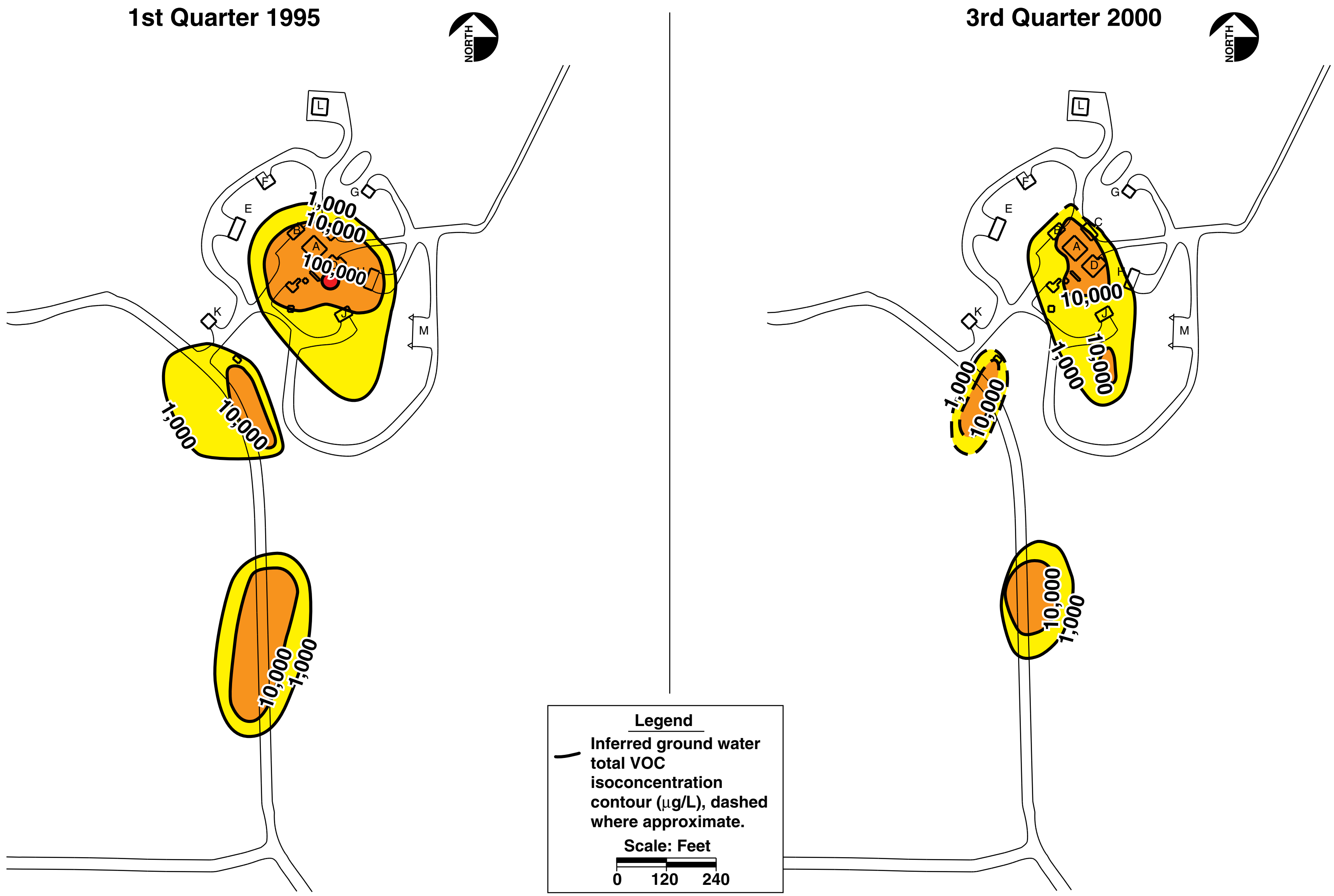

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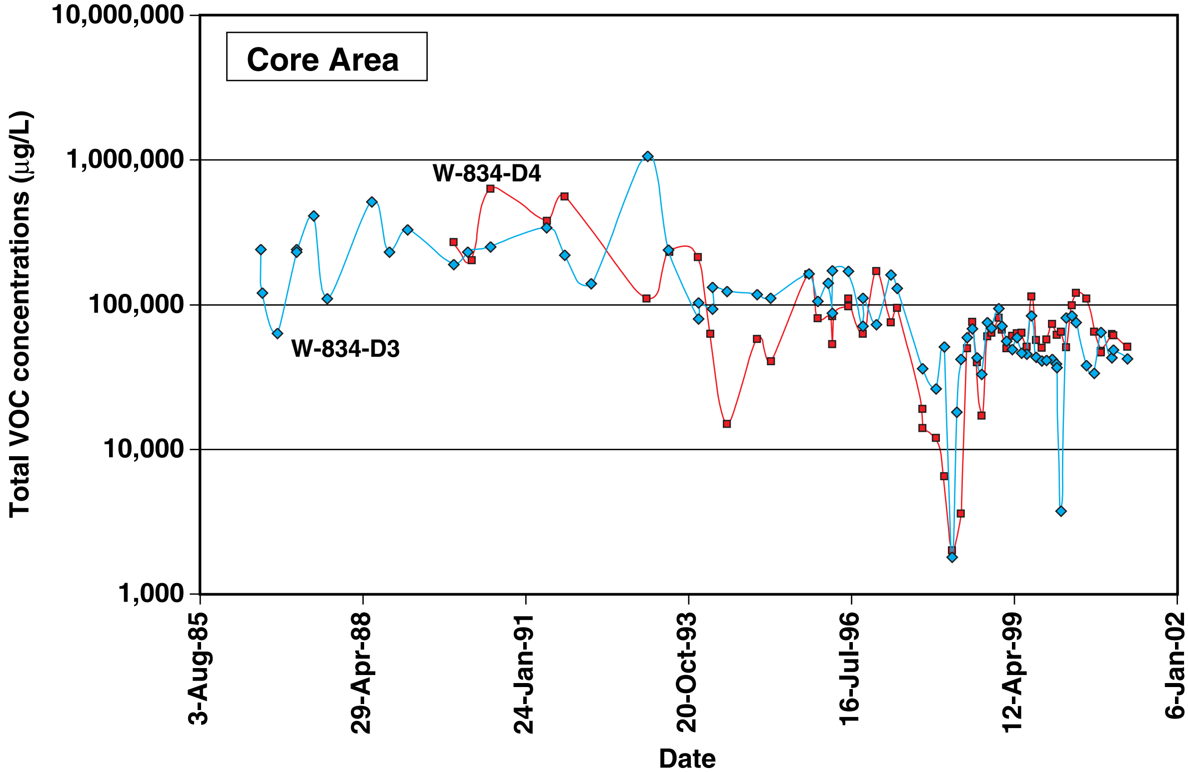
Figure 9. Comparison of the distribution of total VOCs in ground water in the perched water-bearing zone in 1995 and 2000.



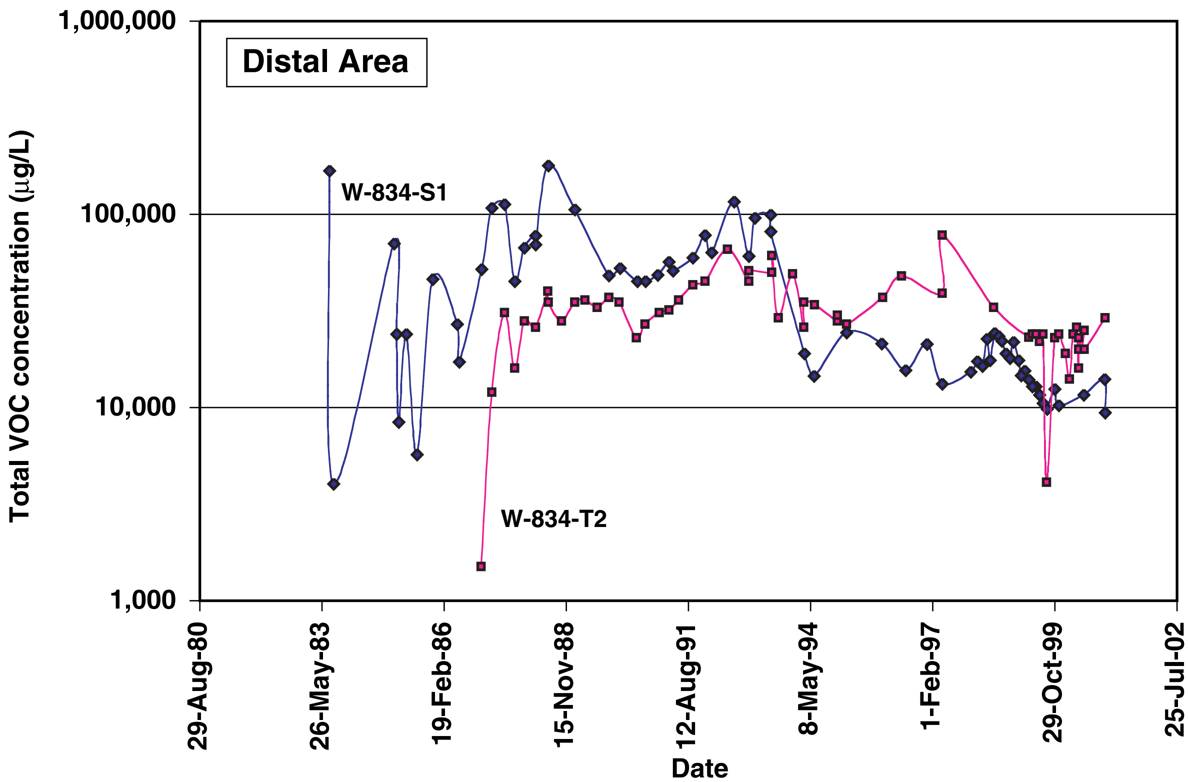


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Figure 10. Time-series plots of total VOC concentration in ground water for selected wells.

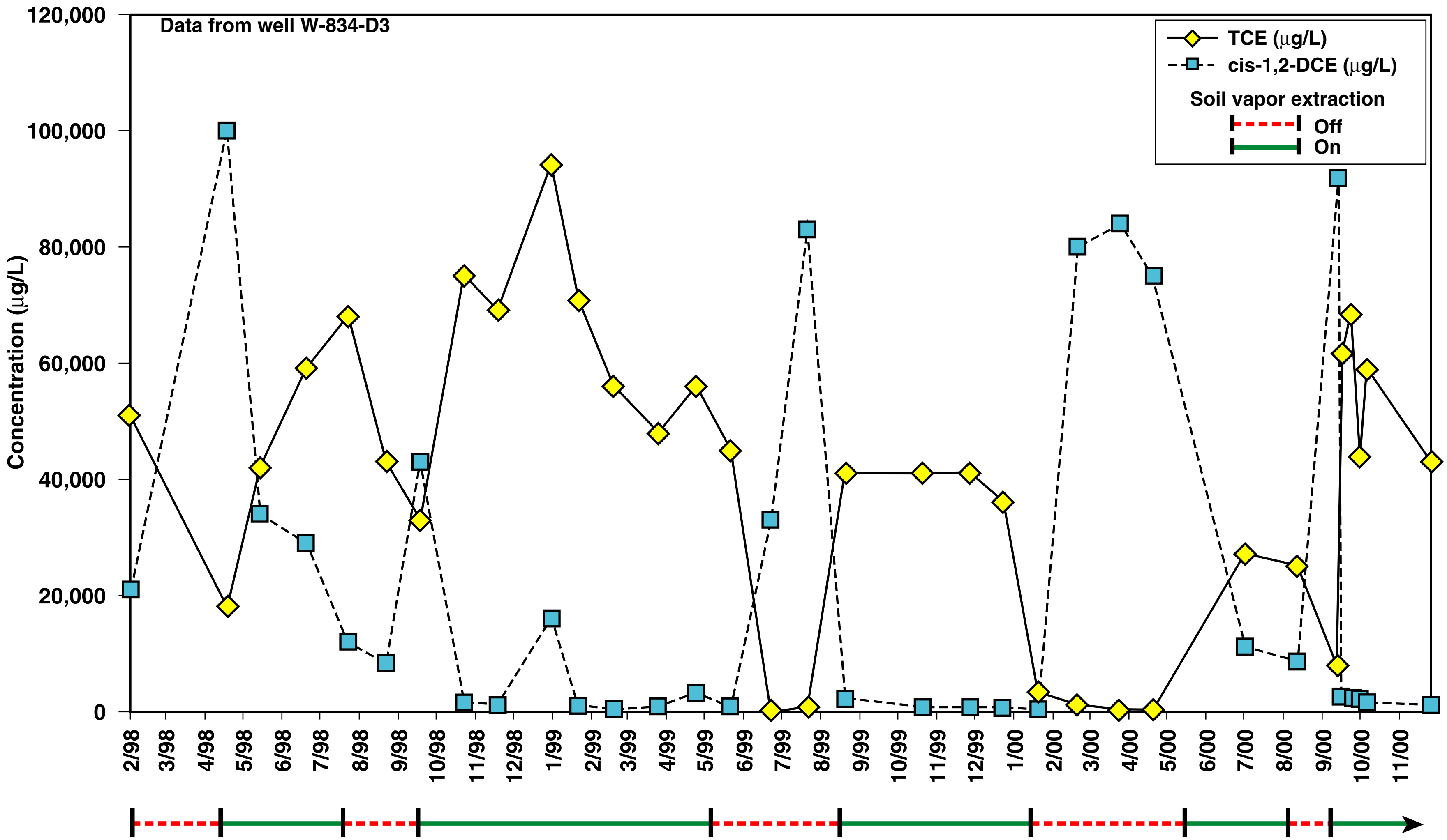

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Figure 11. Time-series plot of TCE and cis-1,2-DCE concentration in ground water correlated to soil vapor extraction operation.

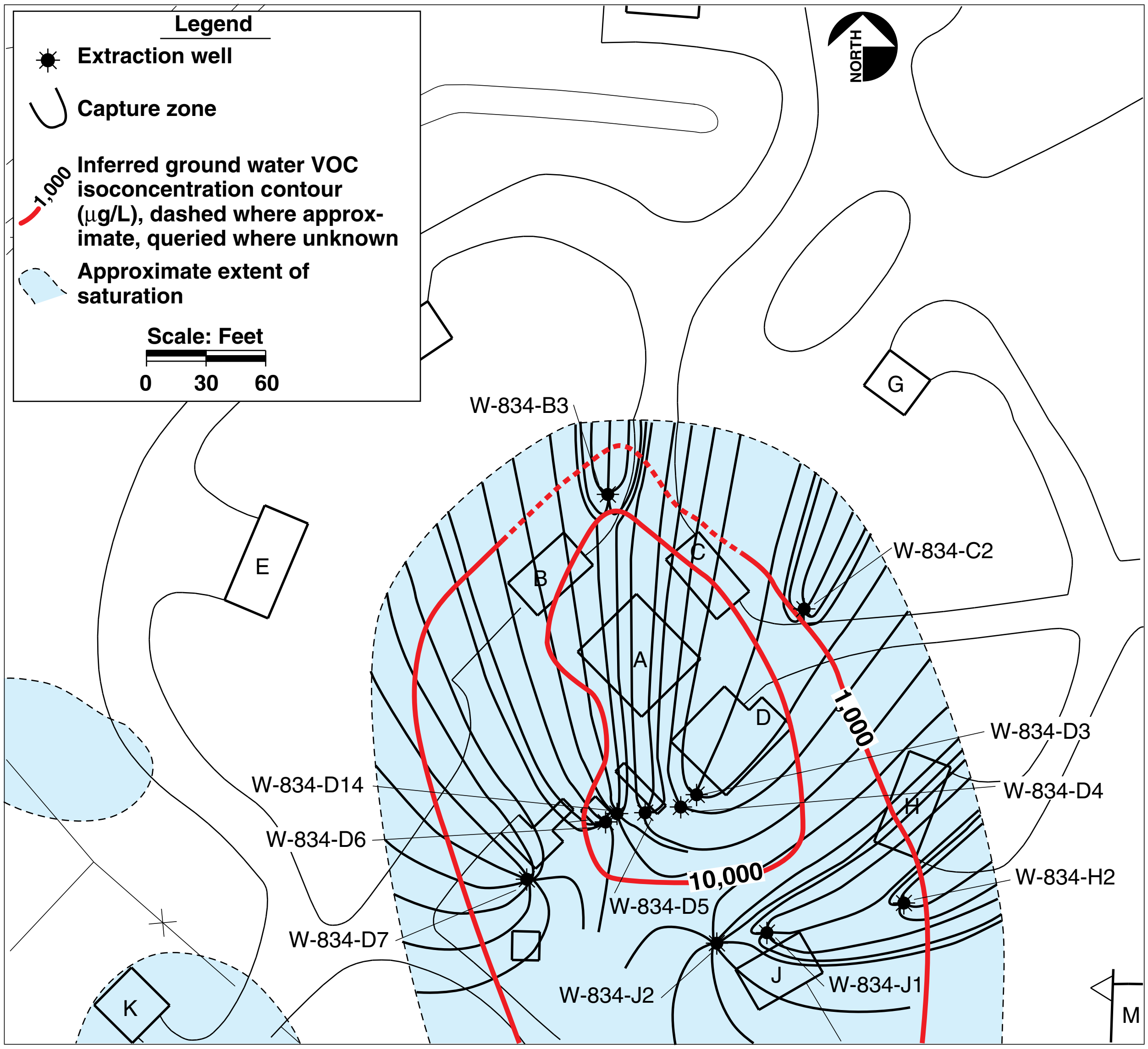

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Figure 12. Ground water capture in the Building 834 Core Area.

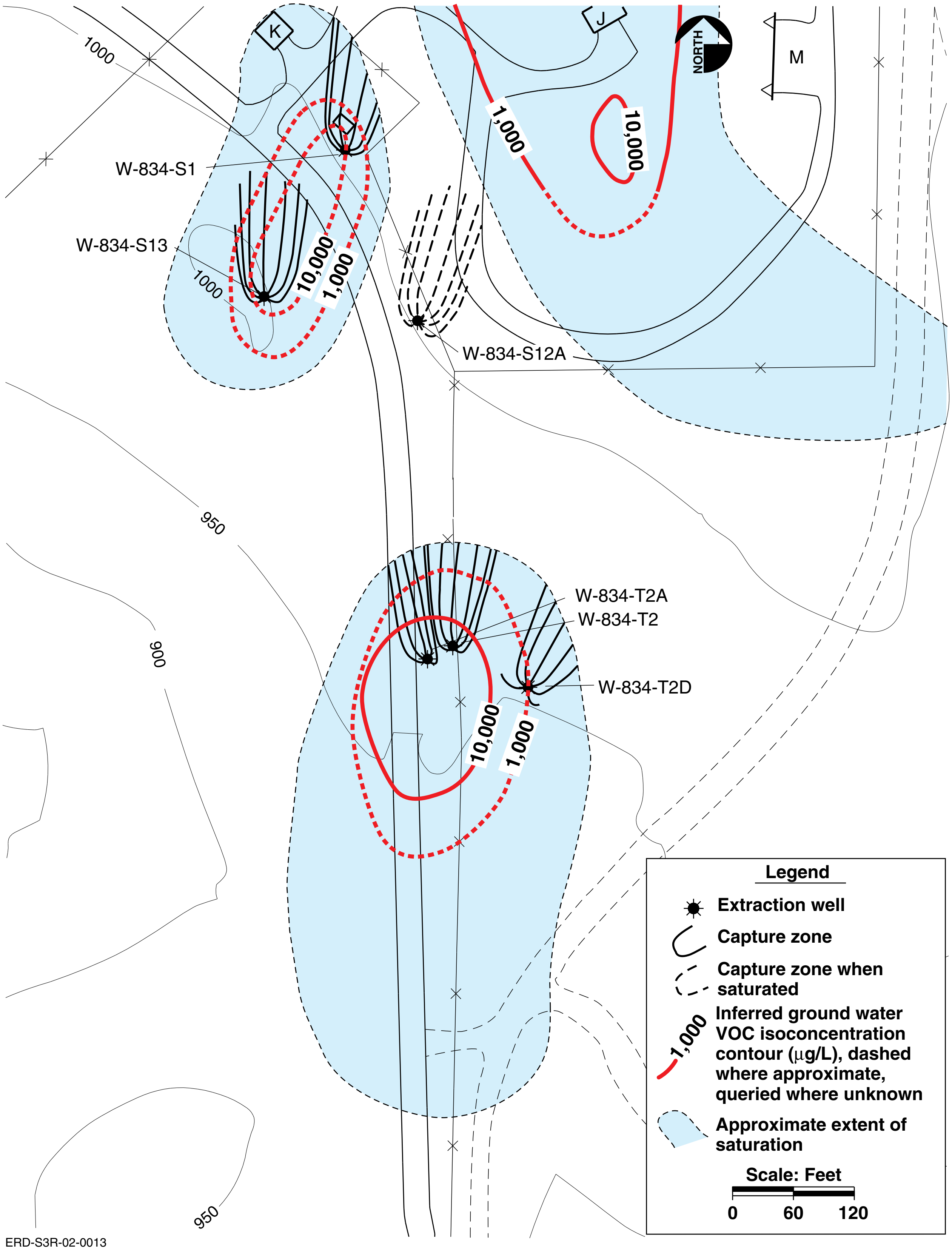

Figure 13. Ground water capture in the Building 834 Distal Area.

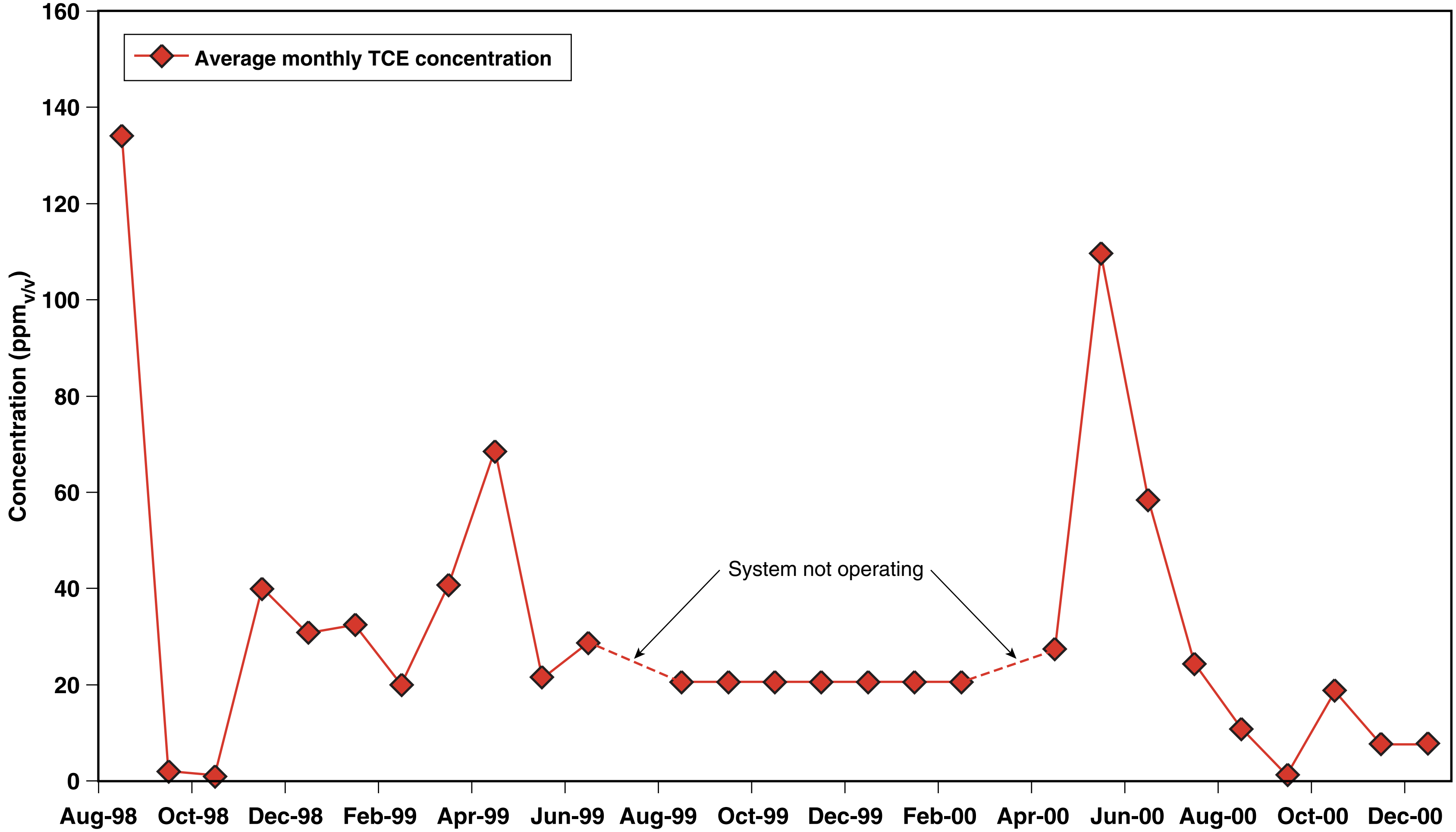

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Figure 14. Time-series plot of TCE concentration in soil vapor treatment system influent.