8

Groundwater Investigation and Remediation

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Introduction

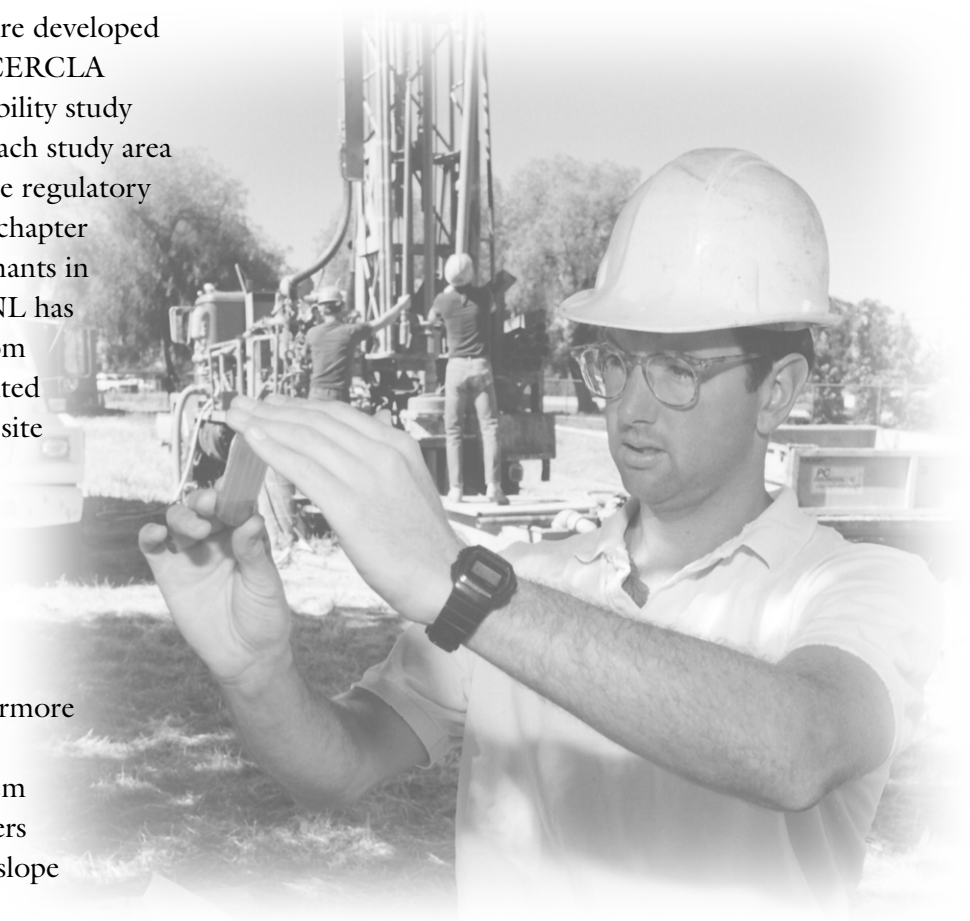
During 2000, groundwater investigations and remediations under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) continued at both the Livermore site and Site 300. LLNL regularly samples and analyzes groundwater from areas of known or suspected contamination. Portions of the two sites that contain groundwater with concentrations of chemicals of concern are actively investigated to determine the magnitude of the contamination and its source. Remediation strategies are developed and evaluated in preparation for a CERCLA removal action or through the feasibility study process. An approved remedy for each study area is developed in consultation with the regulatory agencies and the community. This chapter reviews the distribution of contaminants in groundwater, and the progress LLNL has made in removing contaminants from groundwater and from the unsaturated zones (soil vapor) at the Livermore site and Site 300.

Livermore Site Groundwater Project

Physiographic Setting

The general topography of the Livermore site is described in Chapter 1. The Livermore Valley groundwater system is a sequence of semiconfined aquifers in which groundwater moves downslope from the valley uplands toward the east-west axis of the valley. It then flows generally westward toward the southwest portion of the basin. From there, groundwater has historically flowed south into the Sunol Valley Groundwater Basin.

The largest quantities of groundwater are pumped from the central and western portions of the Livermore Valley, where the valley fill sediment is thickest. These sediments make up two aquifers:



the Livermore Formation and its overlying alluvium. The Livermore Formation averages about 1000 m in thickness and occupies an area of approximately 250 km^2. The alluvium, which is about 100 m thick, is the principal water-producing formation within the valley.

Hydrogeology

Sediment types at the Livermore site are grouped into four categories—clay, silt, sand, and gravel—based on dominant particle size. Groundwater flow beneath the site is primarily in alluvial sand and gravel lenses and channels, bounded by the less permeable clay and silt. The alluvial sediments have been mapped into seven hydrostratigraphic units (HSUs) beneath the Livermore site using data collected over the years. HSUs can be defined as sedimentary sequences whose permeable layers show evidence of hydraulic connection. The HSUs of concern beneath the Livermore site are the Quaternary alluvial deposits of the upper Livermore member of the Livermore Formation (see **Figure 8-1**). HSUs 1B, 2, 3A, 3B, 4, and 5 contain contaminants that are primarily solvents (Blake et al. 1995 and Hoffman et al. 1998).

Background

Initial releases of hazardous materials occurred at the Livermore site in the mid- to late-1940s when the site was the Livermore Naval Air Station (Thorpe et al. 1990). There is also evidence that localized spills, leaking tanks and impoundments, and landfills contributed volatile organic compounds (VOCs), fuel hydrocarbons (FHCs), lead, chromium, and tritium to the groundwater and unsaturated sediment in the post-Navy era. The Livermore site was placed on the EPA National Priorities List in 1987.

A screening of all environmental media showed that groundwater and unsaturated sediment are the only media that require remediation (Thorpe et al. 1990). The identified compounds that currently exist in groundwater at various locations beneath the site at concentrations above drinking standards are trichloroethylene (TCE), perchloroethylene (PCE), 1,1-dichloroethylene (1,1-DCE), chloroform 1, 2-dichloroethylene (1,2-DCE), 1,1-dichloroethane (1,1-DCA), 1,2-dichloroethane (1,2-DCA), trichlorotrifluoroethane (Freon 113), trichlorofluoromethane (Freon 11), and carbon tetrachloride.

Remedial Activities

In 2000, the Livermore site Groundwater Project (GWP) treated more than 1170 million liters (ML) of groundwater and removed approximately 270 kg of volatile organic compounds (VOCs). The GWP also brought new treatment facilities on line, installed wells, conducted hydraulic tests, developed groundwater models, published required documents, and maintained close contact with regulatory agencies and the community.

LLNL removes contaminants from groundwater and from the unsaturated zones (soil vapor) at the Livermore site through a system of 11 treatment facilities located throughout the 6 HSUs containing contaminants of concern. Within each facility, extraction wells are used to extract groundwater, which is then treated to remove VOCs. Treatment usually consists of removing VOCs with a large capacity air-stripping system, after which any VOCs present in the stripper's effluent air are removed with granular activated carbon (GAC) filters. Methods are noted in the following discussion of treatment facilities. **Table 8-1** lists the extraction wells according to the HSU in which they are screened and the total flow rate for each treatment area.

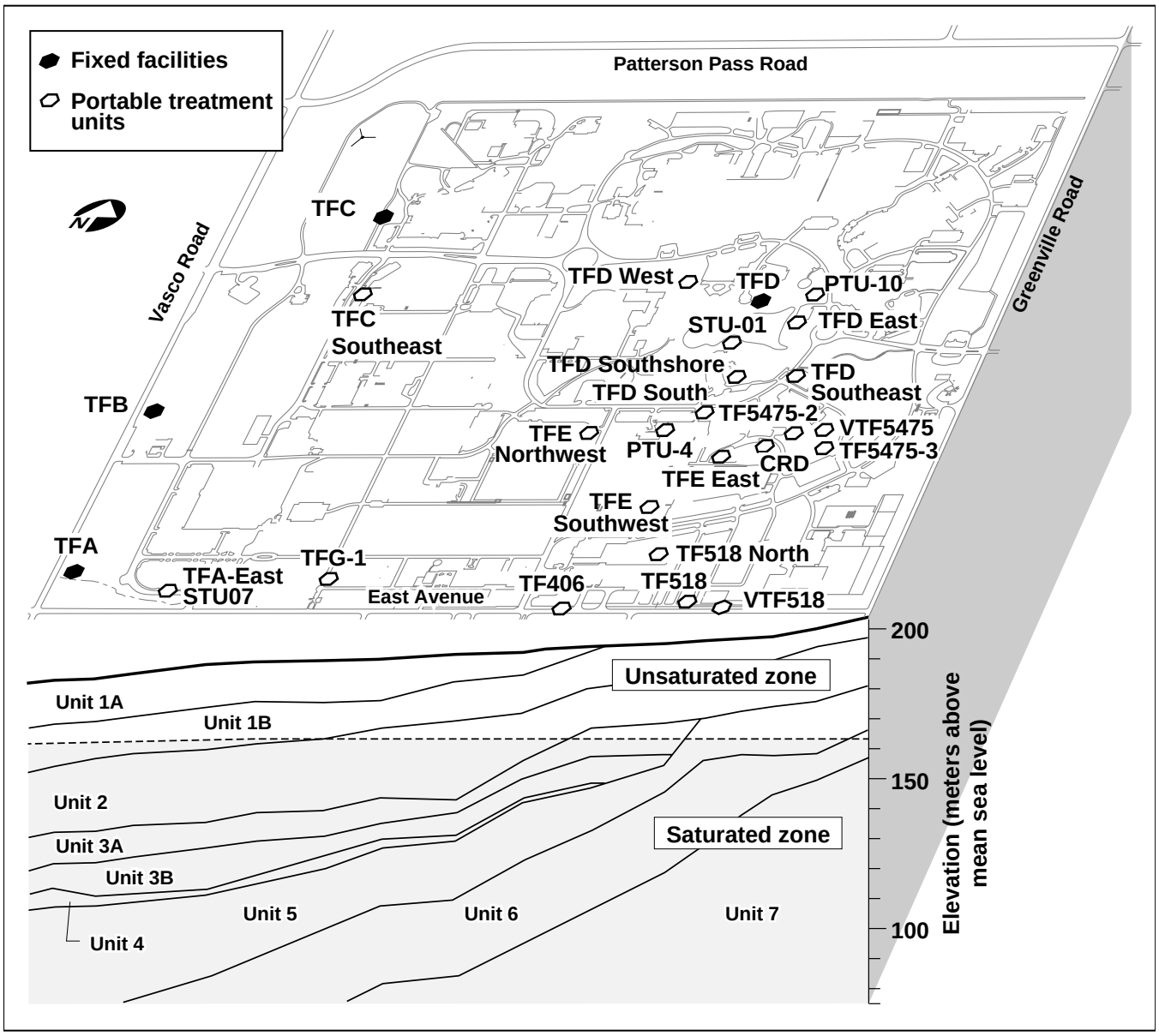


Figure 8-1. Map and cross section of the Livermore site showing hydrostratigraphic units and the locations of the treatment facilities

Of the 11 treatment facilities, 9 are groundwater treatment facilities and 2 are vapor treatment facilities (VTFs). A total of 80 groundwater extraction wells operated at 25 separate locations at an average flow rate of 2540 liters per minute (L / min). A total of three vapor extraction wells operated at two separate locations at an average flow rate of 0.583 standard cubic meters per minute (scmm).

Since operations began, approximately 5413 ML of groundwater and more than 0.695 million standard cubic meters (scm) of vapor have been treated, and more than 1021 kg of VOCs have been removed. Table 8-2 shows both the 2000 totals and the cumulative totals of groundwater and soil vapor treated at the facilities and the estimated VOCs removed from the subsurface. A graph of VOC

Table 8-1. 2000 extraction wells and extraction rates

Treatment facility area	Hydrostratigraphic Unit	Extraction wells	Extraction rate (L/min) [a]
TFA	HSU 1B	W-254, W-262, W-408, W-520, W-601, W-602, W-1001, W-1004	927–1306
	HSU 2	W-109, W-415, W-457, W-518, W-522, W-603, W-605, W-609, W-614, W-714, W-903, W-904, W-1009	
	HSU 3A	W-712	
TFB	HSU 1B	W-610, W-620, W-704	288–299
	HSU 2	W-357, W-621, W-655, W-1423	
TFC	HSU 1B	W-701, W-1015, W-1102, W-1103, W-1104, W-1116	204–265
	HSU 2	W-1213	
TFD	HSU 2	W-361, W-906, W-1215, W-1216, W-1303, W-1306, W-1308, W-1510, W-1550, W-1602	382–666
	HSU 3A/3B	W-1208, W-1301, W-1504, W-1551, W-1552, W-1601, W-1651, W-1654	
	HSU 4	W-314, W-351, W-1206, W-1307, W-1503, W-1523	
	HSU 5	W-907	
TFE	HSU 2	W-1109, W-1409, W-1518,	189–201
	HSU 3A/3B	W-1422, W-1522	
	HSU 4	W-1211, W-1418, W-1520	
	HSU 5	W-359, W-566	
TF406	HSU 4	GSW-445, W-1309	71.9–114
	HSU 5	W-1310	
TFG	HSU 1B/2	W-1111	34.1
TF518	HSU 3B/4	W-1410	18.9–34.1
	HSU 5	W-112	
VTF518		SVI-518-201, SVI-518-303	0.017 (scmm)[b]
TF5475	HSU 2	W-1415	11.4
	HSU 3A	W-1302, W-1606, W-1608	
VTF5475		SVI-EST-504	0.566 (scmm)
	2000 Total		**2126–2931** **0.583 (scmm)**

a L/min= Liters per minute

b scmm = Standard cubic meters per minute

Table 8-2. Volatile organic compounds (VOCs) removed from groundwater and soil at the Livermore site

Treatment facility[a]	Startup date	2000		Cumulative total	
		Water treated (ML)[b]	VOCs removed (kg)	Water treated (ML)	VOCs removed (kg)
TFA	9/89	536	13.8	3004	137
TFB	10/90	105	7.1	535	45
TFC	10/93	94.3	7.9	410	40
TFD	9/94	251	107	947	342
TFE	11/96	106	24	307	95
TFG	4/96	14.8	0.8	52.6	2.7
TF406	8/96	47.3	1.6	131	5.8
TF518	1/98	11	1.7	25	3.0
TF5475	9/98	0.379	0.9	1.17	3.2
Total[c]		1166	165	5413	674
		Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)	Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)
VTF518[d]	9/95	3.94	2.8	422	150.1
VTF5475[d]	1/99	214	102	273	197.7
Total[c]		218	105	695	348

a Includes fixed and portable units

b ML = 1 million liters

c Totals rounded to nearest whole number

d Vapor treatment facility

mass removal at the Livermore site since 1989 is presented in **Figure 8-2**. Concentrations of remaining VOCs in the fourth quarter 2000 are depicted as isoconcentration maps in the six HSUs in **Figures 8-3** through **8-8.** The VOC plumes in HSUs 1B, 2, 3A, 3B, 4, and 5 continue to be hydraulically controlled based on trends in groundwater chemistry, capture zone analysis, and the total VOC isoconcentration maps (**Figures 8-3** through **8-8)** for each HSU.

The numbers and associated treatment faciliy areas of new wells installed in 2000 are shown in **Table 8-3**. Well construction details, well closure data, and results of drawdown tests are provided in the *LLNL Groundwater Project 2000 Annual Report* (Aarons et al. 2001).

Treatment Facility A

Treatment Facility A (TFA) is a fixed facility located in the southwestern quadrant of the Livermore site near Vasco Road and East Avenue (**Figure 8-1**). Groundwater is treated using the large-capacity air-stripping system installed in June 1997. VOCs are stripped from the groundwater, and the effluent air from the stripper is passed through granular activated carbon (GAC) filters to remove VOCs. The treated effluent air is then vented to the atmosphere. The California Regional Water Quality Control Board (RWQCB) permits

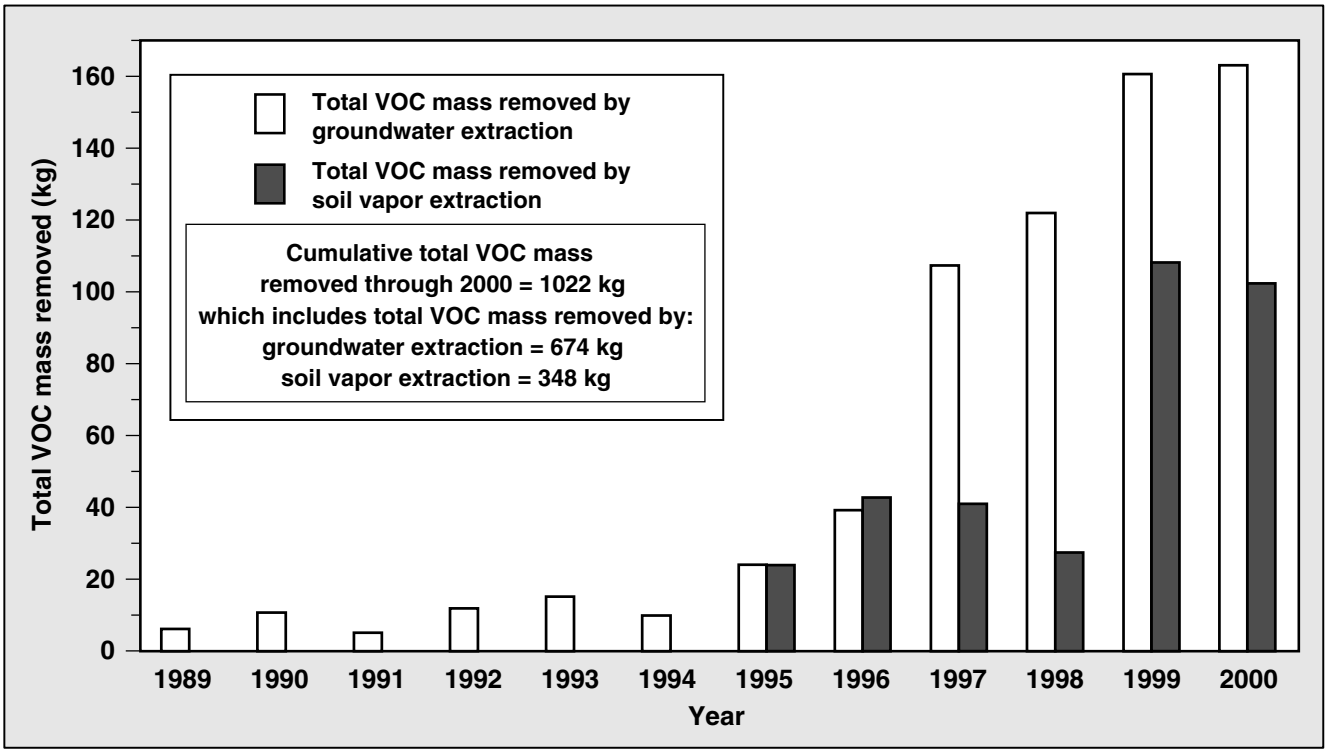


Figure 8-2. Total VOC mass removed from the subsurface of the Livermore site, 1989–2000

LLNL to treat up to 1890 L/min of groundwater. Treated groundwater from TFA is discharged to the Recharge Basin, located about 600 m southeast of TFA on Department of Energy (DOE) property administered by Sandia National Laboratories/California. Since the startup of the new system, TFA has not exceeded the 5 parts per billion (ppb) total VOC discharge limit.

Solar treatment unit (STU) TFA East (TFA-E) is located east of TFA and processes VOCs in groundwater using GAC. TFA-E was in compliance with all permits through 2000.

In 2000, wells at TFA and TFA-E pumped at a combined flow rate of about 1210 L/min and treated 536 ML of groundwater containing an estimated 13.8 kg of VOCs.

One new monitor well was installed in the TFA area in 2000 (see **Table 8-3**).

Treatment Facility B

Treatment Facility B (TFB) is located in the west-central portion of the Livermore site (**Figure 8-1**). Groundwater is treated using the large-capacity air-stripping system installed in October 1998. This unit replaced an ultraviolet/hydrogen peroxide (UV/H_2O_2) system that had been in use since 1990. Groundwater is also treated for chromium(VI) in an ion-exchange unit during December through March, based on the current RWQCB discharge substantive requirements. Treated groundwater from TFB is discharged into the north-flowing drainage ditch parallel to Vasco Road that empties into Arroyo Las Positas to the north.

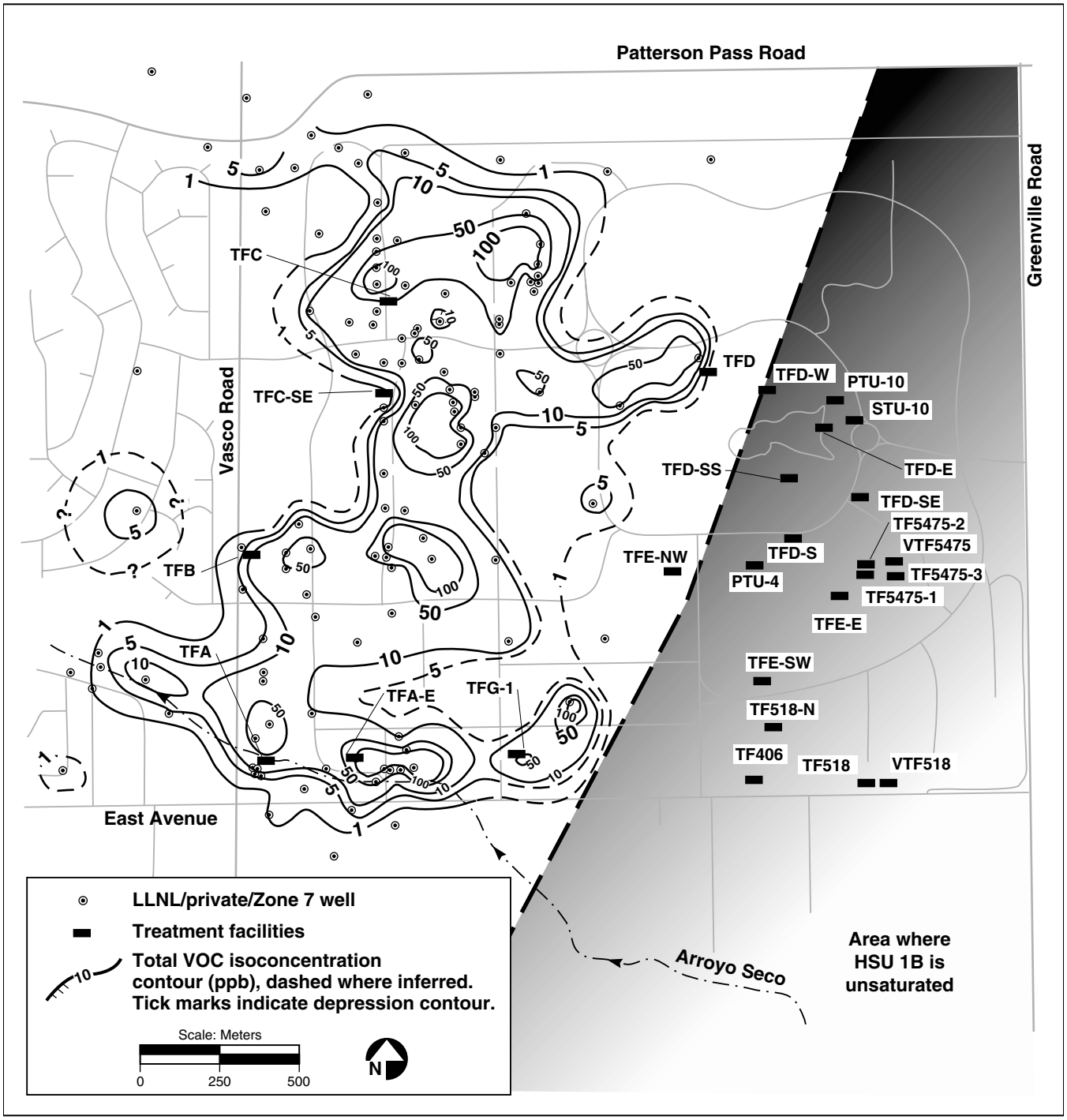


Figure 8-3. Isoconcentration contour map of total VOCs within HSU 1B

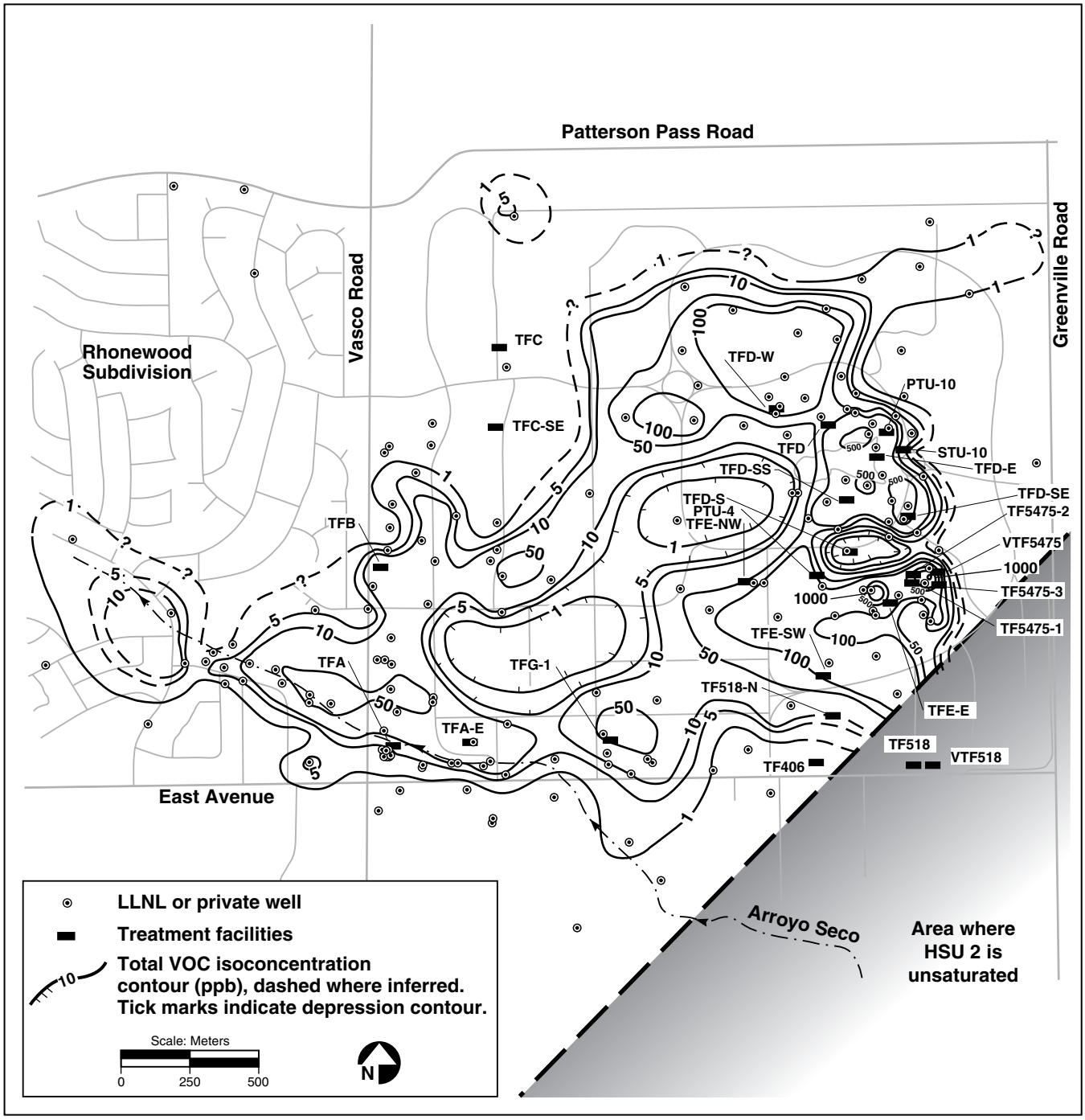


Figure 8-4. Isoconcentration contour map of total VOCs within HSU 2

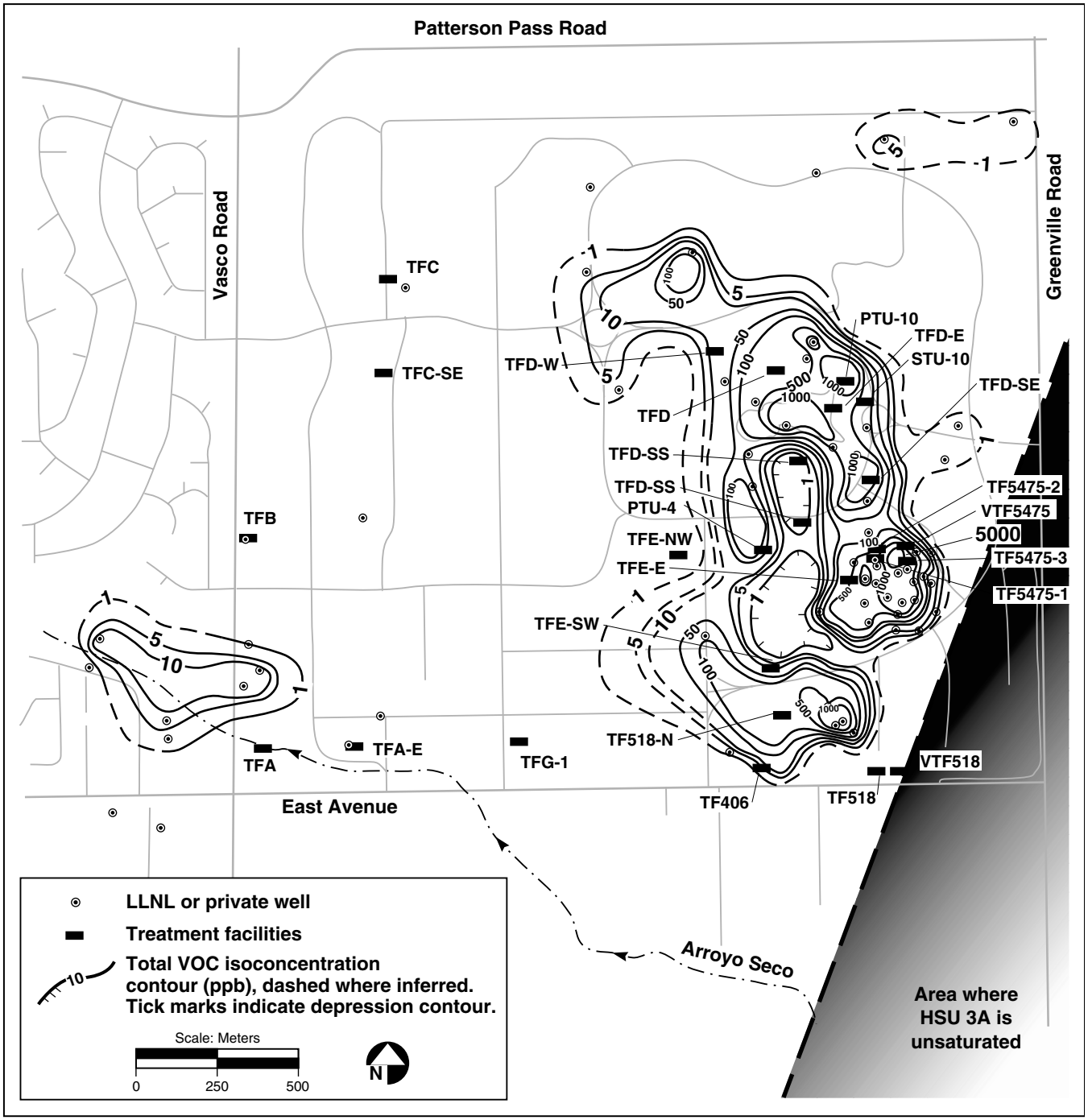


Figure 8-5. Isoconcentration contour map of total VOCs within HSU 3A

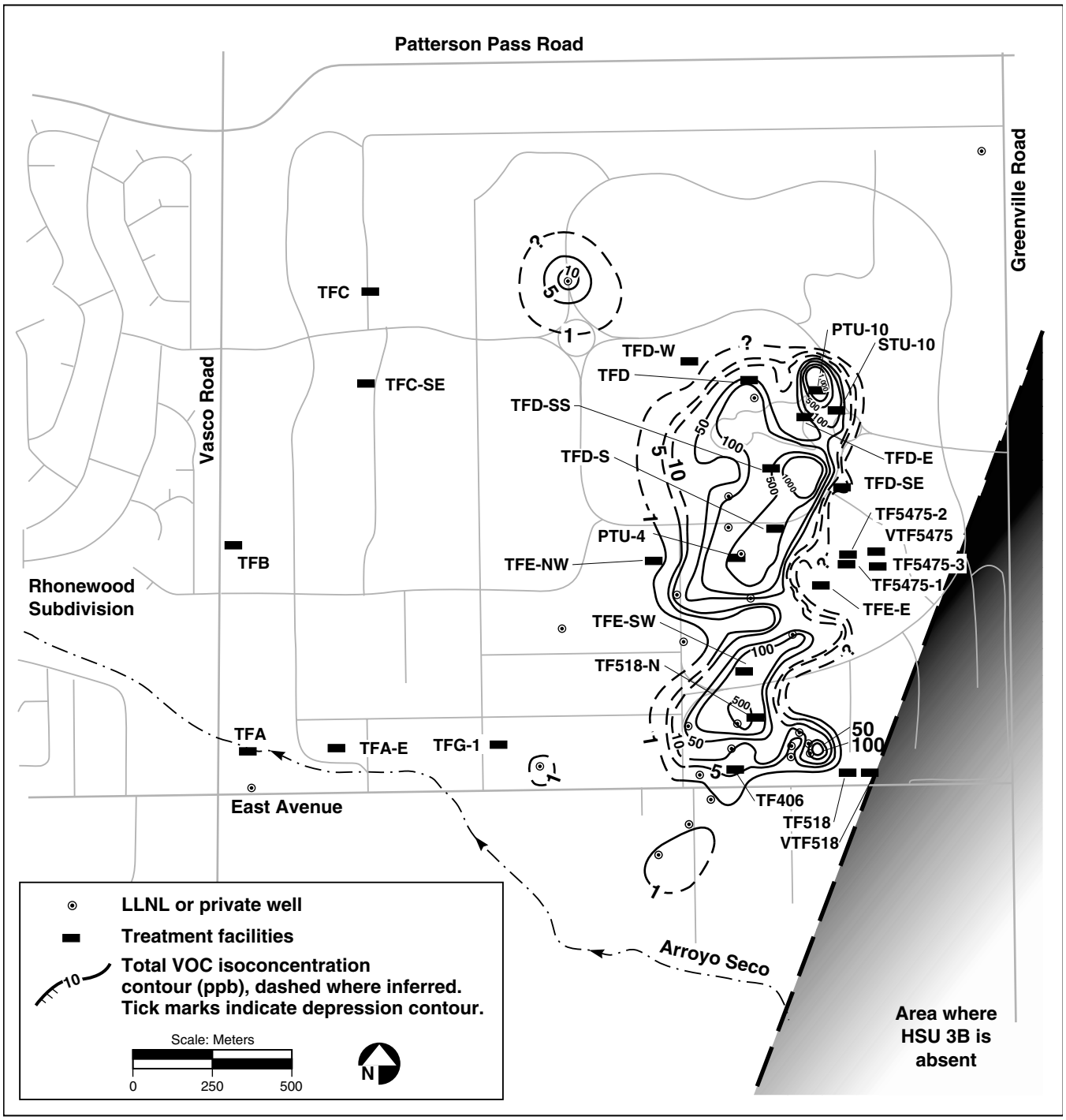


Figure 8-6. Isoconcentration contour map of total VOCs within HSU 3B

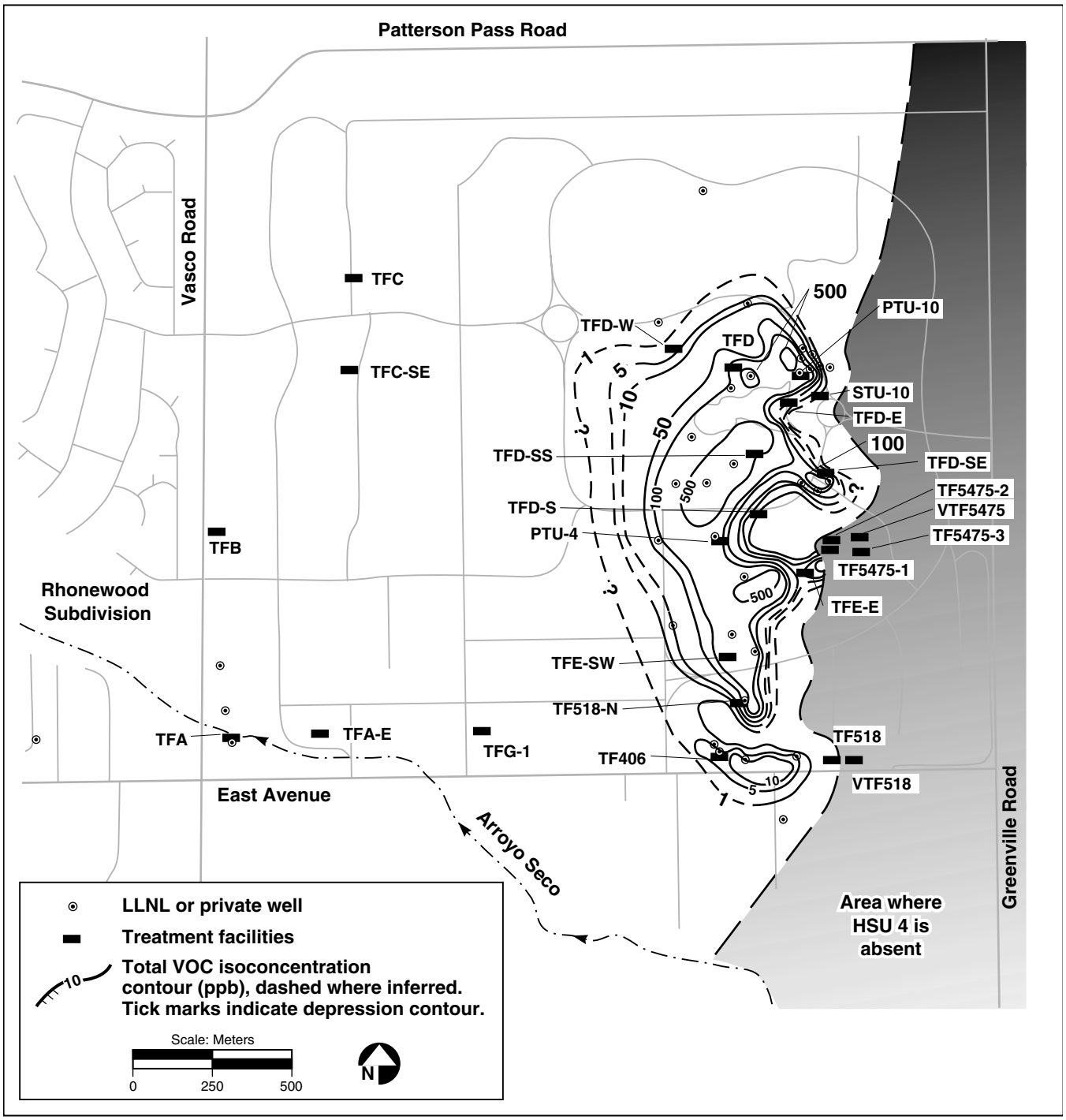


Figure 8-7. Isoconcentration contour map of total VOCs within HSU 4

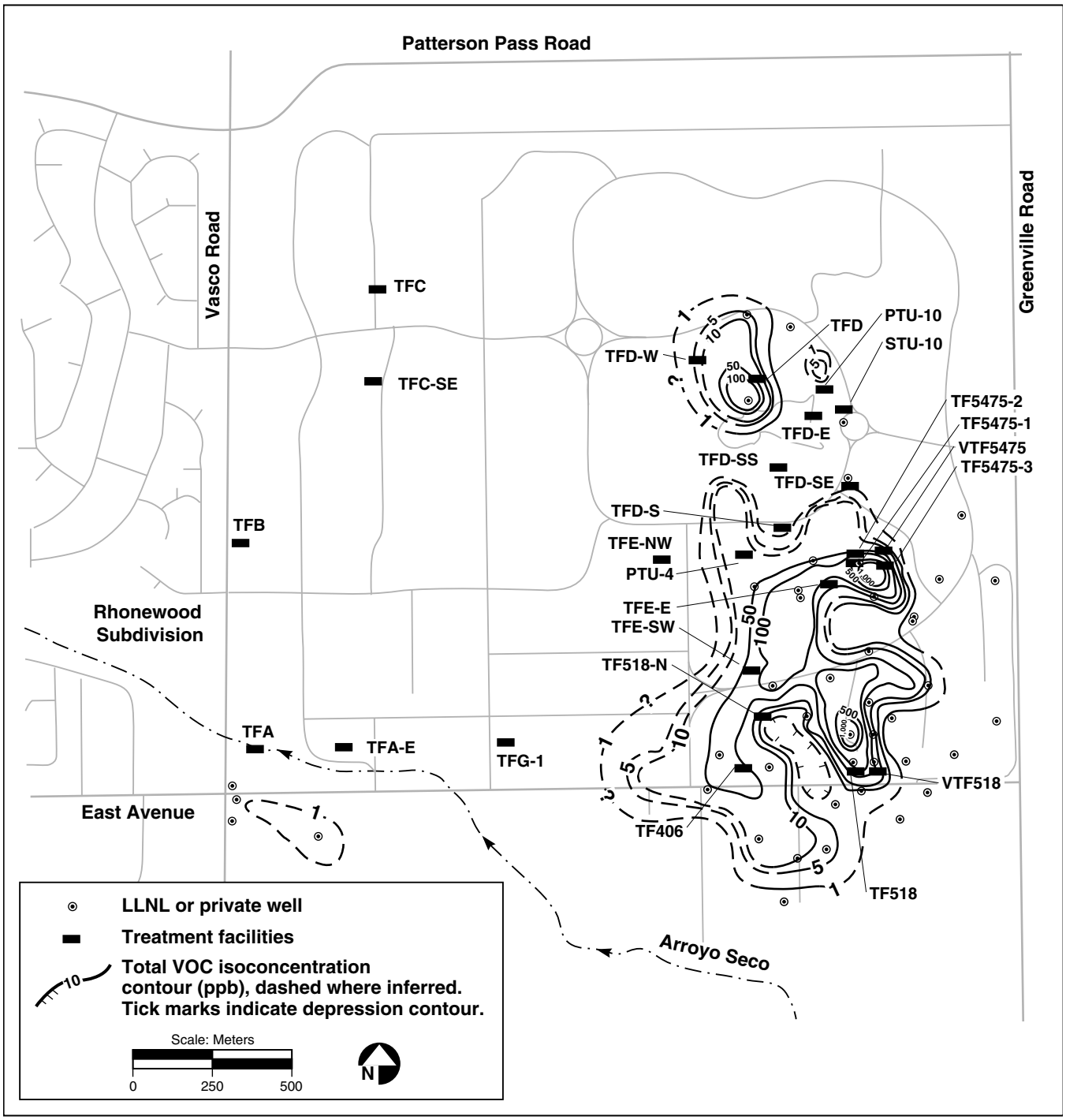


Figure 8-8. Isoconcentration contour map of total VOCs within HSU 5

The seven wells at TFB pumped at a combined flow rate of about 269 L/min, and treated about 105 ML of groundwater containing an estimated 7.1 kg of VOCs.

A control and interlock system failed that allowed the discharge of about 148,000 L of groundwater while the air stripper was off. Other than this incident, TFB was in compliance through 2000. No new wells were installed at TFB during 2000.

Treatment Facility C

Treatment Facility C (TFC) is located in the northwest quadrant of the Livermore site (**Figure 8-1**). Portable Treatment Unit (PTU) location TFC Southeast (TFC-SE) is located near the intersection of Avenue A and Sixth Street in the northwest quadrant of the Livermore site.

TFC and TFC-SE process VOCs in groundwater using air stripping. The effluent air from the stripper is treated with GAC prior to discharge to the atmosphere. Groundwater is treated for chromium(VI) in an ion-exchange unit during December through March in order to meet the current RWQCB discharge substantive requirements. Treated groundwater from TFC is discharged into Arroyo Las Positas; from TFC-SE, groundwater is discharged into a north-flowing drainage ditch that empties into Arroyo Las Positas to the north. The TFC effluent chromium(VI) concentration was below the wet season discharge limit of 22 ppb during 2000. TFC and TFC-SE complied with all permits throughout 2000.

Wells in the TFC area pumped at a combined flow rate of about 212 L/min and treated about 94.3 ML of groundwater containing an estimated 7.9 kg of VOCs. Since system start up in 1993, the combined TFC area facilities have treated more than 410 ML of groundwater and removed about 40 kg of VOC mass from the subsurface.

No new wells were installed in the TFC area during 2000.

Table 8-3. Wells installed in 2000

Treatment facility area	Hydrostratigraphic unit	Monitoring/extraction well
TFA	HSU 1B	W-1614
TFB		None
TFC		None
TFD	HSUs 3A/3B	W-1650, W-1651, W-1652, W-1653, W-1654, W-1655, W-1656, W-1657
TFE		None
TF406	HSU 3B	W-1613
TFG		None
TF518	HSU1B/2	W-1615
TF5475	HSU 3A HSU 5	W-1605, W-1606, W-1607, W-1608 W-1609, W-1610

Treatment Facility D

The Treatment Facility D (TFD) area is located in the northeast quadrant of the Livermore site (see **Figure 8-1**). During 2000, eight treatment facilities operated in the TFD areas. The TFD area extraction wells hydraulically control VOCs in HSUs 2, 3A, 3B, 4, and 5.

One new treatment facility located south of the Drainage Retention Basin (DRB), TFD-SS, was activated on June 30, 2000. With regulatory concurrence, this milestone was delayed three months because of an adjacent drainage and parking lot construction project.

Fixed and portable facilities operating in the TFD area process VOCs in groundwater using air stripping, although the STU uses granular activated carbon. The effluent air from the air strippers is treated with granular activated carbon prior to discharge to the atmosphere. Treated groundwater from TFD and TFD-East is discharged either into the DRB, or into an underground pipeline downstream of the DRB weir, flowing northward to Arroyo Las Positas. Treated groundwater from TFD-West is discharged into a nearby storm sewer that also empties into Arroyo Las Positas. Treated groundwater from TFD-South and TFD-Southeast is discharged into drainage ditches, each flowing north into the DRB.

During 2000, LLNL's Environmental Restoration Department (ERD) began a pilot test to evaluate the potential of electroosmosis (EO) as a means of expediting removal of VOCs from source areas characterized by high VOC concentrations in low permeability sediments (See the section "Groundwater Flow and Transport Modeling" of this chapter.). An EO system was installed near the Helipad VOC source area during the spring and summer of 2000. The EO system consists of a grid of nine electrode-bearing groundwater wells, with screened intervals for the wells ranging from about 29 to 36 m below ground surface. Groundwater impacted by TCE and other VOCs is drawn by an induced direct current from the anode wells (positively charged) to the center array of wells holding negatively-charged electrodes (cathodes) by EO and hydraulic pumping. Preliminary data shows an increase in VOC concentrations at the cathode wells during EO operation.

The combined TFD facilities operated at an average flow rate of 568 L/min in 2000. During 2000, these units treated about 251 ML of groundwater containing an estimated 107 kg of VOCs. The STU contributed about 0.38 ML of groundwater containing an estimated 1.2 kg of VOCs of that total. Distal VOC plumes in the western TFD area should be hydraulically controlled once planned TFC-E and TFC-NE treatment facilities are operating; they are scheduled for January 2002 and May 2003, respectively.

All TFD facilities were in compliance through 2000. Eight wells were installed in the TFD area during 2000 (**Table 8-3**). In 2000, one-hour drawdown tests were conducted on TFD area wells W-1601, W-1602, W-1655, and W-1654 (Aarons et al. 2001).

Treatment Facility E

The Treatment Facility E (TFE) area is located in the southeastern quadrant of the Livermore site (**Figure 8-1**). In 2000, TFE-East (TFE-E) continued treating groundwater using a PTU. TFE-E is located in the east-central portion of the Livermore site and provides hydraulic containment of some portions of VOC plumes in HSUs 2, 4, and 5. TFE-Northwest treats groundwater from extraction wells in HSU 2 and HSU 4 and is located south of the Inner Loop Road, immediately west of Southgate Drive.

TFE-E and TFE-NW treat VOCs using an air stripper. Before the effluent air is vented to the atmostphere, it is treated using granular activated carbon to remove VOCs. Treated groundwater from TFE-E is discharged into a drainage ditch that flows north into the DRB. Treated groundwater from TFE-NW is discharged into a storm drain that flows north into Arroyo Las Positas.

One new treatment facility, TFE-Southwest (TFE-SW), was activated on June 27, 2000, ahead of the June 30, 2000 Remedial Action Implementation Plan (RAIP) milestone date. TFE-SW is located south of the DRB and Inner Loop Road and uses a minature-treatment unit (MTU) to treat VOCs in groundwater via an air stripper. Treated groundwater is discharged into a drainage ditch that flows north into the DRB, and the effluent air is treated with GAC prior to venting to the atmosphere.

In 2000, wells at TFE pumped at a combined flow rate of about 239 L/min and treated about 106 ML of groundwater containing an estimated 24 kg of VOCs. Since system startup in 1996, the combined TFE facilities have treated more than 307 ML of groundwater and removed about 95 kg of VOC mass from the subsurface.

All TFE treatment facilities were in compliance in 2000. No new wells were installed in the TFE area during 2000.

Treatment Facility G

Treatment Facility G (TFG) is located in the south-central portion of the Livermore site (**Figure 8-1**) and treats groundwater from one well at Treatment Facility G-1 (TFG-1), located near Avenue B, about 90 m north of East Avenue. Under the current RWQCB discharge substantive requirements, water from TFG-1 requires treatment for chromium(VI) only during December through March. Treated groundwater from TFG-1 is discharged to a storm drain located about 50 ft north of TFG-1, which empties into Arroyo Seco.

Before May 1999, TFG-1 processed groundwater for VOC treatment using an air stripper, and the effluent air was treated using GAC to remove VOCs before they were vented to the atmosphere. In May 1999, the PTU at TFG-1 was replaced by a GAC treatment unit (GTU). A year-long treatability study conducted in 1998 and 1999 demonstrated that the GAC treatment was effective in the efficient removal of VOCs from TFG area groundwater. Groundwater is no longer treated for chromium(VI) because concentrations from March 1997 through November 1999 were consistently below the discharge limit of 22 ppb.

During 2000, TFG-1 operated at an average flow rate of 32.2 L/min, treating 14.8 ML of groundwater containing an estimated 0.8 kg of VOCs (**Table 8-2**). Since system startup in 1996, TFG-1 has treated almost 53 ML of groundwater and removed about 2.7 kg of VOC mass from the subsurface.

All TFG treatment facilities were in compliance in 2000. No new boreholes or wells were drilled and no hydraulic tests were conducted in the TFG area during 2000.

Treatment Facility 406

Treatment Facility 406 (TF406) is located east of Southgate Drive near East Avenue in the south-central part of the Livermore site (**Figure 8-1**), and processes groundwater from three extraction wells . The TF406 extraction wells continue to provide significant hydraulic control of VOC plumes in HSUs 4 and 5 near the TF406 facility. The VOC plumes in HSUs 3A, 4, and 5 are being hydraulically controlled throughout the TF406 area.

TF406 removes VOCs using an air stripper. The effluent air is passed over granular activated carbon to remove VOCs before it is vented to the atmosphere. All treated groundwater is discharged to a storm drain that flows to Arroyo Las Positas.

During 2000, TF406 operated at an average flow rate of 94.7 L/min, treating more than 47.3 ML of groundwater containing an estimated 1.6 kg of VOCs (see **Table 8-2**). Since system startup in 1996, TF406 has treated about 131 ML of groundwater and removed about 5.8 kg of VOC mass from the subsurface (see **Table 8-1**).

IN 1999, DOE/LLNL began evaluating electroosmosis (EO) for remediating VOCs in fine grained, low permeability sediments (See section "Groundwater Flow and Transport Modeling" of this chapter). The TF406 area was chosen as a test location because of the presence of good candidate lithologic sequences. Initial testing was conducted to determine design parameters (e.g., electrode spacing, voltage gradients), to evaluate operational issues (e.g., control of high pH and hydrogen gas at the cathode), and to measure electrochemical properties of the soil (e.g., electrical and electroosmotic conductivity). The results of this work will be used for subsequent analysis and modeling necessary to evaluate electroosmosis for potential deployment at LLNL. A report summarizing the results of the qualifications phase tests was issued in December 1999 (McNab 1999). In February 2000, DOE/LLNL continued its evaluation of EO and deployed the EO system in the TFD Helipad area.

TF406 was in compliance through 2000. One new well was drilled and completed at TF406 during 2000 (**Table 8-3**).

Groundwater Treatment Facility 518

Treatment Facility 518 (TF518) is located in the southeastern quadrant of the Livermore site, north of East Avenue and near Avenue H, adjacent to VTF518 (**Figure 8-1**). The new treatment facility TF518-N, located south of the South Outer Loop Road north of Building 411, was activated on January 26, 2000, ahead of the June 28, 2000, milestone date.

In July 1998, MTU-1 was activated in the TF518 area, replacing the PTU that had processed groundwater there since January 1998. The MTU processes groundwater for VOC treatment using an air stripper, and the effluent air is treated using GAC to remove VOCs prior to venting to the atmosphere. All treated groundwater is discharged to a storm drain located about 76 m north of TF518, which empties into Arroyo Las Positas.

Decreased waterflow that began in 1999 at TF518 continued in 2000. As discussed in the 1999 SAER, sustainable flow rates from well W-112 decreased steadily from about 75 L/min to about 3.8 L/min in May 1999. TF518 periodically shut down during 1999 because of lack of sustainable flow and low water level conditions within well W-112. Hydraulic data indicate that the cumulative pumping from HSU 5 wells at TF406, TFE, and TF518 has significantly lowered groundwater levels in the southeastern portion of the Livermore site and reduced yields observed in well W-112. Continuous pumping was discontinued from well W-112 in December 1999, because of low water levels caused by dewatering HSU-5 in the southeastern portion of the Livermore Site. In June 2000, cyclic pumping was discontinued after water levels failed to recover sufficiently. Future operation of TF518 is planned if HSU 5 water levels recover sufficiently to provide sustainable flow in well W-112.

During 2000, TF518 facilities operated at an average flow rate of 24.6 L/min and treated about 11 ML of groundwater containing an estimated 1.7 kg of VOCs (see **Table 8-2**). Since the facility started up in January 1998, TF518 facilities have processed about 25 ML of groundwater containing an estimated 3.0 kg of VOCs.

TF518 was in compliance with all permits throughout 2000. One well was drilled in the TF518 area during 2000 (**Table 8-3**). No step-drawdown tests were conducted in the TF518 area during 2000.

Vapor Treatment Facility 518

Vapor Treatment Facility 518 (VTF518) is located in the southeastern quadrant of the Livermore site. Soil vapor is extracted from the vadose zone and VOCs are removed from the vapor using granular activated carbon canisters. Following treatment, the effluent air is discharged to the atmosphere.

Two instrumented membrane system (IMS) sampling/monitoring wells, SEA-518-301 and SEA-518-304, continue to monitor vadose zone remediation in the VTF518 area. The IMS system is used to collect vapor pressure, soil temperature, soil moisture, and soil vapor concentration data at various discrete depths.

During 2000, VTF518 operated at an average flow rate of 0.017 scmm, treating about 3908 m^3 of vapor containing an estimated 2.8 kg of VOCs (see **Table 8-2**). In addition, approximately 2460 L of water containing about 0.09 kg of VOCs were hand-bailed from the two vapor extraction wells at VTF518 in 2000. Since system startup in 1995, VTF518 has treated about 422,000 m^3 of vapor and removed about 150 kg of of VOC mass from the subsurface (see **Table 8-2**).

VTF518 was in compliance with the Bay Area Air Quality Management District (BAAQMD) permit throughout 2000.

Treatment Facility 5475

Treatment Facility 5475, located in the east-central portion of Livermore site, consists of three groundwater treatment facilities (TF5475-1, TF5475-2, and TF5475-3) (**Figure 8-1**).

TF5475-1 uses a catalytic reductive dehalogenation (CRD) unit (CRD-1) to treat VOCs in groundwater. CRD technology is based on the reaction of dissolved hydrogen on a palladium catalyst. When in contact with VOC-bearing groundwater, the VOCs are reduced to ethane, methane, or ethene and free chloride ions. Because of the quick reaction rates of CRD, treatment takes place during one pass through the unit. After treatment, the groundwater is returned to the same HSU from which it was extracted. This technology treats VOCs in groundwater while keeping the groundwater containing tritium in the subsurface in the T5475 area. CRD-1's destruction efficiency at TF5475-1 was over 90% in 2000.

TF5475-1 was shut down on February 24, 2000 because of biological fouling. The unit was flushed and resumed operation from July 12, 2000, to mid November when it was shut down again for maintenance. The facility did not run from mid-November through the end of December.

TF5475-2 employs STU 5, which uses a direct current (DC)-powered pump to extract groundwater through a series of aqueous-phase GAC canisters for treatment. Treated groundwater from TF5475-2 is discharged into a storm sewer that flows north into Arroyo Las Positas. TF5475-2 was in compliance throughout 2000, although anomalous data were reported in June and July that indicated a breakthrough of VOCs from the carbon. Subsequent samples from the same carbon

indicated no detectable VOCs. The effluent water was collected in a storage tank until the samples were analyzed and results indicated no detectable VOCs in the effluent.

TF5475-3 uses CRD-2 to treat VOCs in groundwater. CRD-2 also uses catalytic reductive dehalogenation and is similar in design to CRD-1, except that it is an above-ground treatment unit rather than deployed in a well. Because of elevated tritium concentrations in groundwater within HSU 3A, TF5475-3 is a closed-loop system. Groundwater is extracted from two wells, processed in CRD-2, and then returned to the subsurface using two reinjection wells. The destruction efficiency for CRD-2 was greater than 90% in 2000.

During 2000, the TF5475 area facilities operated at an average flow rate of 6.44 L/min to treat about 0.379 ML of groundwater containing an estimated 0.9 kg of VOCs (see **Table 8-2**). Since system start up in 1998, the combined TF5475 facilities have treated more than 1.17 ML of groundwater and removed about 3.2 kg of VOC mass from the subsurface.

During 2000, two HSU 3A extraction wells and two HSU 3A re-injection wells were installed in the TF5475 area. Two HSU 5 extraction wells were also installed in the same area (**Table 8-3**). An hydraulic injection test was conducted on well W-1610 in the T5475 area during 2000.

Vapor Treatment Facility 5475

Vapor Treatment Facility 5475 (VTF5475) is located on the northern side of Trailer T5475 in the east-central portion of the Livermore site, and it treats soil vapor from vadose zone well SVI-ETS-504 (see **Figure 8-1**). VTF5475 began operation on January 21, 1999.

Soil vapor is extracted from the vadose zone using a vapor extraction system and is processed using GAC. Because of elevated tritium concentrations in the vadose zone, VTF5475 has been designed as a closed-loop system. Following removal of VOCs from the process air stream, the tritiated vapor is reinjected into the subsurface at soil vapor inlet well SVI-ETS-505. Because no effluent vapor from VTF5475 is released to the atmosphere, BAAQMD has granted the facility a letter of exemption for 24-hour operation. Two IMS sampling/monitoring wells, SEA-ETS-506 and SEA-ETS-507, are used to monitor vadose zone remediation in the VTF5475 area. The IMS system is used to collect vapor pressure, soil temperature, soil moisture, and soil vapor concentration data from various discrete depths.

During 2000, VTF5475 operated at an average flow rate of 0.566 scmm and treated about 214,000 m^3 of vapor containing an estimated 102 kg of VOCs. Since system start up in 1999, VTF5475 treated about 273,000 m^3 of vapor containing an estimated 198 kg of VOCs (see **Table 8-2**).

Groundwater Flow and Transport Modeling

Groundwater flow and transport models are used at the Livermore site to support remediation system design, performance evaluation, and ongoing subsurface characterization activities. Models also improve LLNL's ability to forecast, monitor, and interpret the progress of the groundwater remediation program.

HSU 1B /2 Model

In 2000, DOE/LLNL continued to use the three-dimensional groundwater flow and contaminant transport model of HSU 1B/2 for performance evaluation and optimization of remediation systems. The HSU 1B/2 model evaluates PCE

and TCE transport for the Treatment Facility A and B areas. The model proved useful during 2000 as a decision support tool, and was used to optimize well extraction rates, size pumps for wells, analyze capture zones, evaluate interference patterns and the impact of increased pumping on upgradient plumes, and forecast long-term cleanup scenarios.

Electroosmosis Modeling

In 2000, DOE/LLNL continued to evaluate the effectiveness of electroosmosis (EO) in remediating areas with high VOC concentrations in fine-grained sediments. EO applies an electric field in the subsurface by placing electrodes within groundwater wells. This electric field induces migration of groundwater containing VOCs; however, the resulting electrolysis reactions also affect the pH in soil and groundwater. These pH differences can significantly change the solubility of a variety of mineral phases in the soil, affect the adsorption of various trace metals, and may result in the precipitation of metal oxyhydroxide, calcium carbonate, or magnesium carbonate minerals near the cathode. In 2000, model results were used to aid in the design of control mechanisms that will mitigate the adverse effects of these geochemical processes on system performance. To evaluate these effects, DOE/LLNL is using the reactive transport model code PHREEQC Version 2 (Parkhurst and Appelo 1999) to simulate these reactions.

A series of detailed flow and transport models was developed in 2000 for the EO remediation pilot test sites located at TFD Helipad and T5475. The models were used to calculate reasonable extraction/injection rates from wells used in the design of the EO remediation systems and for the selection of the down-hole pumps. Additionally, work began in 2000 on developing a mathematical model that can simulate flow and transport that couples the processes of groundwater flow and EO flow. The model is intended to aid in the evaluation of field data from the EO remediation pilot test sites to determine whether EO remediation can effectively reduce contamination in fine-grained sediments that are not significantly impacted by groundwater extraction.

Environmental Impact

Notable results of VOC analyses of groundwater received from January through December 2000 are discussed below. **Figures 8-3** through **8-8** are isoconcentration maps for total VOCs underlying the Livermore site and vicinity within HSU 1B, HSU 2, HSU 3A, HSU 3B, HSU 4, and HSU 5, respectively.

Overall, the decrease in size and concentration observed in the Livermore Site VOC plumes is consistent with the 270 kg of VOC removed by the groundwater extraction wells during 2000. Therefore, most of the observed trends in VOC concentrations are attributed to the active groundwater extraction system operating at the Livermore Site.

Concentrations in the HSU 1B, 2, and 3A VOC plumes along the western margin of the Livermore Site in the TFA, TFB, and TFC areas continued to decline in response to groundwater extraction. Offsite HSU 1B wells are now below MCLs for all contaminants of concern with the exception of two wells, W-571 and W-1425, that had maximum PCE concentrations of 6.2 ppb and 7.9 ppb in 2000 (PCE MCL = 5 ppb).

In the TFD area, VOC concentrations in parts of HSU 2 continue to decline in response to pumping the TFD extraction wells. Total VOC concentrations in HSU 2 extraction well W-906 decreased from 789 ppb in 1995 to 100 ppb in October 2000. In nearby HSU 2 monitor well W-355, TCE concentrations have decreased from a maximum of 3100 ppb in April 1992 to 36 ppb in October 2000.

The HSU 2 Freon 11 plume in the northeastern TFD area continues to decline in response to pumping at TFD-W extraction wells W-1215 and W-1216. Freon 11 concentrations in monitor well W-316, located near the source area, have decreased from 1100 ppb in 1992 to 230 ppb in August 2000.

In the southern TFD and northern TFE areas, VOC concentrations in HSU 4 are showing significant decreases because of pumping at HSU 4 extraction wells W-1418 and W-1504. Total VOC concentrations in well W-1418 have declined from 945 ppb in 1998 to 153 ppb in November 2000. Total VOC concentrations in well W-1504 have declined from 338 ppb in 1999 to 231 ppb in October 2000.

In the TFE-E area, total VOC concentrations in HSU 2 extraction well W-1109 have decreased from 1744 ppb in January 1998 to 586 ppb in October 2000. In nearby HSU 2 monitor well W-257, TCE concentrations have decreased from a maximum of 6400 ppb in 1988 to 110 ppb in May 2000.

East of TFE in the T5475 area, significant decreases in VOC concentrations in HSU 3A were observed during 2000. Total VOC concentrations in monitor well SIP-ETS-204 have decreased from 8130 ppb in 1998 to 600 ppb in May 2000. However, total VOC concentrations in HSU-3A monitor well W-1117 increased from 120 ppb in 1995 to 1663 ppb in November 2000.

In the TF518 area, the offsite HSU 5 VOC plume continues to show significant decreases in VOC concentrations since the start of pumping at the TF406 and TF518 facilities in August 1996 and January 1998, respectively. Total VOC concentrations in offsite monitor well W-219 have declined from 114 ppb in October 1997 to 3 ppb in October 2000. Total VOC concentrations in another offsite monitor well, W-225, have declined from more than 2100 ppb in 1987 to 4 ppb in October 2000.

At VTF518, field investigations indicate a relatively recent development of perched water that is mobilizing VOCs from the vadose zone. Total VOC concentrations from samples of perched water in two vapor extraction wells ranged from 24,000 to 81,000 ppb in SVI-518-204, and 7000 to 18,000 ppb in SVI-518-303.

In the TF518 North area, a significant increase in VOC concentrations was observed in HSU 3B monitor well GSW-011. Total VOC concentrations have increased from 31 ppb in February 1998 to 556 ppb in October 2000. This VOC plume appears to be migrating out of the B419 source area located about 122 m to the east.

Site 300 CERCLA Project

Environmental investigations and cleanup activities at Site 300 began in 1981. Site 300 became a CERCLA/Superfund site in 1991, when it was placed on the National Priorities List (NPL). The CERCLA environmental restoration operable units (OUs) are shown in **Figure 8-9**. All contaminant release sites have been assigned to one of eight OUs that are based on the nature and extent of contamination, and topographic and hydrologic considerations. The major contaminants of concern are listed in **Table 8-4**.

Geology of Site 300

Site 300 is located in the sparsely populated Altamont Hills, which are part of the Coast Ranges Physiographic Province and separate the Livermore Valley to the west from the San Joaquin Valley to the east. Site 300 stratigraphy is shown in **Figure 8-10**. Rocks exposed in the region are classified into three groups:

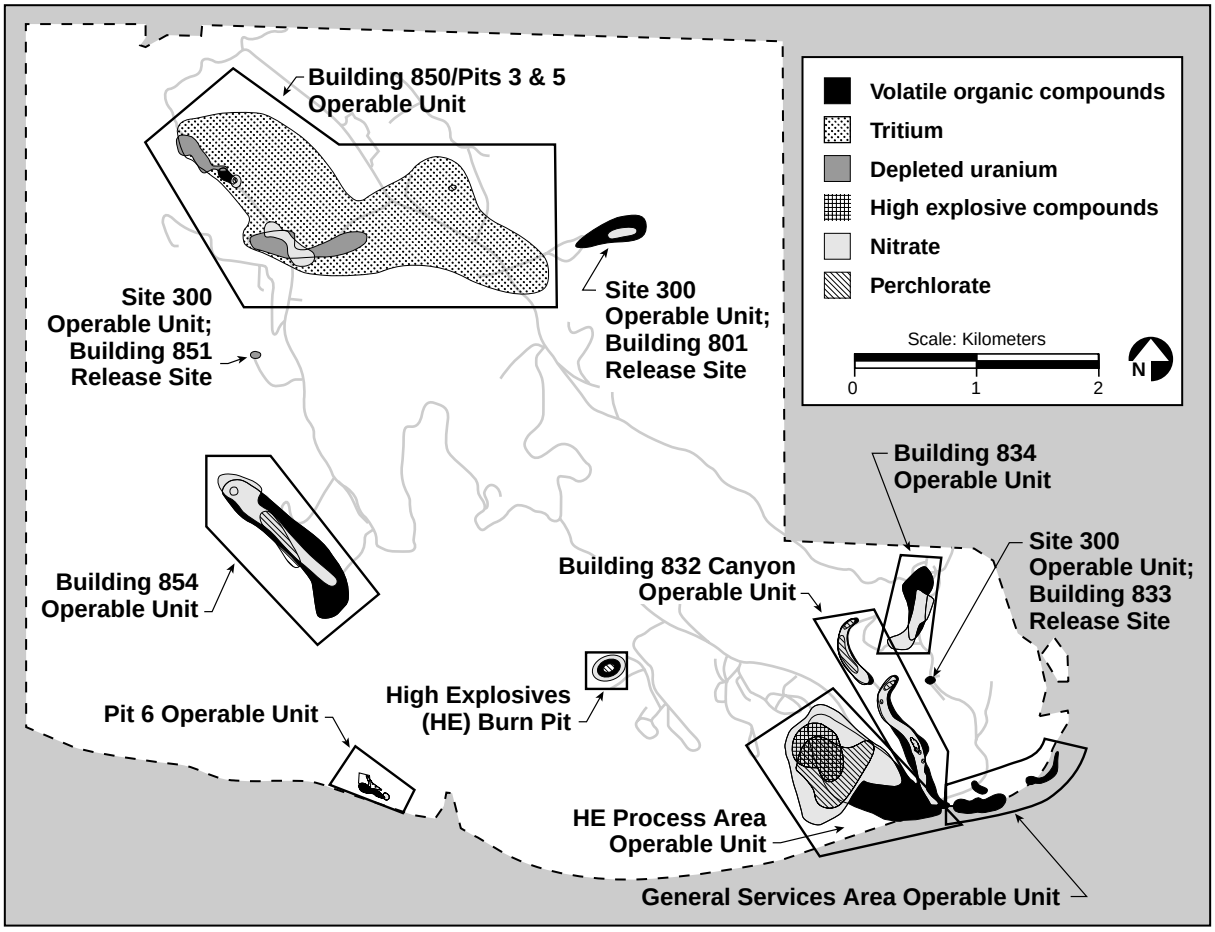


Figure 8-9. Environmental restoration operable units at Site 300

- Late Tertiary-Quaternary (0–5 million years ago)—alluvium and semilithified sediments, mainly of continental origin.

- Early to late Tertiary (5–65 million years ago)—shallow marine and continental sedimentary and volcaniclastic rocks.

- Jurassic-Cretaceous (65–180 million years ago)—Great Valley sequence (marine sedimentary rocks and ophiolites) and Franciscan Complex (sheared and variably metamorphosed sedimentary and igneous rocks).

Distinctive blue-gray to brown weathering volcaniclastic sandstone and sandy siltstone, interbedded with light gray weathering tuffaceous claystone and conglomerate, are exposed extensively within Site 300. These rocks are mapped as the late Miocene Neroly Formation (Huey 1948; Dibblee 1980). The Neroly Formation is also present in the subsurface beneath Site 300.

The Neroly Formation is the principal hydrologic unit within Site 300 and has been the focus of the detailed geologic and hydrogeologic studies conducted during recent years (summarized in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300,*

Table 8-4. Major contaminants of concern found in soil, rock, and groundwater at Site 300

Operable Unit (OU)	Contaminant of concern
General Services Area (GSA) (OU1)	VOCs (primarily TCE)
Building 834 Complex (OU2)	VOCs (primarily TCE), organosilicate oil, nitrate
High Explosives Process Area (OU4)	VOCs (primarily TCE) HE[a] (primarily HMX[b]) Nitrate, perchlorate
Building 850/Pits 3 & 5 (OU5)	Tritium Depleted uranium VOCs (primarily TCE) Nitrate, perchlorate
Building 854 (OU6)	VOCs (primarily TCE) Nitrate, perchlorate
Pit 6 (OU3)	VOCs (primarily TCE) Tritium, nitrate, perchlorate
Building 832 Canyon (OU7)	VOCs (primarily TCE) Nitrate, perchlorate
Site 300 (OU8)	VOCs (primarily TCE and Freon 113) Nitrate, perchlorate

a HE = high explosives

b HMX = octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine

[Webster-Scholten 1994]). The complete section of the Neroly Formation is about 150 m thick beneath Site 300.

The floodplain of Corral Hollow Creek lies along the southern boundary of Site 300 and borders portions of the General Services Area (GSA), the High Explosives Process Area, and the area of closed landfill Pit 6. Floodplain alluvium consists dominantly of coarse cobble and boulder-bearing terrace gravel derived from sources to the south, with lenses and local cappings of sandy silt and silty clay.

The bedrock sequence within Site 300 has been slightly deformed into several gentle, low-amplitude folds. The locations and characteristics of these folds, in combination with the regional fault and fracture patterns, locally influence groundwater flow within the site and have therefore been studied in great detail as part of the CERCLA investigations.

Hydrogeology of Site 300

Site 300 is semiarid, with an average annual rainfall of 27 cm. The site is underlain by gently dipping sedimentary bedrock dissected by steep ravines. The bedrock consists of interbedded conglomerates, sandstones, siltstones, and claystones (see **Figure 8-10**).

Groundwater primarily occurs in the Neroly Formation upper and lower blue sandstone units ($Tnbs_2$ and $Tnbs_1$) and in the underlying Cierbo Formation (Tmss). Groundwater can also be present in permeable Quaternary alluvium valley fill (Qal) during the winter rainy season. Some

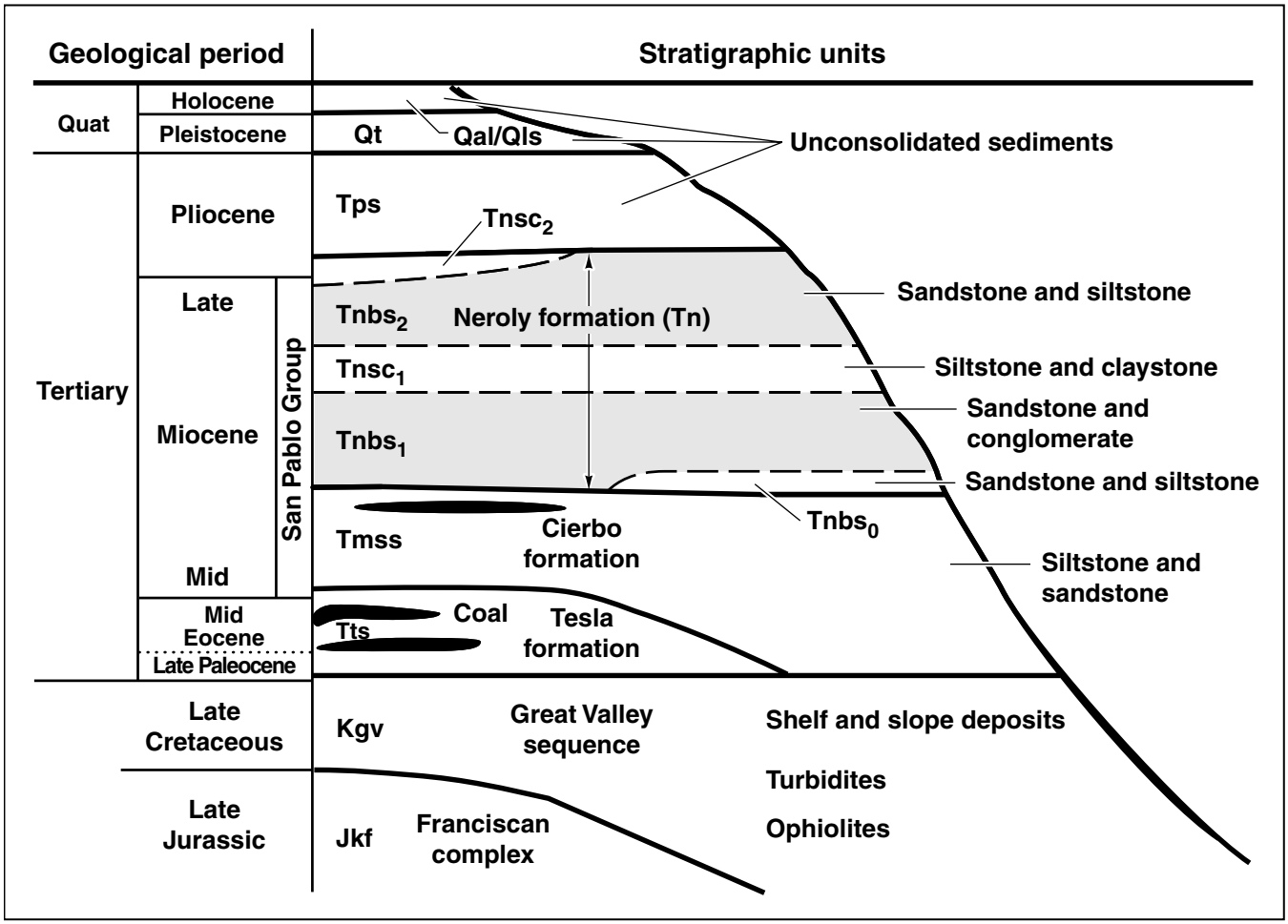


Figure 8-10. Site 300 stratigraphy (Webster-Scholten 1994)

groundwater is present as perched water-bearing zones beneath hilltops. The perched water-bearing zones primarily occur in the unconsolidated sediments of the Miocene-age nonmarine unit (Tps) in the Building 833 and 834 areas and in the Explosives Process Area. However, an extensive perched water-bearing zone occurs in $Tnbs_1$ sandstones in the northwestern portion of the East and West Firing Area. Fine-grained siltstone and claystone interbeds in $Tnbs_1$ and Tmss act as aquitards, confining layers, or perching horizons. Portions of the bedrock section at Site 300 are abundantly fractured, and thus much of the groundwater flow occurs in fractures as well as in pores. Groundwater is present under confined conditions in the southern half of the site but is generally unconfined elsewhere. **Figure 8-11** is a map of the potentiometric surface for the first continuous water-bearing zone at Site 300, which principally occurs in the Neroly lower blue sandstone aquifer ($Tnbs_1$).

Recharge occurs where saturated alluvial valley fill is in contact with underlying permeable bedrock, and where bedrock strata crop out. Local recharge occurs on hilltops, creating the perched water-bearing zones in the Building 832, 834, and 854 areas. Low rainfall, high evapotranspiration rates, steep topography, and intervening aquitards generally preclude direct vertical recharge to the deeper bedrock aquifers.

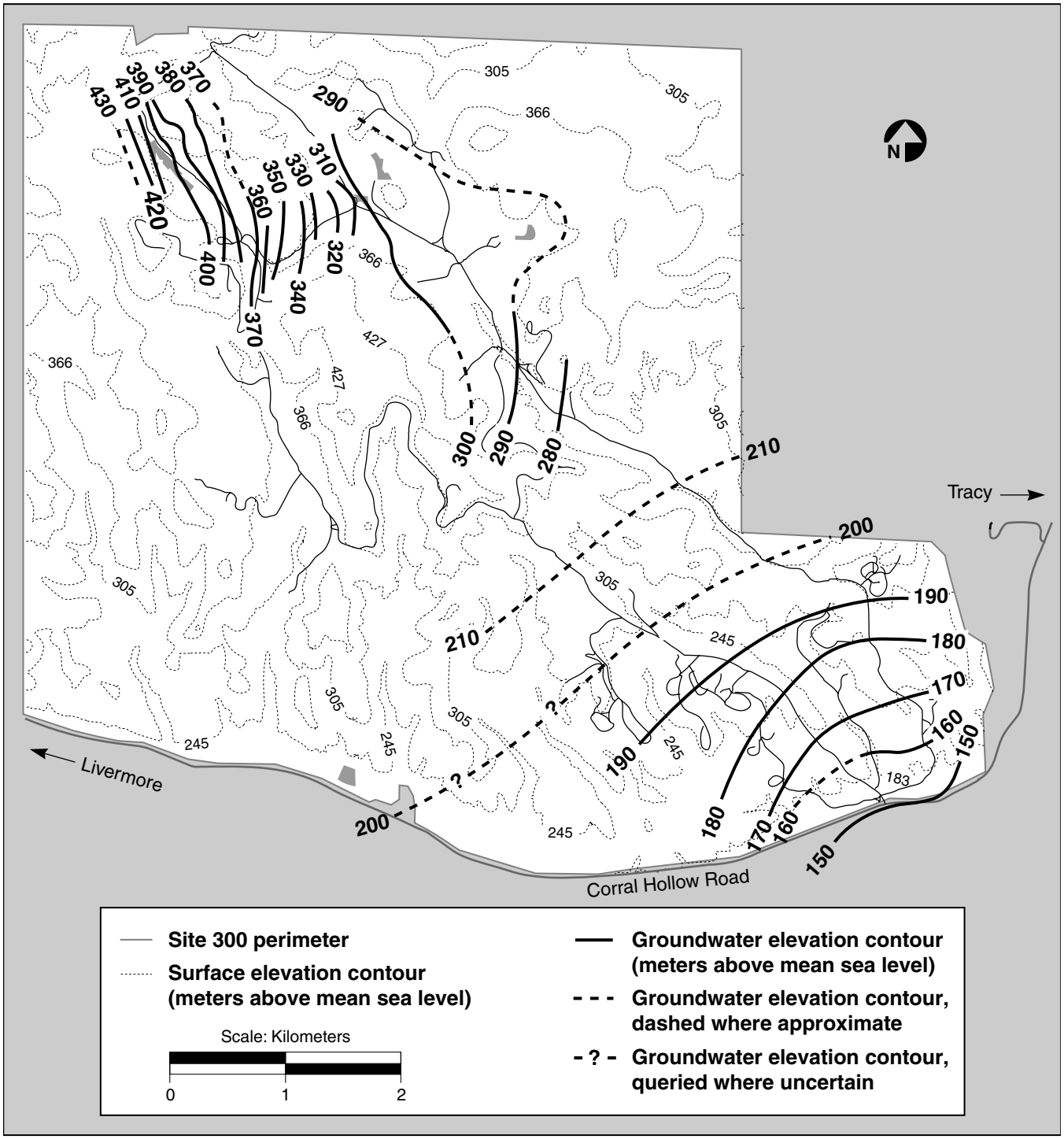


Figure 8-11. Approximate groundwater elevations in the principal continuous water-bearing zone at Site 300

Groundwater flow in the bedrock follows the inclination, or dip, of the layers. The tectonic forces that uplifted the Altamont Hills faulted, gently folded, and tilted the once-horizontal sedimentary strata. A major structure, the east-west trending Patterson anticline, occupies a central location within the site. North of the anticline, bedrock dips east-northeast, and groundwater flows generally east-northeast. South of the anticline, bedrock dips south-southeast, and thus groundwater flows roughly south-southeast.

The Cierbo Formation (Tmss) is saturated beneath Doall Ravine, the Building 851 and 854 areas, and the southern part of the East Firing Area. The Tmss unit is unsaturated or does not otherwise yield water to wells in other parts of the East and West Firing Areas. The thickness of the Cierbo Formation is not well known because most boreholes are not deep enough to completely penetrate this formation. Some of the deeper wells in the GSA penetrate the uppermost Tmss. The continuity of saturation in the Tmss between the north-west and southeast areas of Site 300 is undetermined. Groundwater in the Tmss occurs under unconfined to artesian conditions.

The Tps unit is the youngest bedrock unit identified at Site 300 and is generally present only on hilltops. Where present, groundwater is typically perched, discontinuous, and ephemeral. The exception to this condition exists in the Explosives Process Area, where the extent of saturation in Tps sediments is significant. Groundwater in the Tps unit is generally unconfined, although water under confined conditions does occur locally.

Quaternary alluvium (Qal) is present as valley fill in ravines throughout Site 300, but is saturated only in the Corral Hollow Creek stream channel, in Doall Ravine, and in southern Elk Ravine in the vicinity of Building 850. Saturated Quaternary terrace alluvium deposits (Qt) are present at Pit 6, in the General Services Area (GSA,) and in the Building 832 Canyon area; some of these groundwater occurrences are ephemeral. Small quantities of groundwater are present in some local landslide (Qls) deposits.

All groundwater contaminant plumes at Site 300 occur in Neroly Formation (Tn) rocks, unnamed Pliocene nonmarine sediments (Tps), or unconsolidated Quaternary sediments (Qal , Qls, or Qt) stratigraphic units. The extent of groundwater contamination at Site 300 is shown on Figure 8-12.

Operable Unit Highlights and Activities

Background information for LLNL environmental characterization and restoration activities at Site 300 can be found in the *Final Site-Wide Remedial Investigation Report, Lawrence Livermore National Laboratory Site 300* (Webster-Scholten 1994). In 1999, LLNL submitted the *Draft Final* and *Final Site-Wide Feasibility Study for Lawrence Livermore National Laboratory Site 300* (Ferry et al. 1999a,b) and the *Draft Final Proposed Plan for Environmental Cleanup at Lawrence Livermore National Laboratory Site 300* (Dresen et al. 1999).

Background and activities for each of the study areas are described in the following sections. Groundwater remediation for Site 300 is discussed in more detail later in this chapter. See Chapter 9 for a discussion of 2000 groundwater monitoring.

General Services Area Operable Unit

In the GSA, past leaks of solvents from storage areas and other facilities have resulted in several plumes of VOCs in groundwater. Two groundwater TCE plumes and two corresponding treatment facilities are present at both the eastern and central GSA. The VOC groundwater plume in the eastern GSA is present in stream channel alluvium (Qal) at 3–9 m below ground surface; the plume, as defined by the 1 ppb contaminant contour, is

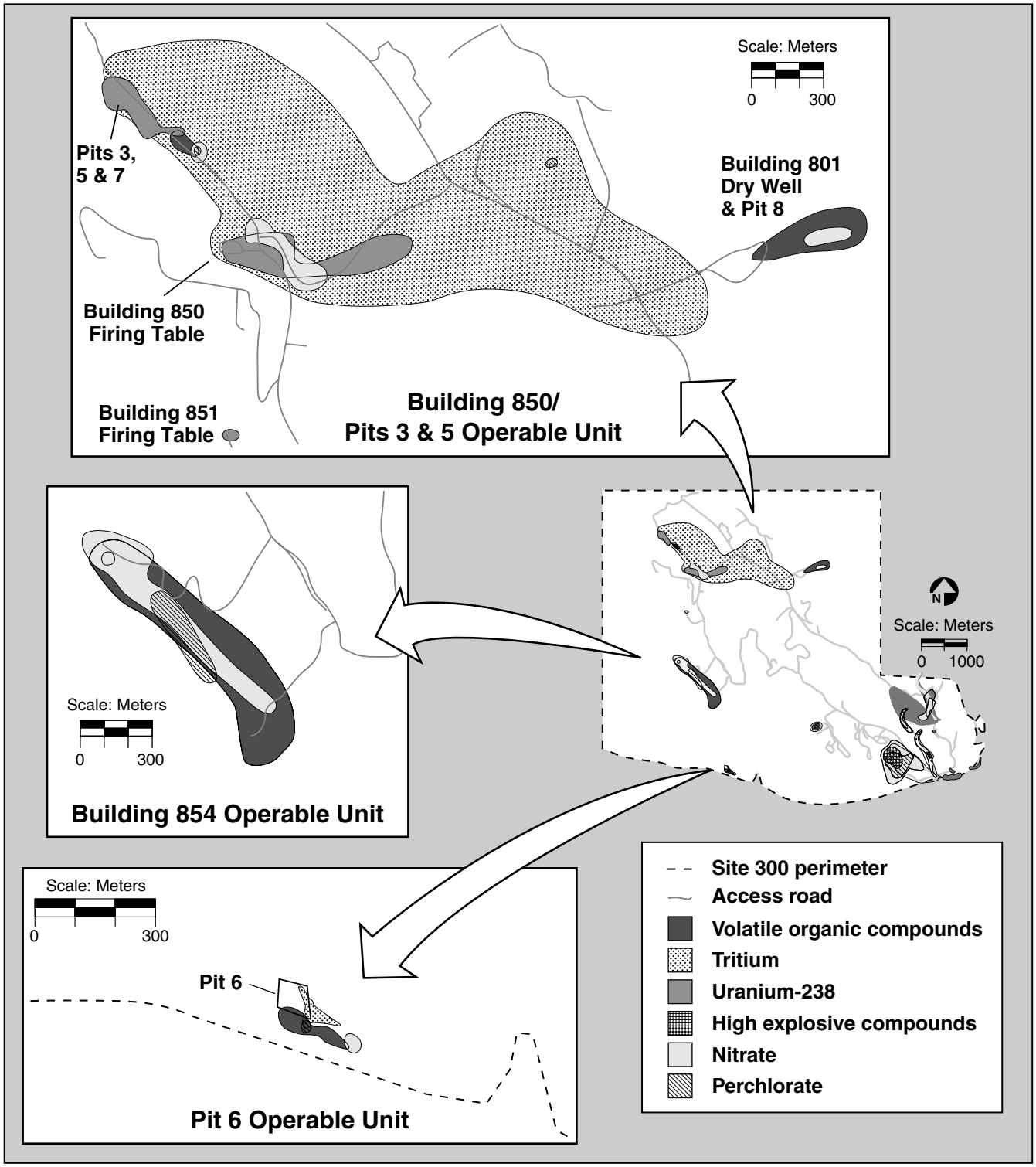
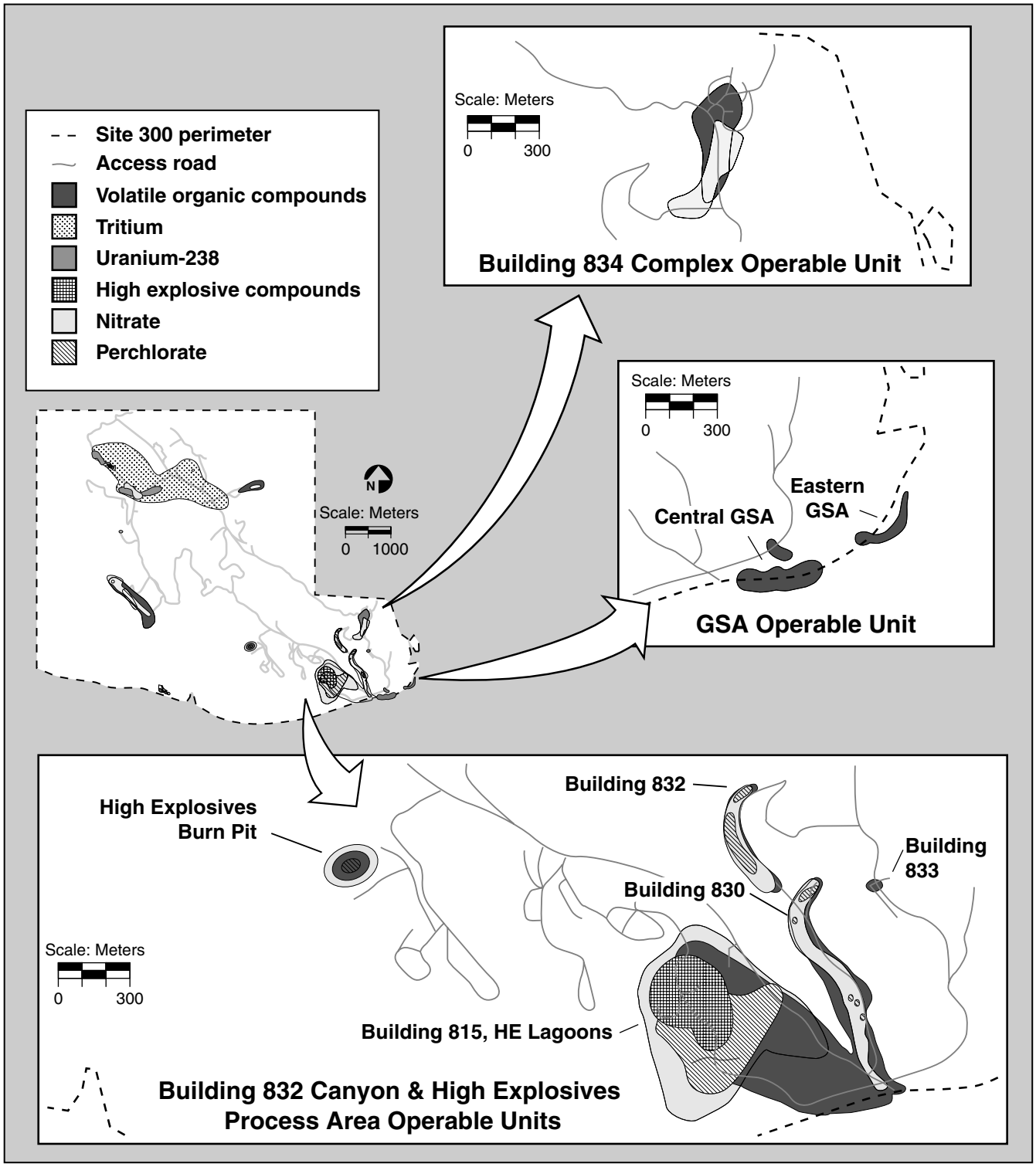


Figure 8-12. Extent of groundwater contamination at Site 300


Site 300 perimeter
Access road
Volatile organic compounds
Tritium
Uranium-238
High explosive compounds
Nitrate
Perchlorate
Scale: Meters
0 300
Building 834 Complex Operable Unit
N
Scale: Meters
0 1000
Scale: Meters
0 300
Central GSA
Eastern GSA
GSA Operable Unit
High Explosives Burn Pit
Building 832
Building 833
Building 830
Scale: Meters
0 300
Building 815, HE Lagoons
Building 832 Canyon & High Explosives Process Area Operable Units

about 433 m long (**Figure 8-13**). Groundwater in the alluvium flows down Corral Hollow Creek, east and northeast. VOC groundwater concentrations from eastern GSA monitoring wells were a maximum total of 86 ppb in the fourth quarter of 2000. The Qal alluvium is hydraulically connected to the Neroly Formation lower blue sandstone ($Tnbs_1$) unit.

The two VOC groundwater plumes in the central GSA are present in terrace alluvium (Qt) and Neroly Formation upper blue sandstone ($Tnbs_2$), at a depth of 3–9 m below ground surface. These VOC plumes are about 133 m and 433 m long (**Figure 8-14**). Maximum fourth quarter 2000 total VOC alluvial groundwater concentrations were 1600 ppb. Deeper regional groundwater also contains total VOCs at a maximum fourth quarter 2000 concentration of 12 ppb. This groundwater occurs at depths of 11–56 m below ground surface.

Details of current and planned environmental restoration activities at the GSA are summarized in the *Final Remedial Design* document (Rueth et al. 1998). The remedial design document includes the Contingency Plan and Compliance Monitoring Plan for the GSA OU.

Using the results from several hydraulic tests, LLNL determined that the direction of plume migration may follow a previously unknown, now subterranean, river bed. It was observed in the fall of 1999 that the eastern GSA off-site plume (as defined by the >5 ppb TCE maximum contaminant level contour line) has been restricted to the Site 300 property, with the exception of one off-site well. It had previously extended more than a mile down the Corral Hollow stream channel toward the City of Tracy, before the treatment facility started up in 1991. We estimate that, through the continued efforts of source elimination and hydraulic containment, LLNL will be able to close the eastern GSA within a few years.

After determining that the eastern GSA VOC plume was primarily restricted to the site, LLNL reconsidered the need for an off-site treatment facility as originally planned for in the Record of Decision (ROD). Chemical data indicate that trichloroethylene (TCE) concentrations have decreased to near or below drinking water standards in groundwater from all off-site wells. Based on this information, LLNL has determined that an off-site extraction and treatment system is not needed or justified. The regulatory agencies have concurred that the off-site treatment system milestone can be delayed and the need will be reevaluated during the GSA Five-Year Review.

Building 834 Operable Unit

The Building 834 facility contains buildings where, in the past, TCE was used as a heat transfer fluid. Several large spills of TCE to the ground resulted in TCE contamination of a shallow perched water-bearing zone beneath the site. Natural biodegradation of the TCE has been occurring in discrete zones resulting in the formation of appreciable amounts of 1,2-DCE. An isolated, discontinuous, perched water-bearing zone occurs in Pliocene non-marine gravels (Tpsg) and occurs at a maximum depth of 9 m below the center of the complex. The Tpsg is underlain by a clay perching horizon (Tps) that is also nearly saturated. The perched zone Tpsg and Tps crop out on all sides of the hill housing the Building 834 complex and are isolated from the underlying regional aquifer by more than 90 m of vadose zone. Although the maximum VOC groundwater concentration within the Tpsg during 2000 was 120,000 µg/L, (entirely 1,2-DCE), the highest VOC concentrations in groundwater were found in the Tps perching horizon. This perching horizon has a very low hydraulic conductivity, but does yield some groundwater. The highest concentration of VOCs in groundwater samples obtained from the Tps during 2000 was 210,000 µg/L, and was predominantly TCE. VOC distribution within the Tpsg is

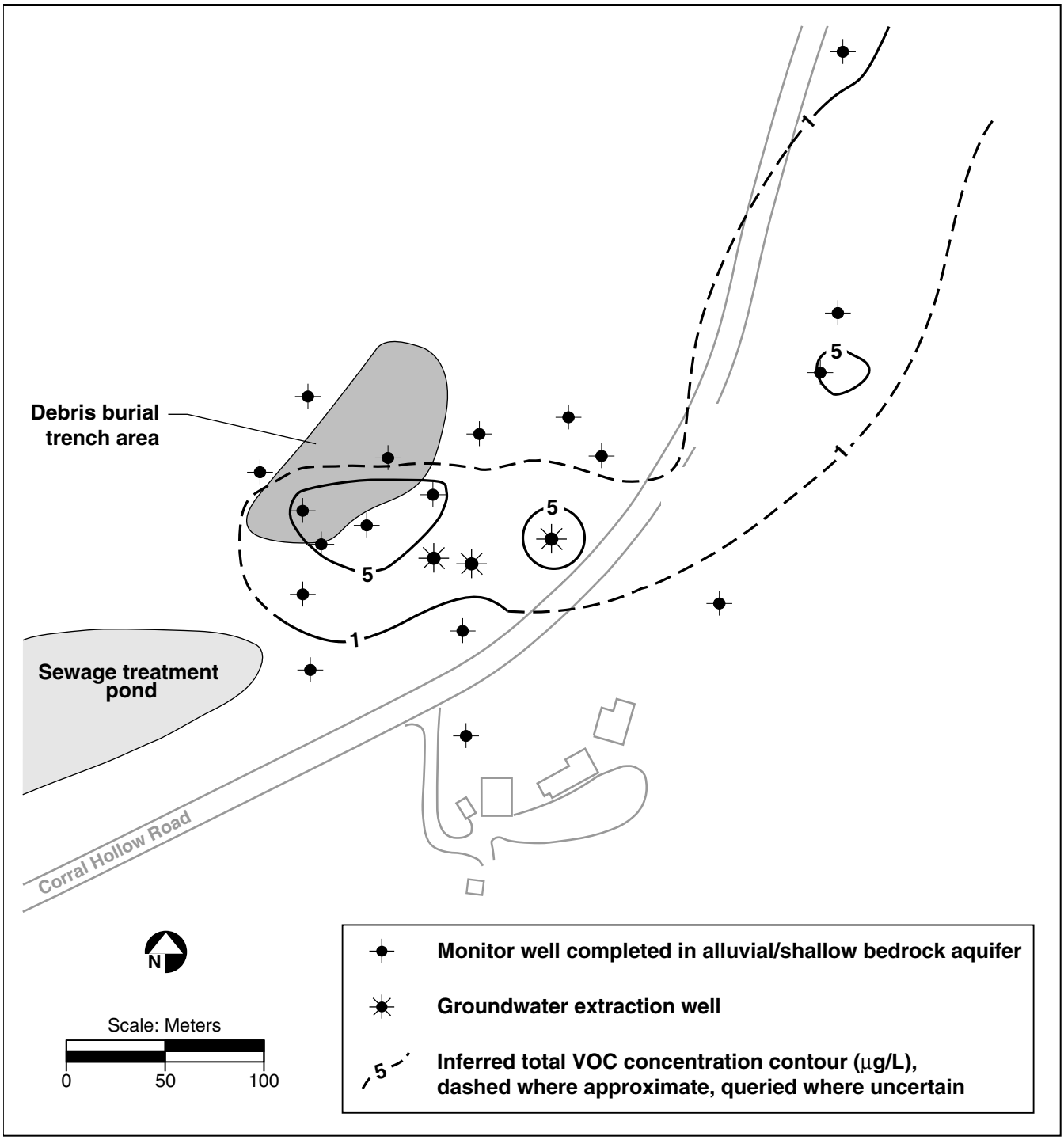


Figure 8-13. Total VOC concentrations in groundwater in the eastern GSA and vicinity (4th quarter, 2000)

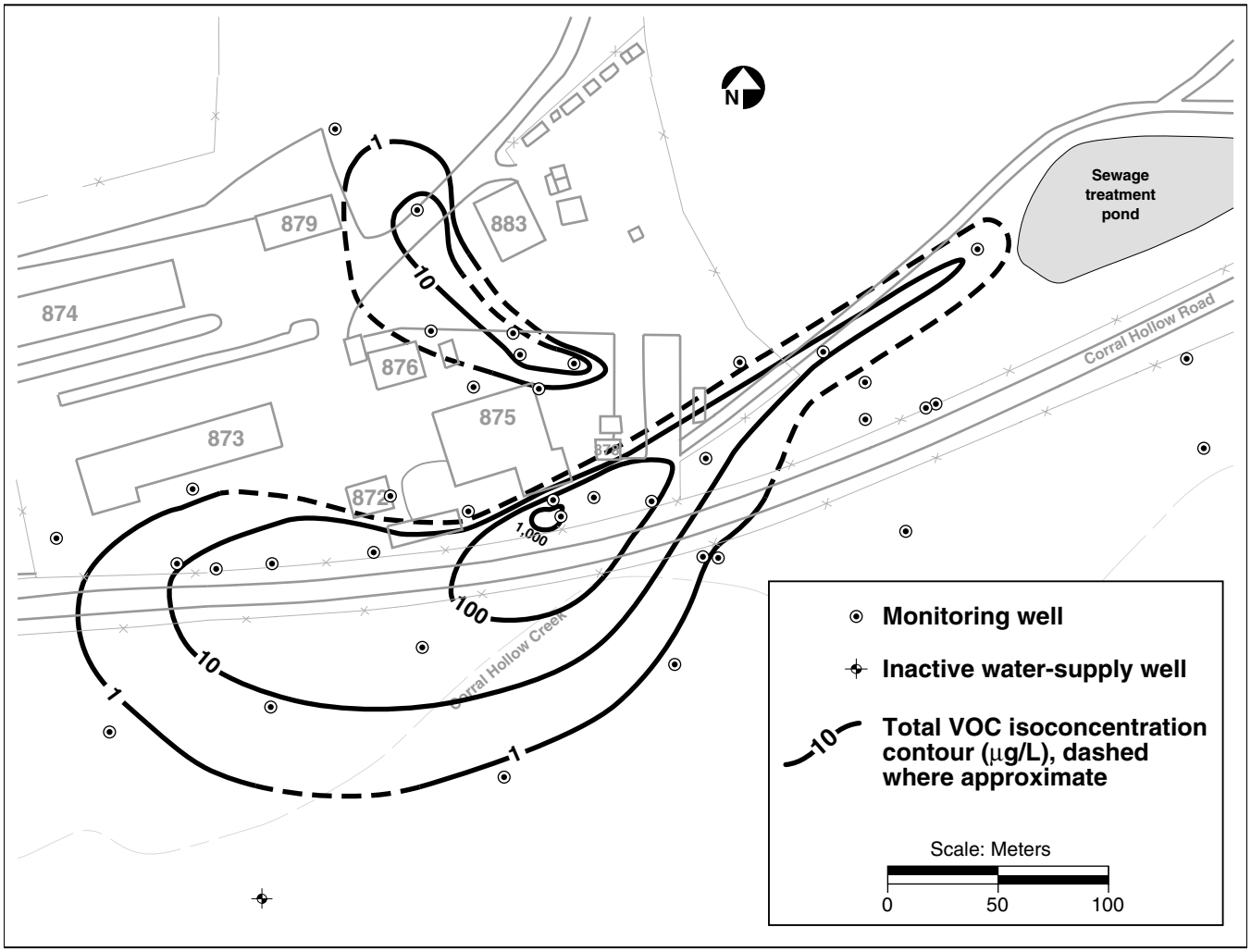


Figure 8-14. Total VOC concentrations in groundwater in the central GSA (4th quarter, 2000). Monitoring wells are completed in the Qt-Tnsc hydrologic unit.

presented in **Figure 8-15**. Data suggest that two, and possibly three, distinct plumes exist and may be in hydraulic communication only during or following heavy rainfall events.

The maximum groundwater nitrate concentration during 2000 from one particular well was approximately 750 mg/L. This well, however, is adjacent to a leach field. The next highest nitrate concentration in groundwater was about 240 mg/L. A silicate oil (tert-butyl orthosilicate) was detected at a maximum concentration of 126,000 µg/L during 2000. Currently, groundwater and soil vapor extraction and treatment are in progress, using air-sparging and granular activated carbon (GAC), respectively. Use of liquid phase GAC for VOC removal from the groundwater is in the process of being tested to possibly replace air sparging.

High Explosives Process Area Operable Unit

The High Explosives Process Area was established in the 1950s to chemically formulate, mechanically press, and machine high explosives (HE) compounds for use in detonation devices that are

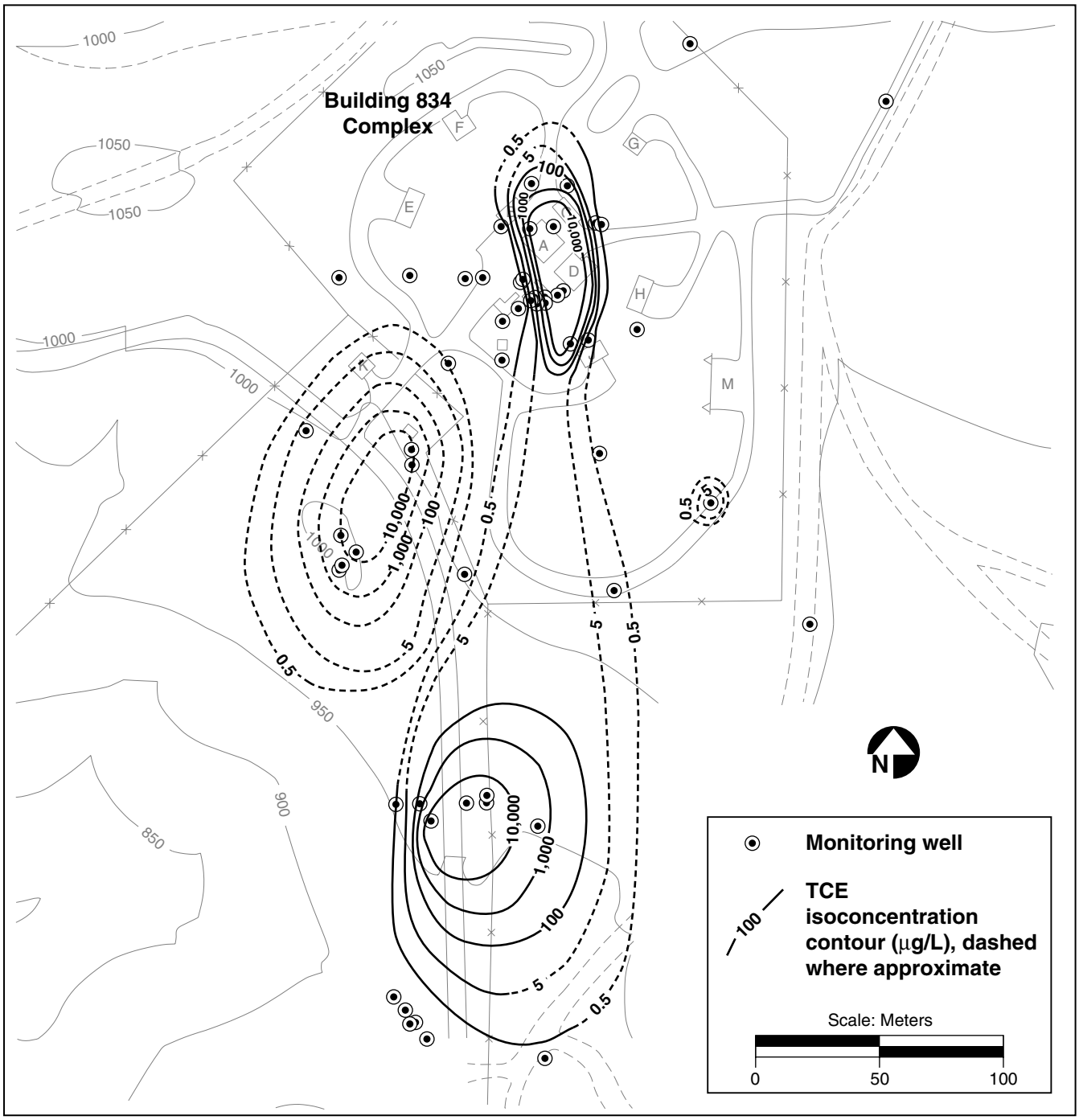


Figure 8-15. Distribution of total VOCs in groundwater in the Qt-Tpsg hydrologic unit at the Building 834 complex (4th quarter, 2000)

tested in explosives experiments in the East and West Firing Areas of Site 300. Process wastewater from HE machining operations containing HMX, RDX, nitrate, and possibly perchlorate, was discharged to nine former unlined lagoons at concentrations high enough to impact groundwater. A TCE hardstand located near the former Building 815 steam plant is considered to be the primary source of TCE groundwater contamination. HMX and RDX are the most frequent and widespread HE compounds detected in soil and groundwater. TCE, nitrate, perchlorate, and RDX occur in two water-bearing zones within the HE Process Area. These two water-bearing zones occur in Tps sediments and $Tnbs_2$ sandstone, respectively. Groundwater occurs in these two zones at depths of 2–30 m, and 20–76 m, respectively. The VOC (principally TCE) plume in Tps strata is about 200 m long. The TCE plume in $Tnbs_2$ strata is about 900 m long (**Figure 8-16**). The RDX plume is about 200 m long. The nitrate plume in $Tnbs_2$ strata is about 700 m long. The perchlorate plume in $Tnbs_2$ strata is 600 m long. Current 2000 maximum concentrations of TCE, RDX, nitrate, and perchlorate are 65, 220, 220, and 33 ppb, respectively. In 1999, a treatment facility (B815-DSB) was installed near the Site 300 boundary to prevent off-site migration of VOCs in groundwater. In 2000, a second treatment facility was installed in the Building 815 source area (B815-SRC). A small plume of TCE (maximum 2000 concentration of 380 ppb) also occurs in a local perched water-bearing zone within $Tnsc_1$ strata at a depth of 24–30 m below the HE burn pits; this plume is less than 5 m long. These burn pits were closed and capped under RCRA in 1998.

Building 850/Pits 3 & 5 Operable Unit

Explosives experiments conducted at outdoor firing tables in this area have generated wastes that in the past were disposed at several unlined landfills. Tritium has been released to groundwater from landfill Pits 3 and 5 and the Building 850 firing table (**Figure 8-17**). Depleted uranium has been released to groundwater from landfill Pits 5 and 7 and the Building 850 firing table. The resulting plumes occur in a perched water-bearing zone within Qal alluvium and bedrock at the base of $Tnbs_1$. The water-bearing zone occurs at depths of 5–20 m below surface. There are three overlapping plumes of tritium in groundwater.

The maximum 2000 tritium activity is about 20,350 Bq/L (550,000 pCi/L). The total length of the co-mingling tritium plumes is about 3000 m. The perched water-bearing zone is connected to the regional $Tnbs_1$ aquifer at the Elk Ravine Fault. Maximum 2000 groundwater tritium activities in this aquifer are about 740 Bq/L (20,000 pCi/L). There are two smaller plumes of depleted uranium (uranium-238) in groundwater, with maximum 2000 activities of less than 1.24 Bq/L (33.4 pCi/L). The depleted uranium is confined to the perched water-bearing zone; the lengths of the two uranium plumes are 370 m and 500 m, respectively. Computer modeling of contaminant fate and transport indicates that by the time the tritium and uranium in groundwater reach the Site 300 boundary, these radionuclides will exist at near-background activities.

Although tritium continues to leach into groundwater from vadose zone sources at Building 850, the long-term trend in total groundwater tritium activity in this portion of the tritium plume is one of decreasing activity at approximately the radioactive decay rate of tritium. The extent of the 740 Bq/L (20,000 pCi/L) MCL contour for this portion of the plume is shrinking.

Nitrate and perchlorate in the Building 850/Pits 3 and 5 areas occur at maximum 2000 concentrations of less than 1200 ppm and 5 ppb, respectively. Trace amounts of TCE (less than 5.8 ppb) are also present in groundwater near Pit 5.

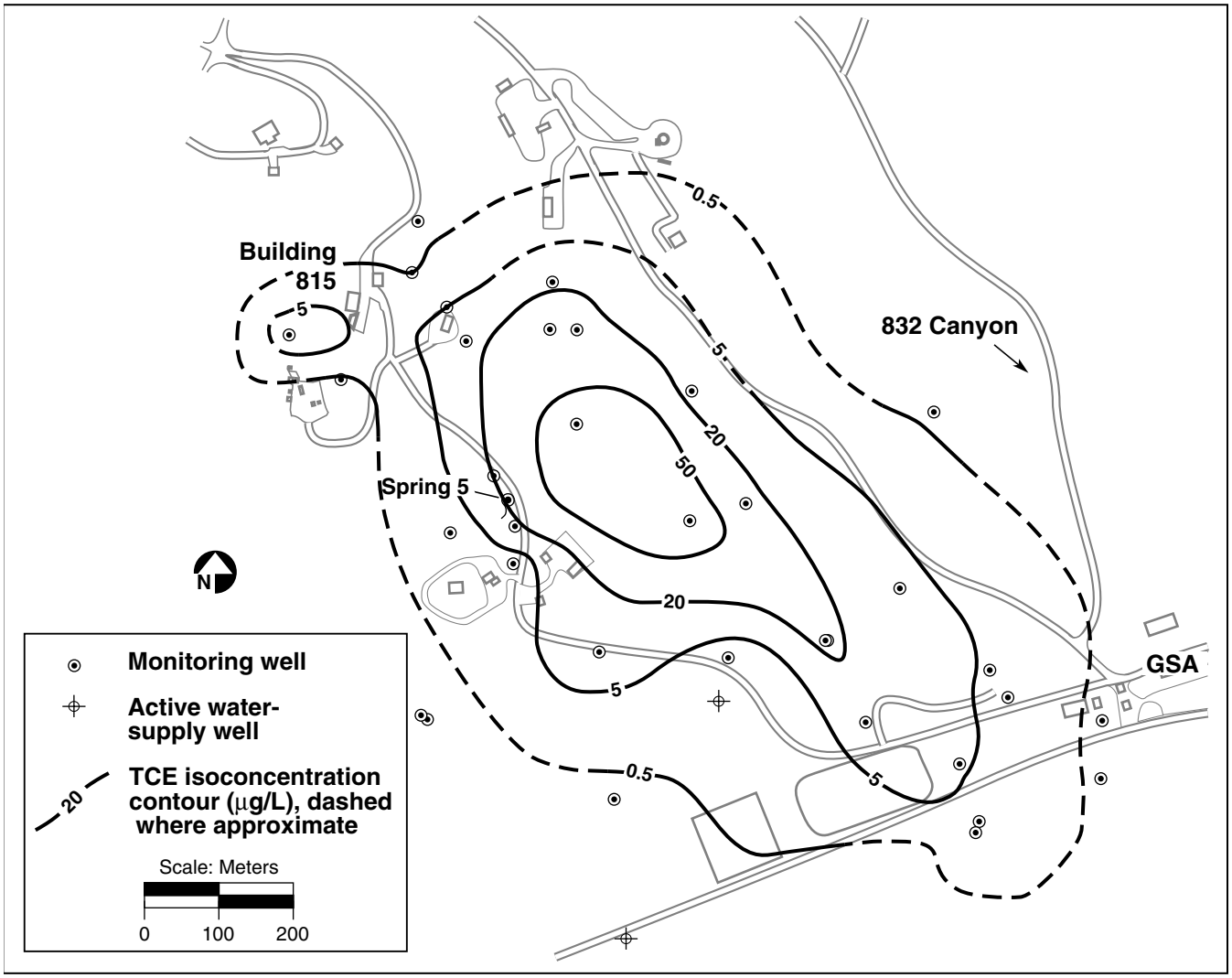


Figure 8-16. Trichloroethene (TCE) isoconcentration contour map in the $Tnbs_2$ aquifer in the HE Process Area (2nd quarter, 2000)

TCE also occurs in a small groundwater plume monitored by two wells at the Building 801 firing table.

Building 854 Operable Unit

Trichloroethene in groundwater was previously found to arise principally from leaks in the former overhead TCE brine system at Buildings 854E and 854F. Trichloroethene, nitrate, and perchlorate occur in groundwater in the Building 854 area in Neroly Formation $Tnbs_1$ strata at maximum 2000 concentrations of 400 ppb, 190 ppm, and 13.1 ppb, respectively. The affected aquifer occurs at depths of 9–50 m below ground surface. The TCE plume is about 1000 m long (**Figure 8-18**).

During 2000, LLNL continued to define the extent of TCE in groundwater. Four new monitor wells were installed along the downgradient and west sides of the groundwater TCE plume. In 1999, LLNL installed and began operating a solar-powered portable treatment unit at Building 854

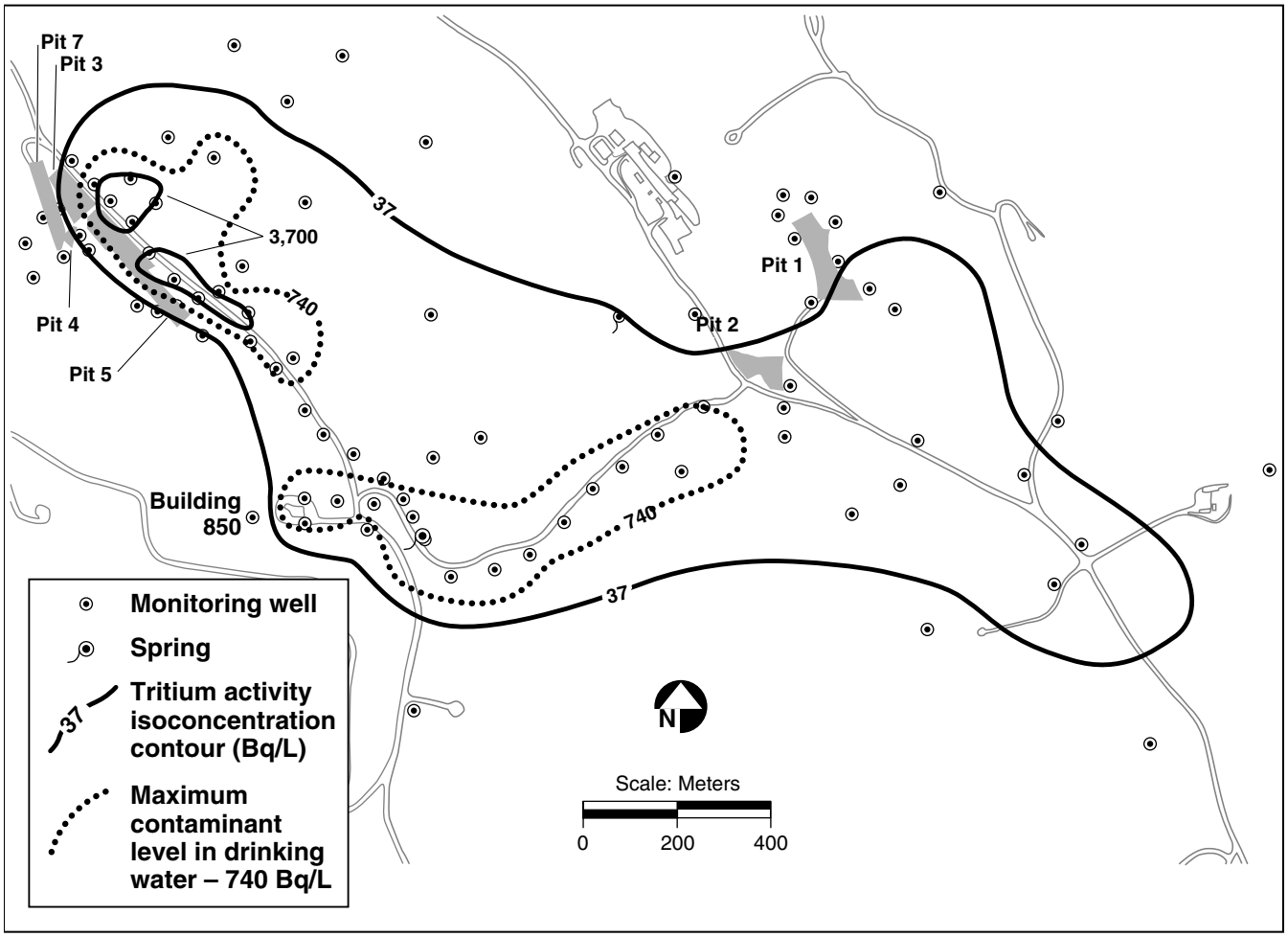


Figure 8-17. Distribution of tritium in groundwater in the first water-bearing zone in the Building 850/Pits 3 and 5 Operable Unit (2nd quarter, 2000)

to treat extracted groundwater containing VOCs and nitrate. A second treatment unit was installed in 2000. This treatment unit uses activated carbon and a containerized wetlands to treat VOCs, nitrate, and perchlorate.

Pit 6 Operable Unit

A low concentration groundwater TCE plume in perched terrace alluvium (Qt) and in the upper part of underlying sandstone discharges to the surface at small springs at the southeastern edge of the Pit 6 area. The perched water-bearing zone occurs at depths of 0–25 m below ground surface. The source of the TCE plume, which is about 300 m long, is likely the southeast corner of the CERCLA-closed Pit 6 landfill (**Figure 8-19**). Concentrations of VOCs in the plume have declined by more than tenfold since 1992. Calendar year 2000 maximum TCE concentrations are about 5.1 ppb. Tritium (at maximum activities of 126.5 Bq/L (3,420 pCi/L), nitrate (at maximum concentrations of 230 ppm), and perchlorate (at maximum concentrations of 47 ppb) also occur in the perched water-bearing zone. The lengths of the tritium and perchlorate plumes are 275 and 200 m, respectively. During

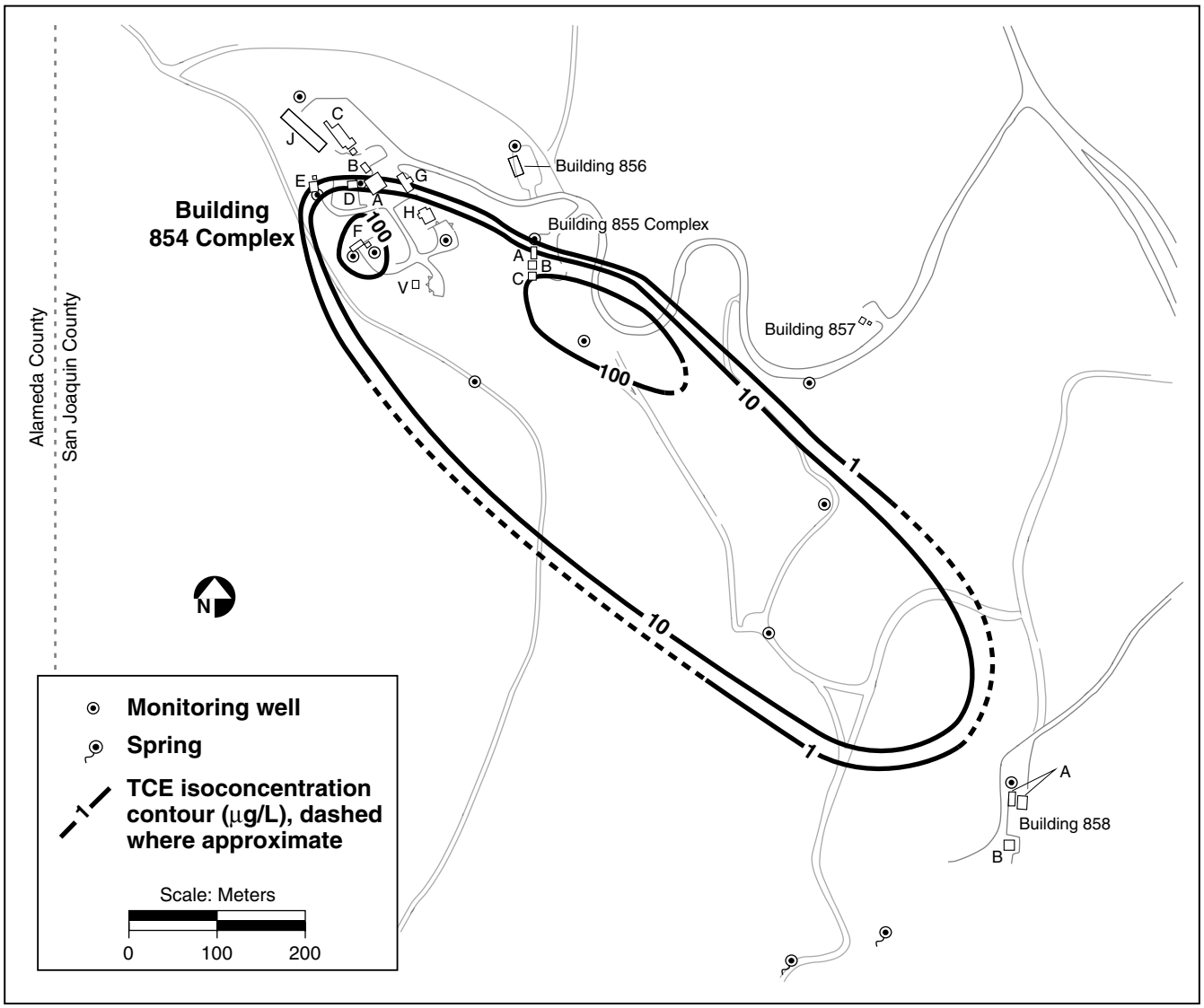


Figure 8-18. Distribution of TCE in groundwater in the Building 854 area (4th quarter, 2000)

1997, a 2.4-acre engineered cap was constructed over the landfill as a CERCLA nontime-critical removal action. During 1998, the post-closure plan (Ferry et al. 1998) for the Pit 6 cap was submitted to the regulatory agencies.

Building 832 Canyon Operable Unit

At the Building 832 Canyon area (Buildings 830 and 832), solvents were released from weapons component test cells in the past. TCE and nitrate occur in groundwater in Qal alluvium and in Neroly Formation sandstone units within $Tnsc_1$ silty-claystone strata 15–25 m beneath the Building 832 Canyon Study Area. Solvents were at maximum 2000 concentrations of 10 mg/L and 206 mg/L, respectively. The TCE plume emanates from both the Building 830 and 832 areas and is about 1300 m long (**Figure 8-20**). Perchlorate

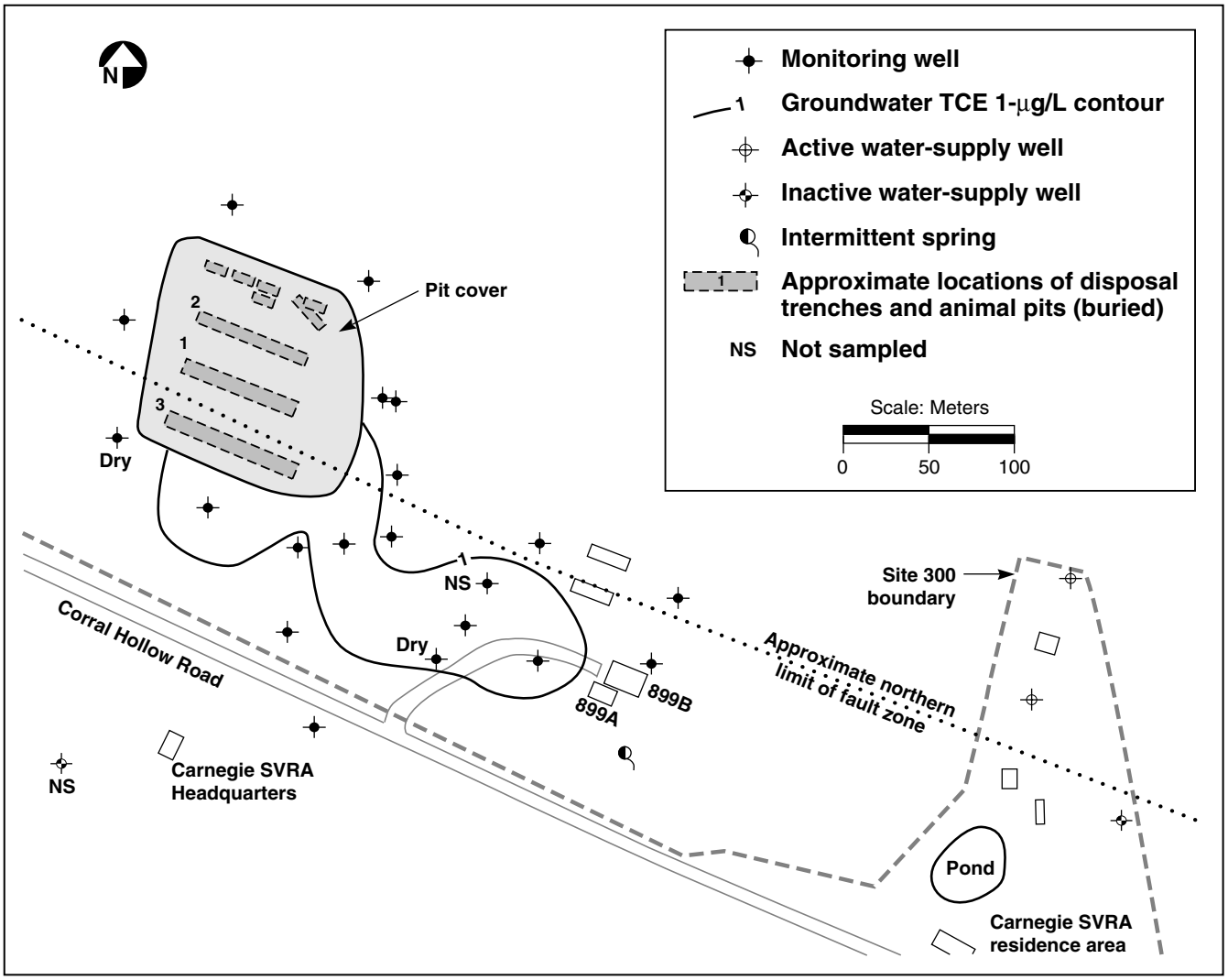


Figure 8-19. Distribution of TCE in groundwater in the Pit 6 area (4th quarter, 2000)

has also been detected at a maximum concentration of .023 mg/L. Well drilling during 1999 and 2000 indicated that the TCE contaminant plume and the nitrate in groundwater, both emanating from the Building 832 complex, are likely merging with the TCE and nitrate in groundwater from the Building 830 area. Perchlorate has also been detected in groundwater samples from 15 monitor wells in the area.

A groundwater and soil vapor extraction and treatment system has been operating to remove contaminant mass at the Building 832 source area. Groundwater is extracted and treated to remove VOCs, nitrate and perchlorate at two remediation systems located downgradient of the Building 830 source area.

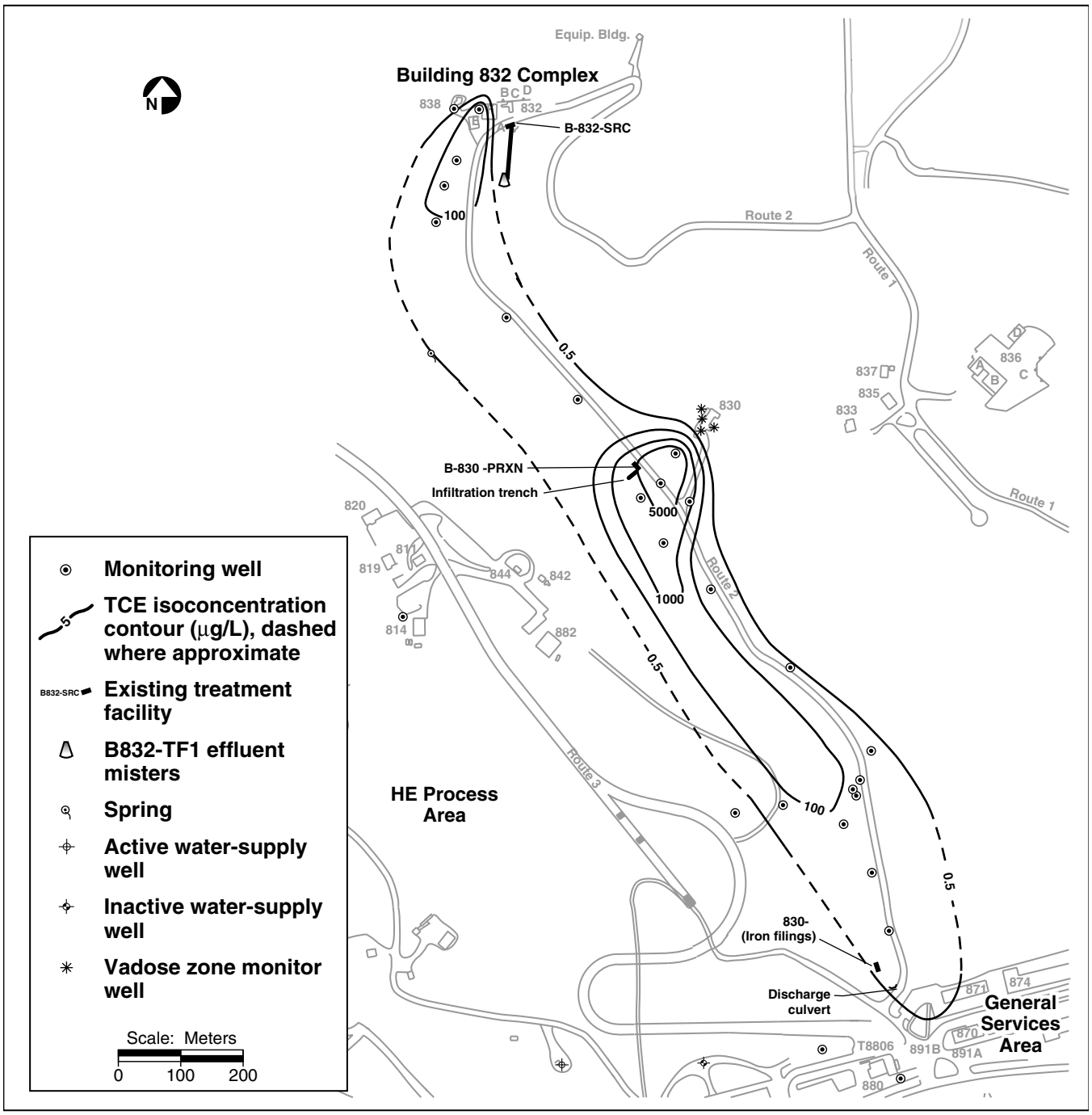


Figure 8-20. Distribution of TCE in groundwater in the Building 832 Canyon (4th quarter, 2000)

Site 300 Operable Unit

The Site 300 OU consists of several small release sites where active remediation is not required, as well as several sites where characterization has yet to be completed including:

- Building 801 dry wells and Pit 8 Landfill
- Building 833
- Building 845 Firing Table and Pit 9 Landfill
- Building 851 Firing Table
- Building 812
- Building 865
- Sandia Test Site

VOCs have been detected in groundwater in the vicinity of the Building 801 dry wells; however, concentrations have declined to below drinking water standards in recent years. Debris from the Building 801 firing table was buried in the Pit 8 Landfill. No contaminants have been detected in the vicinity of the landfill. Groundwater monitoring will continue in this area to monitor the decreasing VOC concentrations and to detect any future releases from the landfill.

Contaminant releases, such as spills and leaching from a disposal lagoon adjacent to Building 833, resulted in VOC contamination of the emphemeral perched aquifer. VOC concentrations have decreased over time and the monitoring of groundwater will continue in this area.

Leaching of contaminants from the Building 845 firing table resulted in the contamination of subsurface soil with uranium, tritium, and HMX. The underlying groundwater has not been impacted. Firing table debris from Building 845 was disposed in the Pit 9 Landfill in the late 1950's and early 1960's. No contamination has been detected in the vicinity of the landfill. Groundwater monitoring will continue in this area to detect any future releases of contaminants from soils under the firing table or the landfill.

Explosive experiments at the Building 851 firing table resulted in the release of low concentration of metals, RDX, tritium, and uranium to soil. Although isotopic ratios indicative of depleted uranium have been found in groundwater samples from one well, groundwater has not otherwise been impacted. Therefore, monitoring is being conducted to evaluate any future impacts to groundwater from soil contaminants.

LLNL continues to evaluate the nature and extent of Freon-113 at Building 865 (the closed Advanced Testing Accelerator). Freon-113 was used as a degreasing agent at the facility. Freon-113 was originally discovered in groundwater samples from wells in the Pit 1 monitoring network, downgradient and southeast of Building 865. Maximum Freon-113 concentrations in groundwater in this area are significantly less than the 1.2 ppm MCL for Freon-113.

During 2000, LLNL installed eight monitor wells at Building 812, a firing table where depleted uranium and thorium were used in explosives experiments. The maximum total calendar year 2000 uranium activity found in groundwater sampled from these wells is 1.33 Bq/L (35.9 pCi/L). Further investigative work is planned for the future.

From 1959 to 1960, Sandia National Laboratory, Livermore, operated a small, temporary firing table in the East Firing Area of Site 300. Future characterization work is planned for this area.

Environmental Remediation at Site 300

Dedicated groundwater and soil vapor extraction and treatment facilities operate at the eastern GSA, central GSA, and Building 834 areas. Eight treatment facilities that remove and treat VOCs operated throughout 2000. Additionally, three new treatment facilities were constructed and began operation at Site 300 during 2000. Fourteen wells that extract only groundwater, and 32 wells that extract both groundwater and soil vapor, operated during 2000, treating about 102.5 ML of groundwater. The 32 wells that extract both vapor and groundwater removed 352,905 m^3 of vapor. In 2000, the Site 300 treatment facilities removed approximately 27.7 kg of VOCs. Since remediation efforts began in 1990, more than 667 ML of groundwater and approximately 1.61 million m^3 of vapor have been treated, to yield about 168.7 kg of removed VOCs.

During 2000, a groundwater treatment system consisting of aqueous phase GAC and a fixed-film bioreactor was installed at the Building 815 (HE Process Area) source area, an aqueous phase GAC/ion exchange resin/containerized wetland system was installed at Building 854, and an above-ground iron filings treatment system was installed at Building 832 Canyon.

The central GSA, eastern GSA, and Building 815 treatment facilities discharge to surface drainage courses. The other treatment systems discharged to air by misting or, in the case of the new Building 854 system, discharge to an infiltration trench. **Table 8-5** summarizes calendar year 2000 and cumulative totals of volumes and masses of contaminants removed from groundwater and soil vapor at Site 300.

General Services Area

Compliance: During 2000, extraction and treatment systems were consistently maintained and operated. The soil vapor extraction and treatment system in the central GSA dry-well source area reduced VOC concentrations in soil vapors, remediated dense nonaqueous-phase liquids in the soil, and mitigated the VOC inhalation risk inside Building 875. The groundwater extraction and treatment systems in the central and eastern GSA area reduced VOC concentrations to drinking water maximum contaminant levels (MCLs), prevented further migration of the contaminant plume, and dewatered the shallow water-bearing zone in the Building 875 dry-well area to enhance soil vapor extraction. These wells are being considered as possible extraction wells for the expansion of the groundwater treatment facility.

Four quarterly reports were submitted to the EPA and RWQCB in 2000 that detail the performance of the treatment facilities (Lamarre 2000i, j, k, and l). During 2000, the groundwater extraction system at the central GSA was expanded to further contain the contaminant plume, increase mass removal, and eliminate contaminant sources as part of a regulatory-driven milestone. Two monitoring wells located at known contaminant sources and one monitoring well located downgradient of the source were converted to extraction wells. With the increased flow, the existing treatment system was converted and upgraded from batch mode to continuous flow operation.

Permit requirements for the central and eastern GSA groundwater treatment system are listed in **Table 8-6**. Both the central and eastern GSA treatment systems operated in compliance with regulatory requirements during 2000. LLNL submitted quarterly reports for the GSA treatment

Table 8-5. Volatile organic compounds (VOCs) removed from groundwater and soil vapor at Site 300

Treatment area	Startup date	2000		Cumulative total	
		Water treated (ML)[a]	VOCs removed (kg)	Water treated (ML)[a]	VOCs removed (kg)
General Services Area					
Eastern GWTF[b]	1991	83.5	0.35	640.9	6.21
Central GWTF	1993	11.5	1.06	20.5	8.60
Building 834	1995	0.043	1.57	0.633[c]	27.2[c]
Building 815	1999	1.85	0.007	2.19	0.017
Building 832	1999	1.74	0.19	34.1	0.194
Building 854	1999	3.90	1.33	4.09	1.37
Pit 6	1998	—[c]	—[c]	0.268	0.0014
		Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)	Soil vapor treated ($10^3 m^3$)	VOCs removed (kg)
General Services Area					
Central	1994	97.3	2.46	1590	67.08
Building 834	1998	151	20.44	511[c]	73.66[c]
Building 832	1999	105	0.30	108	0.674

a ML = 1 million liters

b GWTF = Groundwater treatment facility

c Pit 6 is not routinely used for groundwater treatment. A hydraulic pump test was conducted there in 1998.

systems to the California EPA and the RWQCB in accordance with the National Pollutant Discharge Elimination System Order No. 97-242 for the eastern GSA and the Substantive Requirements for Waste Discharge for the Central GSA (Lamarre 2000i, j, k, and l).

Eastern GSA: The eastern GSA groundwater treatment system operates under NPDES Permit No. CA0082651, issued by the Central Valley RWQCB for discharges into Corral Hollow Creek. The system operated under WDR91-052 until December 5, 1997, when WDR 97-242 was issued. Based on the NPDES permit five-year review, sampling requirements were reduced at the eastern GSA groundwater treatment facility. The eastern GSA treatment facility employs granular activated carbon (GAC) canisters to remove VOCs from extracted groundwater. In accordance with NPDES Permit No. CA0082651, groundwater treated at the eastern GSA groundwater treatment facility was discharged off site to Corral Hollow Creek. **Table 8-5** shows the amount of the water treated and VOCs removed at the eastern GSA.

The length of the eastern GSA TCE plume with concentrations over the cleanup standard of 5 ppb (MCL) has been reduced by more than 1400 m. The off-site portion of the plume now extends 200 m beyond the site boundary. TCE concentrations in influent from the eastern GSA groundwater treatment system were reduced from 64 ppb in January 1992 to 3.1 ppb in November 1999.

Table 8-6. General Services Area groundwater treatment system surface discharge permit requirements

Parameter	Treatment facility	
	Central General Services Area	Eastern General Services Area
VOCs	Halogenated and aromatic VOCs	Halogenated VOCs
Maximum daily	5.0 μg/L	5.0 μg/L
Monthly median	0.5 μg/L	0.5 μg/L
Dissolved oxygen	Discharges shall not cause the concentrations of dissolved oxygen in the surface water drainage course to fall below 5.0 mg/L.	Discharges shall not cause the concentrations of dissolved oxygen in the surface water drainage course to fall below 5.0 mg/L.
pH (pH units)	Between 6.5 and 8.5, no receiving water alteration greater than ±0.5 units	Between 6.5 and 8.5, no receiving water alteration greater than ±0.5 units
Temperature	No alteration of ambient receiving water conditions more than 3°C	No alteration of ambient receiving water conditions more than 3°C
Place of discharge	To groundwater during dry weather and to surface water drainage course in eastern GSA canyon during wet weather.	Corral Hollow Creek
Flow rate	272,500 L (30-day average daily dry weather maximum discharge limit)	272,500 L per day
Mineralization	Mineralization must be controlled to no more than a reasonable increment.	Mineralization must be controlled to no more than a reasonable increment.
Methods and detection limits for VOCs	EPA Method 601—detection limit of 0.5 μg/L EPA Method 602—method detection limit of 0.3 μg/L	EPA Method 601—detection limit of 0.5 μg/L

No off-site wells in the eastern GSA yielded groundwater TCE concentrations in excess of the cleanup standard of 5 ppb (MCL).

Central GSA: The central GSA groundwater treatment system is operating under substantive requirements for wastewater discharge issued by the Central Valley RWQCB. The central GSA treatment facility discharges to bedrock in the eastern GSA canyon, where the water percolates into the ground. Extracted central GSA groundwater runs through an air-sparging PTU to remove VOCs. Extracted soil vapor at the central GSA runs through GAC canisters to remove VOCs. In accordance with the substantive requirement for wastewater discharge, treated groundwater at the central GSA was collected and batch-discharged in a remote Site 300 canyon.

TCE concentrations in central GSA groundwater treatment system (GWTS) influent have been reduced from 9400 ppb in 1993 to 51 ppb in 2000. Volumes of water extracted and masses of VOCs removed from Central GSA groundwater are tabulated in **Table 8-5**.

Soil vapor extraction and treatment of VOCs began in 1994, following dewatering of bedrock through groundwater extraction. **Table 8-5** shows the amounts of soil vapor treated and VOCs removed at the central GSA. From 1994 through the end of 2000, VOC concentrations in the central GSA soil vapor extraction influent stream were reduced from 450 parts per million by volume (ppmv) to 5.5 ppmv. VOC concentrations in individual central GSA soil vapor extraction wells have also been significantly reduced.

After the central GSA well field expansion increased flow rate, the existing treatment system was converted and upgraded from batch mode to continuous flow operation. An additional interlock was added to stop groundwater extraction from all wells with pneumatic and electrical pumps during system shutdown. To increase accuracy in measuring extracted air flow, a new vortex meter was installed at the soil vapor extraction and treatment system. A new 1000-gallon polyethylene effluent surge tank with liquid level switches replaced the Baker tank at the central GSA groundwater extraction and treatment system.

Building 834 Complex

In 2000, the GWTS was operated at full scale for only the month of January. From February through June 2000, the GWTS was off-line to conduct a groundwater rebound study, to test the performance of the soil vapor extraction system in various configurations, and to evaluate the effectiveness of in situ bioremediation via reductive dechlorination of VOCs. For the remainder of 2000, the GWTS and the soil vapor extraction (SVE) and treatment system operated periodically to continue testing the facility performance under various configurations, and to continue evaluating the effectiveness of in situ bioremediation. Treatment facility performance under these various extraction well configurations is currently being evaluated to optimize our cleanup operations. Data collected during bioremediation monitoring strongly indicates that during periods when the SVE, and to a lesser extent groundwater extraction, is not in operation, anaerobic microbial dehalogenation is taking place. A peer-reviewed publication reported on the novel microbial process that exploits alkoxysiloxane lubricants as drivers for TCE bioattenuation at Building 834 (Halden et al. 1999).

Because of reduced operations in 2000, and to a lesser extent declining VOC concentrations, overall mass removal was down by 42% from 1999, when the combined groundwater and soil vapor VOC mass removal at Building 834 was 52.5 kg. During 2000, the combined VOC mass removal at Building 834 was 22.0 kg. Additional VOC mass was destroyed during 2000 through in situ bioremediation, although the amount was not quantified.

Table 8-5 shows the amounts of water and soil vapor treated and VOCs removed at Building 834. Quarterly reports for the Building 834 treatment facility were submitted to the California EPA and the RWQCB in accordance with the Substantive Requirements for Waste Discharge (Lamarre 2000e, f, g, and h). Because treated groundwater is discharged to misters and is not discharged to the ground, there are no treatment system surface discharge permit requirements for Building 834.

High Explosives Process Area

The final *Action Memorandum for the Building 815 Operable Unit Removal Action at Lawrence Livermore National Laboratory Site 300* (Ziagos and Jakub 1998) was submitted to the regulatory

agencies on August 17, 1998. This report describes the main components of the removal action, estimates removal action costs, and addresses all verbal and written comments submitted by the community during the public workshop. The *Building 815 Removal Action Design Workplan for the High Explosives Process Area at Lawrence Livermore National Laboratory Site 300* (Ziagos and Reber-Cox 1998a) was submitted to the regulatory agencies on November 15, 1998. This report describes the removal action in more detail and provides a contingency plan to address foreseeable problems that may arise during this removal action.

Treatability testing began in 1998 to evaluate cost-effective groundwater treatment technologies for the second phase of groundwater cleanup. Removal and destruction technologies are being considered to remediate nitrates and HE compounds, including perchlorate. These technologies use granular-activated carbon or ion-exchange for contaminant removal and ex situ bioremediation for contaminant destruction. Phytoremediation, using indigenous grasses, is also being evaluated for treating nitrate-bearing groundwater.

In 1999, a groundwater treatment facility (B815-TF1) was installed near the Site 300 boundary to prevent off-site migration of VOCs in groundwater. Using granular-activated carbon, the system pumps and treats water from an existing groundwater monitoring well that was converted to an extraction well. Depending on the performance from these two wells, additional wells may be added. A second monitor well will be converted to an extraction well and connected to this treatment facility in 2001. In 2000, a groundwater treatment system (B815-SRC) consisting of aqueous phase GAC and a fixed-film bioreactor was installed at the Building 815 source area. This treatment system is designed to treat VOCs, RDX, and perchlorate and to reduce nitrate concentrations to levels permissible for discharge (i.e., < 45 mg/L). **Table 8-5** shows amounts of water treated and VOCs removed in the treatment system.

Building 854 Area

In December 1999, a groundwater treatment facility (B854-SRC) was installed near the TCE source area at Building 854F as a part of a groundwater treatability study. The facility uses granular activated carbon to treat VOCs in groundwater. In March 2000, a second groundwater treatment facility (B854-PRXN) began operation. This system uses granular activated carbon to remove VOCs, resins to remove perchlorate, and containerized wetlands to remove nitrate. Both systems are operating under waste discharge requirements that were finalized in 2000. **Table 8-5** shows amounts of water treated and VOCs removed in the treatment systems. Treated groundwater from B854-SRC is misted to air; treated effluent from B854-PRXN is discharged to an infiltration trench. Progress of the pump-and-treat systems and groundwater monitoring results are published quarterly (Lamarre 2000a, b, c, and d).

Building 832 Canyon

The Building 832 Canyon OU Treatability Study Workplan sets forth plans for groundwater and soil vapor TCE extraction and treatment, using portable treatment units, solar-powered water activated-carbon treatment units, and soil vapor extraction systems. Additionally, an aboveground iron filings treatment system is being employed in the lower canyon area to treat extracted TCE-laden groundwater, destroy the TCE and degradation products, and help control the migration of the TCE plume off-site.

In 1999, the Building 832 Canyon groundwater and soil vapor treatment system, B832-TF1, began continuous operation. In June 2000, the Building 830 portable groundwater treatment

system (B830-PRXN) began operation. This system uses a PTU outfitted with GAC treatment. The iron filings treatment unit (B830-DISS), located near the mouth of the Building 832 Canyon, was completed and began operation in July 2000. This system also includes a containerized wetland unit for the treatment and removal of nitrate. The waste discharge requirements for these facilities were finalized during 2000. **Table 8-5** shows volume of water treated and mass of VOCs removed in the treatment systems. The treated water is discharged into the canyon. Progress of the pump-and-treat systems and groundwater monitoring results are published quarterly (Lamarre 2000a, b, c, and d).

East and West Firing Areas

To determine the appropriate remediation strategy for the Pits 3 and 5 landfills, LLNL is currently conducting an evaluation of tritium, depleted uranium, and metal sources within the landfills and is continuing to build and calibrate a three-dimensional geological structural model and a finite element model of groundwater flow and contaminant transport. Additionally, LLNL is evaluating several remediation strategies to keep water from entering the landfills. These techniques include subsurface groundwater interceptor trenches, landfill freezing and other forms of permeability reduction, and geochemical techniques to immobilize uranium in groundwater. LLNL is also conducting a water budget and field studies to elucidate how water recharges the perched water-bearing zone and enters the landfills.

Community Relations

During 2000, LLNL met quarterly with members of Tri-Valley Citizens Against a Radioactive Environment and their technical advisor as part of the activities funded by an EPA Technical Assistance Grant. On May 5, 2000, the remedial project managers held a public meeting to present to the community the preferred remedial alternatives outlined in the *Final Proposed Plan for Environmental Cleanup at Lawrence Livermore National Laboratory Site 300* (Dresen et al. 2000).