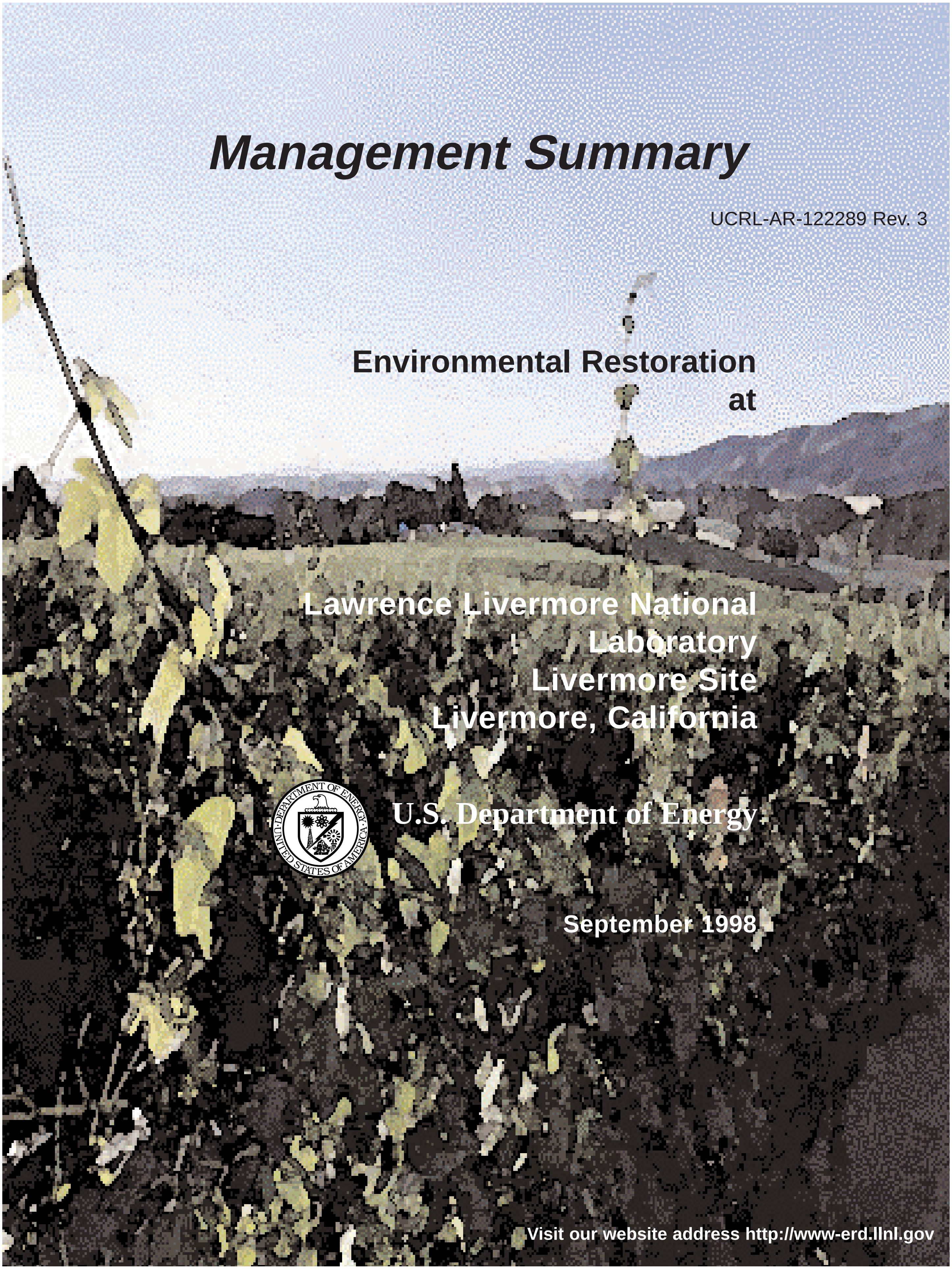


Management Summary

UCRL-AR-122289 Rev. 3

Environmental Restoration at

Lawrence Livermore National Laboratory Livermore Site Livermore, California

U.S. Department of Energy

September 1998

Visit our website address http://www-erd.llnl.gov

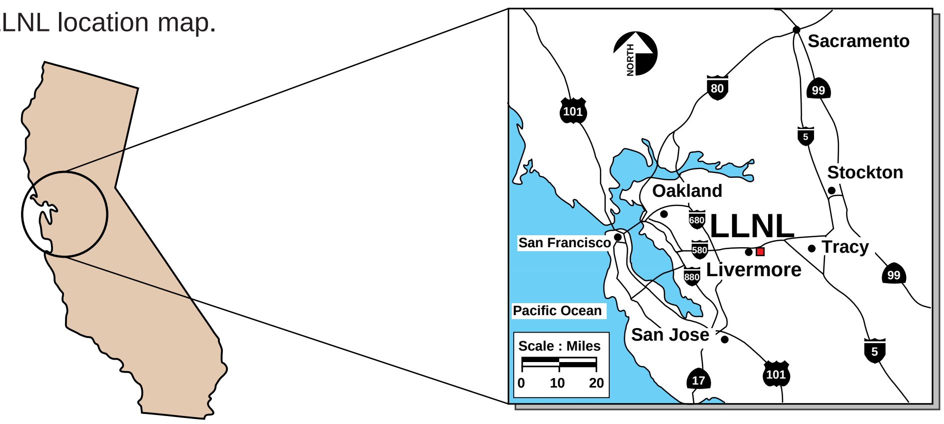
Work performed under the auspices of the U.S. Department of Energy by
Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Management Summary

EXECUTIVE SUMMARY

This management summary describes the status of environmental cleanup at Lawrence Livermore National Laboratory (LLNL) Livermore Site, Livermore, California (Figure 1). LLNL's Environmental Restoration Division (ERD) is using optimized hydraulic control, source removal, and advanced technologies to clean up ground water contaminated with volatile organic compounds (VOCs), fuel hydrocarbons (FHCs) and chromium. ERD is using a network of treatment facilities employing air stripping, ion exchange, and granular activated carbon (GAC) technologies. Initial treatment began in 1989 and additional treatment systems are being phased in through an ongoing evaluation process. Soil vapor extraction (SVE) is the primary technology being employed to clean up the vadose zone at LLNL source areas.

Figure 1. LLNL location map.



SITE CHARACTERISTICS

Site History/Release Characteristics

• The 800-acre LLNL site was converted from agricultural use into a Navy flight training base and aircraft assembly and repair facility in 1942. In 1951, the Atomic Energy Commission converted the site into a weapons design and basic physics research laboratory. Later site missions have included programs in biomedicine, energy, lasers, magnetic fusion energy, and environmental science.
• Initial releases of hazardous materials occurred in the mid to late 1940s. There is also evidence that subsequent localized spills, leaking tanks and impoundments, process cooling water and landfills released VOCs, FHCs, chromium and tritium to sediments and ground water, primarily from 14 major areas of concern.
• In 1983, VOCs were detected by LLNL in domestic water-supply wells west of the site. A regulatory order to investigate ground water quality was issued by the state in 1984 and ultimately lead to investigation of over 350 potential release sites.
• Bottled drinking water was supplied to nearby residents beginning in 1983 and all affected supply wells were permanently sealed between 1985 and 1989 by LLNL. Waste pits and a landfill were excavated and backfilled in 1982/83 and 1984, respectively. The LLNL Livermore Site was added to the Comprehensive Environmental Remediation Compensation and Liability Act (CERCLA) National Priorities List in 1987. The CERCLA Record of Decision (ROD) was signed in 1992.

Site Conditions

• The ground surface slopes gently across the site, changing in elevation from 670 ft above mean sea level (MSL) in the southwest corner to 570 ft above MSL in the northwest corner. Two intermittent streams, the Arroyo Seco and the Arroyo Las Positas, traverse the area.
• Climate is semiarid with annual precipitation about 14 inches/year.
• Land north and south of the site is zoned for industrial use, west of the site is medium to high-density residential areas, and east of the site is primarily agricultural land.
• Municipal water-supply wells in downtown Livermore, approximately 1.6 miles away from the contaminant plume, are the primary drinking water source for over 10,000 of Livermore's 60,000 residents.

Nature and Extent of Contaminants

VOCs: • VOCs are found in saturated sediments underlying approximately 85% of the Livermore Site and occupy an area of about 1.4 square miles. The VOC ground water plumes vary between 10 and 100 ft in thickness and are generally found within the first 200 ft of sediments.

• TCE is the predominant VOC, with maximum concentrations on the order of 5,000 parts per billion (ppb); PCE, 1,1-DCE, 1,2-DCA, 1,1,1-TCA, carbon tetrachloride, chloroform, Freon 113 and Freon 11 are also frequently present.

• VOCs occur in varying concentrations in the vadose zone of identified source areas. At several locations, vadose zone VOCs are still impacting ground water.

FHCs: • Fuel hydrocarbons, including free product, are present in saturated sediments associated with previous gasoline releases near the southern boundary of the site.

• Dynamic underground steam stripping, electrical heating, and ground water and vapor extraction have removed approximately 10,000 gallons of gasoline product from the subsurface.

• Residual fuel hydrocarbons are still present up to 2 parts per million (ppm) in ground water within 50 ft of the source and up to approximately 3,000 ppm in soils at one location.

• Based on evidence that remediation by natural bioattenuation of FHCs is occurring, LLNL obtained a No Further Action status at the southern release site from the regulators in 1996.

Metals: • Metals from both natural conditions and facility activities exceed drinking water standards in several locations. Chromium, naturally occurring and used as a corrosion inhibitor in cooling towers in the past, is found in concentrations up to 160 ppb in ground water.

Radiological Parameters: • Tritium has been detected in ground water in the few wells but is expected to decay below federal and state drinking water standards before the water migrates offsite, even if no remediation was conducted.

Contaminants of Concern

VOCs:	
Trichloroethylene	(TCE)
Perchloroethylene	(PCE)
1,1 & 1,2-Dichloroethylene	(DCE)
1,1 & 1,2-Dichloroethane	(DCA)
Carbon tetrachloride	(CCl_4)
1,1,1-Trichloroethane	(TCA)
Chloroform	(HCl_3)
FHCs:	
Benzene	(B)
Toluene	(T)
Ethylbenzene	(E)
Xylenes	(X)
Ethylene dibromide	(EDB)
Metals:	
Chromium	(Cr)
Trivalent chromium	(Cr^{3+})
Hexavalent chromium	(Cr^{6+})
Radiological Parameters:	
Tritium	(H^3)

Remediation Strategy

The remediation strategy now being implemented at the LLNL Livermore Site is an extension of the original ROD cleanup effort, which was largely based on detailed chemical depth sampling and a simplified 2-D numerical model of the site. The current strategy, based on a detailed 3-D hydrogeochemical model of the site, consists of a systematic, aggressive, cleanup strategy known as Engineered Plume Collapse (EPC). EPC is made up of four phases, shown on Figure 2.

Phase I-Target contamination using hydrostratigraphic analysis to map individual ground water contaminant plumes and their source areas, based on site-specific geologic, geophysical, hydraulic, and chemical data (Figures 4 and 5).

Phase II-Hydraulically contain and isolate source areas to stop resupplying contaminants to distal plumes. Collapse distal plumes back to their source areas using pump and treat technology with extraction wells positioned in high-permeability sediments to optimize mass removal and hydraulic capture (Figure 9).

Phase III-Apply conventional and advanced technologies to cleanup contaminated fine-grained source area sediments in a phased approach that ensures cost-effective remediation. These technologies include various types of pump and treat, soil vapor extraction, electro-osmosis, and thermal and/or other technologies (Figure 3).

Phase IV-Negotiate Site Closure with the regulatory agencies based on a rigorous analysis of the health threats posed by any residual contamination remaining at the site.

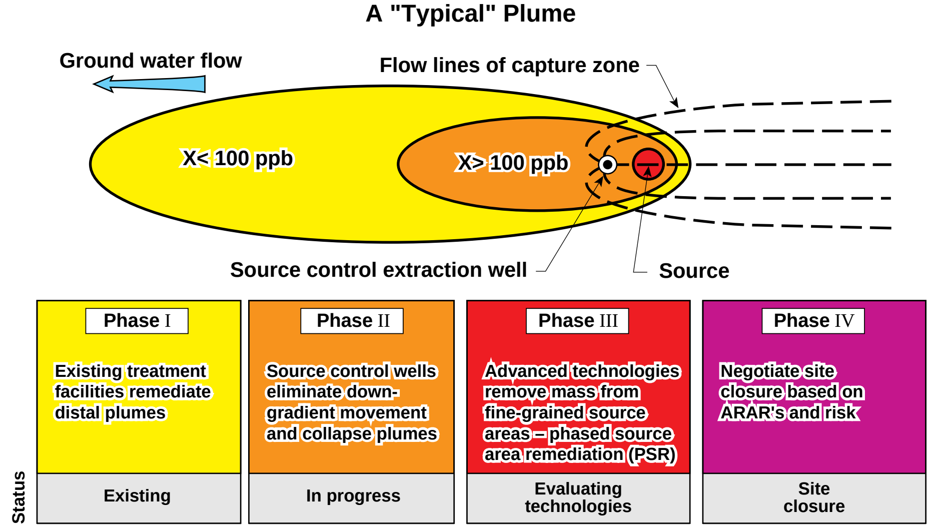


Figure 2. Engineered Plume Collapse focuses the right remediation technologies at the right place at the right time.

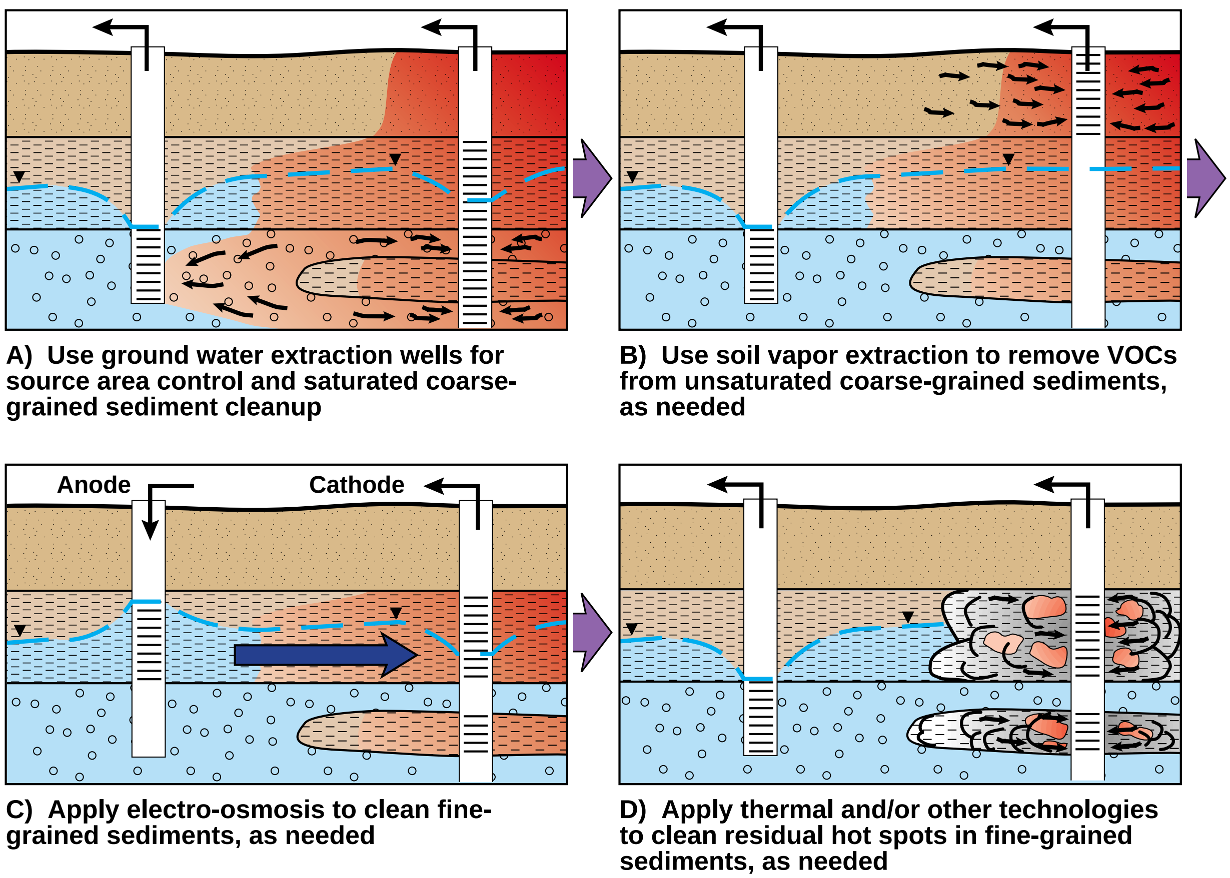


Figure 3. Phased source area remediation (PSR) – use increasingly energetic (costly) remediation technologies, as needed (Phase **III** of EPC, Figure 2).

Over the last nine years, ERD has focused its remediation efforts on implementing Phases **I** and Phase **II** of EPC. Since 1989, ERD's primary cleanup strategy has been to use pump and treat technology to capture and collapse contaminant ground water plumes moving offsite (Figure 7). As of 1998, ERD has:

• Achieved successful hydraulic containment of all contaminant plumes on the western site margin using strategically positioned wells at Treatment Facilities A, B, and C (Figures 6 and 8).

• Optimized remediation wellfield design and operation using numerical flow and transport model simulations and detailed 3-D visualizations of contaminant distribution and hydraulic capture (Figures 17, 19, and 21).
• Begun collapsing and treating contaminant plumes within the interior of the site at Treatment Facilities D, E, and F.
• Deployed portable treatment units to hydraulically isolate source areas and collapse rapidly moving distal plumes within the interior of the site at Treatment Facility TF406, TFD, TF518, TFE, and TFG (Figure 13).
• Significantly increased mass removal at treatment facility areas using EPC (Figures 15 and 16).
• Begun treating a VOC/tritium ground water plume at TF5475 using an innovative *in situ* remediation technology.
• Begun evaluating advanced technologies for cost-effectively remediating source areas in fine-grained sediments.

ERD is currently planning the implementation of Phase **III** of EPC. Without remediation, VOCs in fine-grained sediment source areas slowly diffuse into more permeable zones, significantly extending long-term cleanup. To ensure cost-effective cleanup of these areas, ERD will use a cleanup strategy known as “phased source area remediation” (PSR). As shown in Figure 3, PSR involves using increasingly energetic and costly remediation technologies to eliminate source area release points. These technologies may include pump and treat, soil vapor extraction, electro-osmosis, and thermal (steam or electric heating) and/or other technologies. PSR ensures that more energetic technologies are only applied where less expensive technologies fail to meet cleanup objectives.

A well-characterized source area at TFD, located in the east-central portion of the site, has been selected for the initial implementation of PSR. Ground water extraction wells for source area control and saturated coarse-grained sediment cleanup have been installed and are operational. Planning for, fine-grained source area sediment cleanup is underway, and the results of laboratory studies of electro-osmosis (EO) will be available this fall.

STATUS OF CLEANUP

Contaminant Locations and Hydrogeologic Profiles

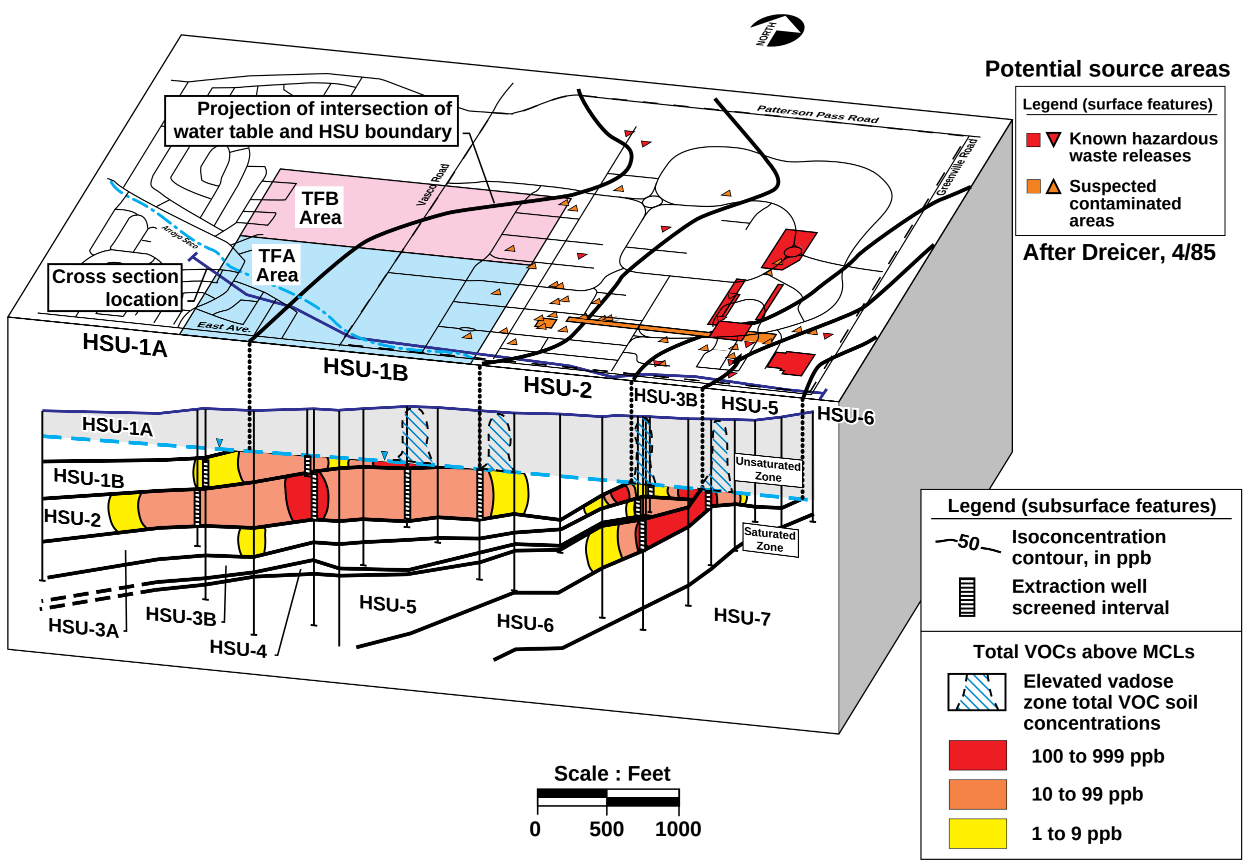


Figure 4. Block diagram showing the current distribution of VOCs within individual hydrostratigraphic units (HSUs) beneath the site. This level of mapping was required in order to implement cost-effective ground water clean up at the LLNL Livermore Site.

Remediation investigation activities at the LLNL Livermore Site involved review of over 350 potential release sites which were incorporated within 14 areas of concern. The source investigation methodology involved review of historical information, sample collection and drilling of over 800 boreholes. The site hydrogeology was characterized from:

- Field borehole logs.
- Borehole geophysical logs.
- Hydraulic test data (over 300 tests were conducted over a 4-year investigation period).
- Sediment and water chemical concentrations.
- Subsurface data from other investigations, including seismic and soil vapor surveys.

This data was used to develop a contaminant hydrogeological model of the site (Figure 4).

Status of Cleanup Highlights

- The lateral and vertical extent of the primary VOC plumes has been characterized, mapped in detail, and related to individual source areas (Figure 4).
- Individual contaminant plumes have been targeted for cleanup using adaptive pump and treat and innovative technologies at each Treatment Facility Area (Figures 5, 7, and 9).
- Extraction well locations have been optimized for VOC mass removal and hydraulic control to inhibit migration of plumes offsite (Figures 6-9).
- Time series maps show successful hydraulic capture and cleanup of individual plumes on the downgradient western margin of the LLNL Livermore Site (Figures 7 and 9).

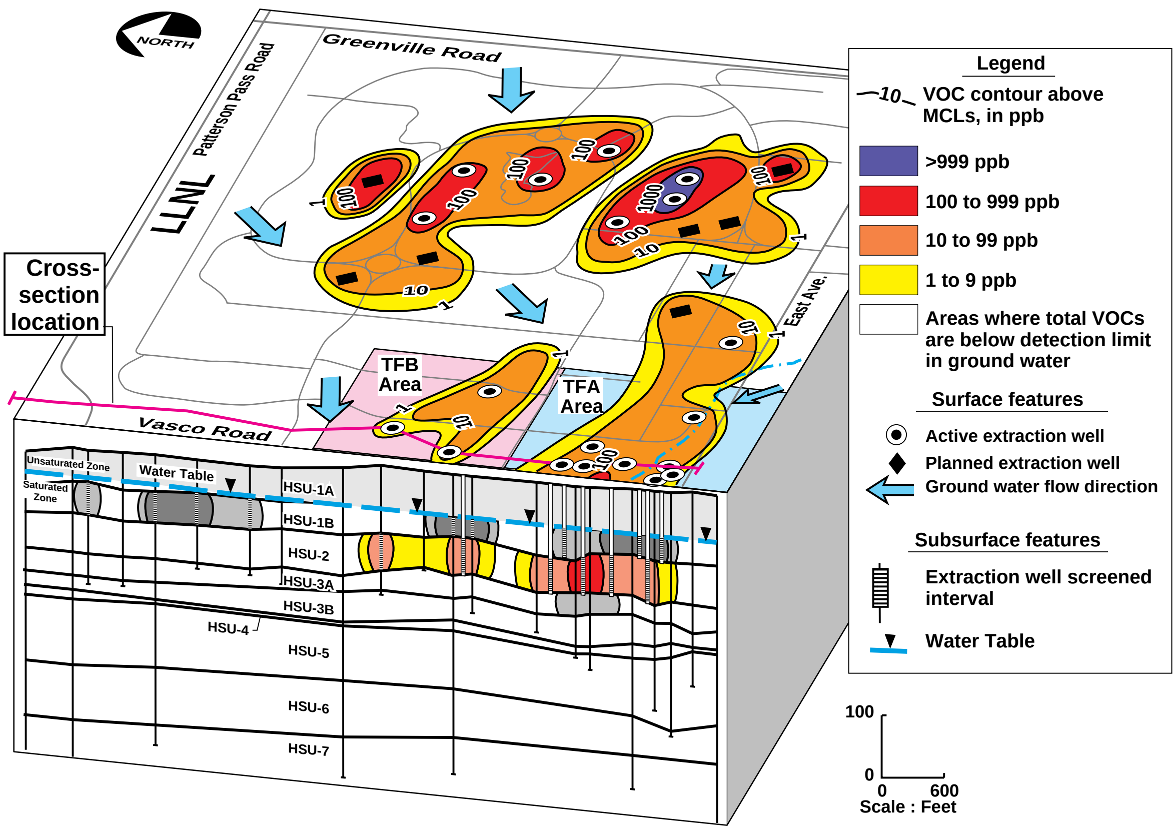


Figure 5. Block diagram showing a map view and cross-sectional view of contaminant distribution in hydrostratigraphic unit HSU-2. Extraction wells have been located and designed for maximum mass removal and hydraulic capture of individual VOC plumes within each hydrostratigraphic unit.

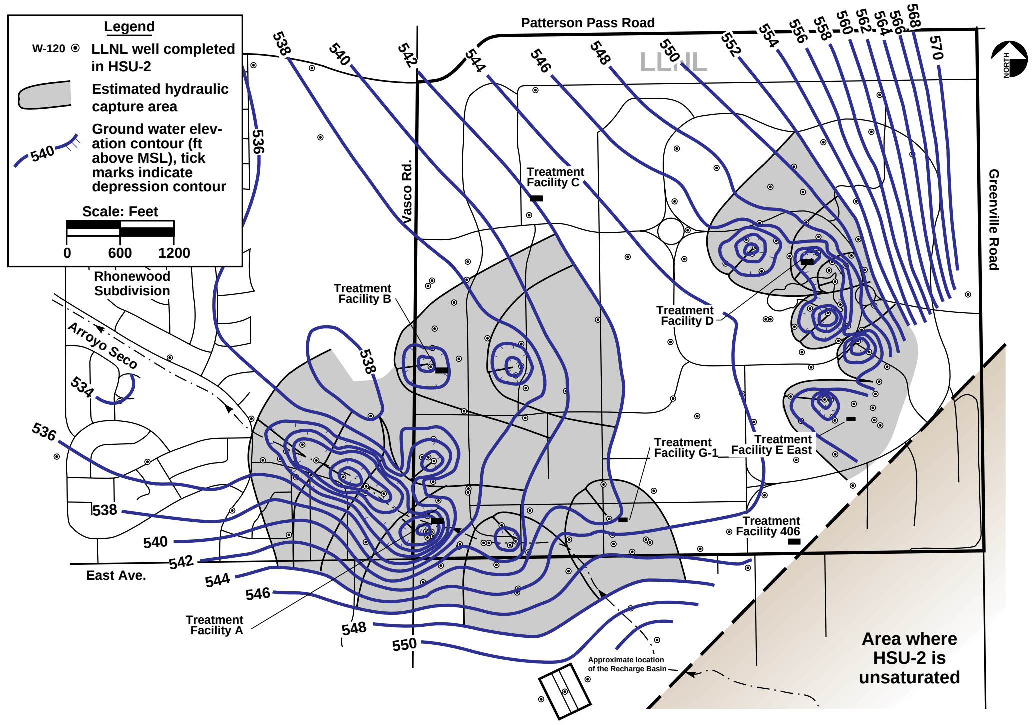
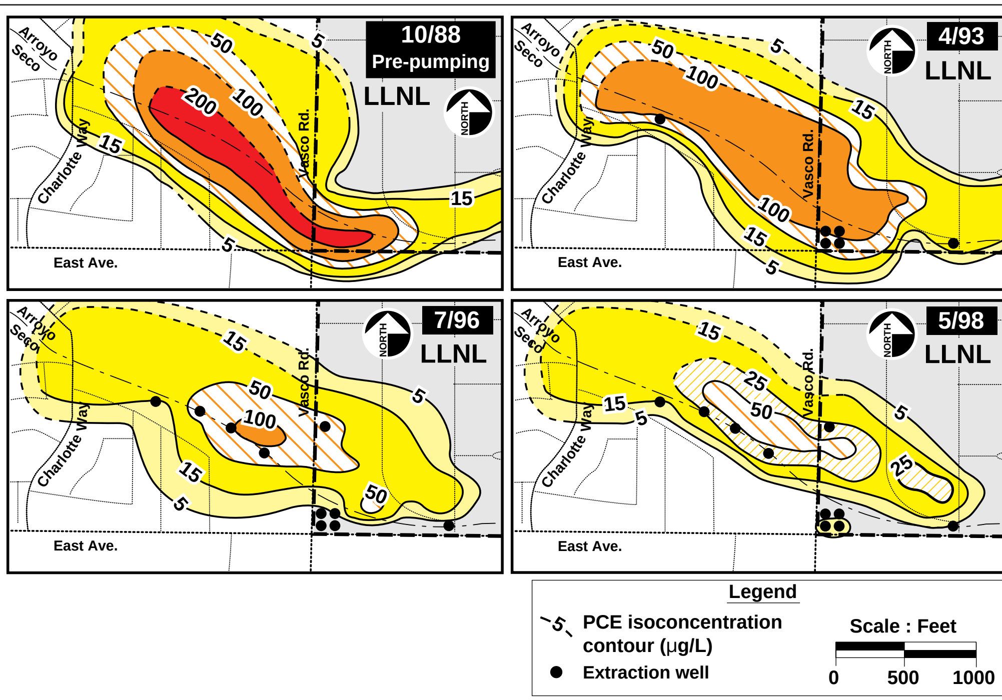


Figure 6. 1998 ground water elevation map showing hydraulic capture areas (shaded areas) that encompass onsite and offsite VOC plumes in HSU-2 (see Figure 7) along the western margin of the site.

Figure 7. VOC plume maps in HSU-2 near TFA show a dramatic decrease in concentrations of PCE with time in response to ground water extraction and treatment. New HSU-2 extraction wells have expanded the hydraulic capture area to encompass the western margin of the plume and are targeting the residual concentrations above 50 ppb.



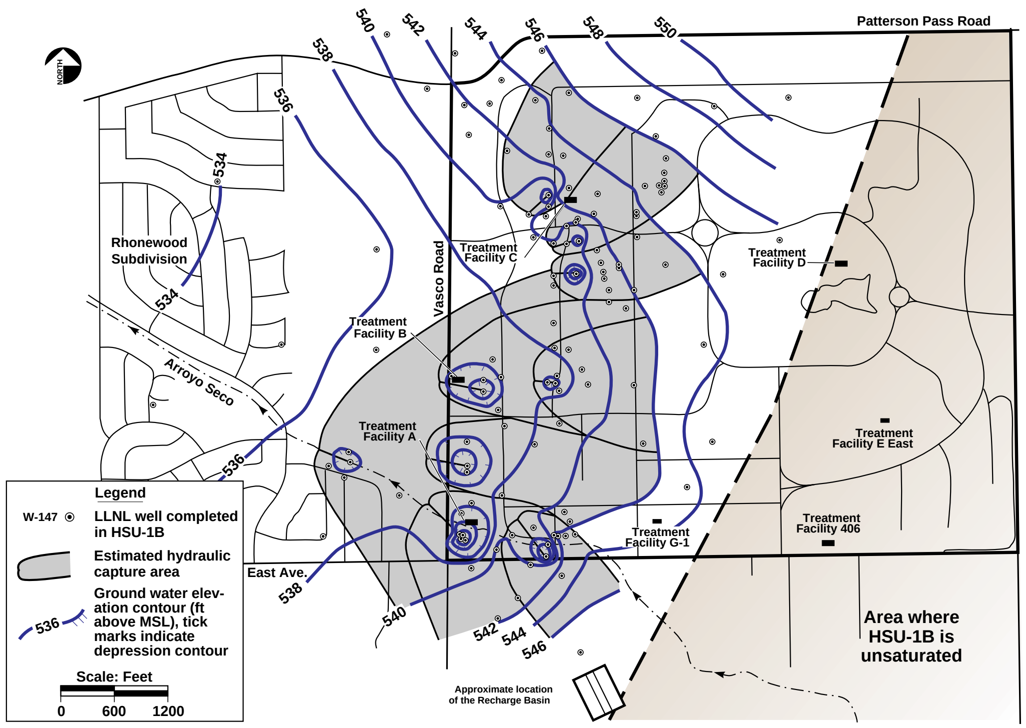


Figure 8. 1998 ground water elevation map showing hydraulic capture areas (shaded areas) that encompass onsite and offsite VOC plumes within HSU-1B along the Wesstern margin of the site (see Figure 9).

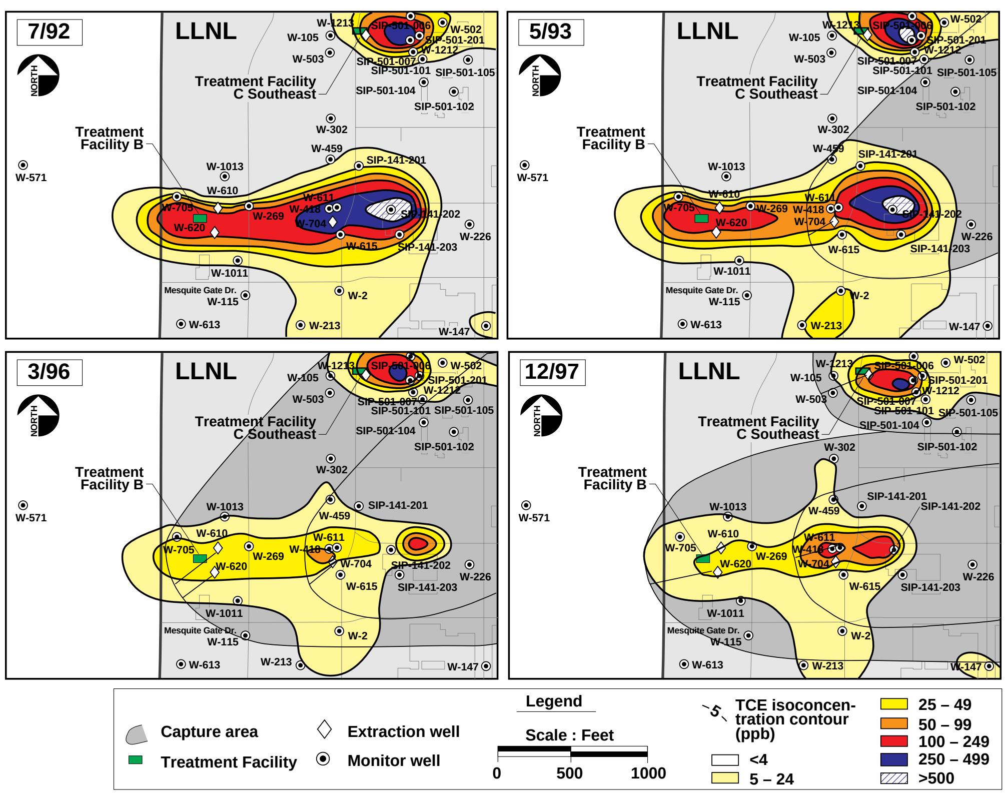


Figure 9. VOC plume maps in HSU-1B at TFB show a dramatic decrease of concentrations over time in response to ground water extraction and treatment. The shaded area represents the hydraulic capture area created by TFB extraction wells pumping from HSU-1B.

HYDROSTRATIGRAPHIC CHARACTERIZATION

Site Characterization Methodology

Initial remediation investigation efforts at the LLNL Livermore Site using a depth-sampling technique developed at LLNL led to an understanding of subsurface conditions and contaminant distributions. Geologic cross sections (see Figure 11) showing locations of contaminants were constructed using these data. More recent site characterization activities have focused upon the development of a comprehensive hydrostratigraphic characterization of the site through application of a systematic methodology for partitioning the aquifer into hydrostratigraphic units (HSUs). By grouping the aquifer's permeable zones into HSUs, redundant and mislocated extraction wells and monitoring wells were eliminated, resulting in estimated cost savings of over $800 thousand in fiscal year 1998 (Figures 10 and 12). This methodology entails:

1 *Evaluating Independent Data Sets*
- hydraulic test results & water levels
- geophysical well logs
- geologic core descriptions
- chemical analyses of soil & ground water
- high-resolution seismic reflection

2 *Defining Hydrostratigraphy*

3 *Generating Informational Displays*
- hydrostratigraphic cross sections
- hydraulic communication maps
- subsurface structure maps
- isopach maps
- potentiometric surface maps
- isoconcentration maps

4 *Developing of a Conceptual Model for 3-D Fate and Transport Simulations*

5 *Applying Results to Site Cleanup*

Overall, 4 lithologic units (not shown below) and 7 hydrostratigraphic units (shown below) have been identified.

This methodology provides information for optimizing the location of extraction wells to:
- maximize contaminant mass removal rates,
- hydraulically control plumes, and
- optimize extraction well locations to target individual VOC plumes

Figure 10. Hydrostratigraphic cross sections at LLNL were constructed using multiple, independent data sets to reduce uncertainty in subsurface correlations. Partitioning the aquifer into HSUs reduces the number of extraction wells required for cleanup and simplifies extraction well and treatment facility networks.

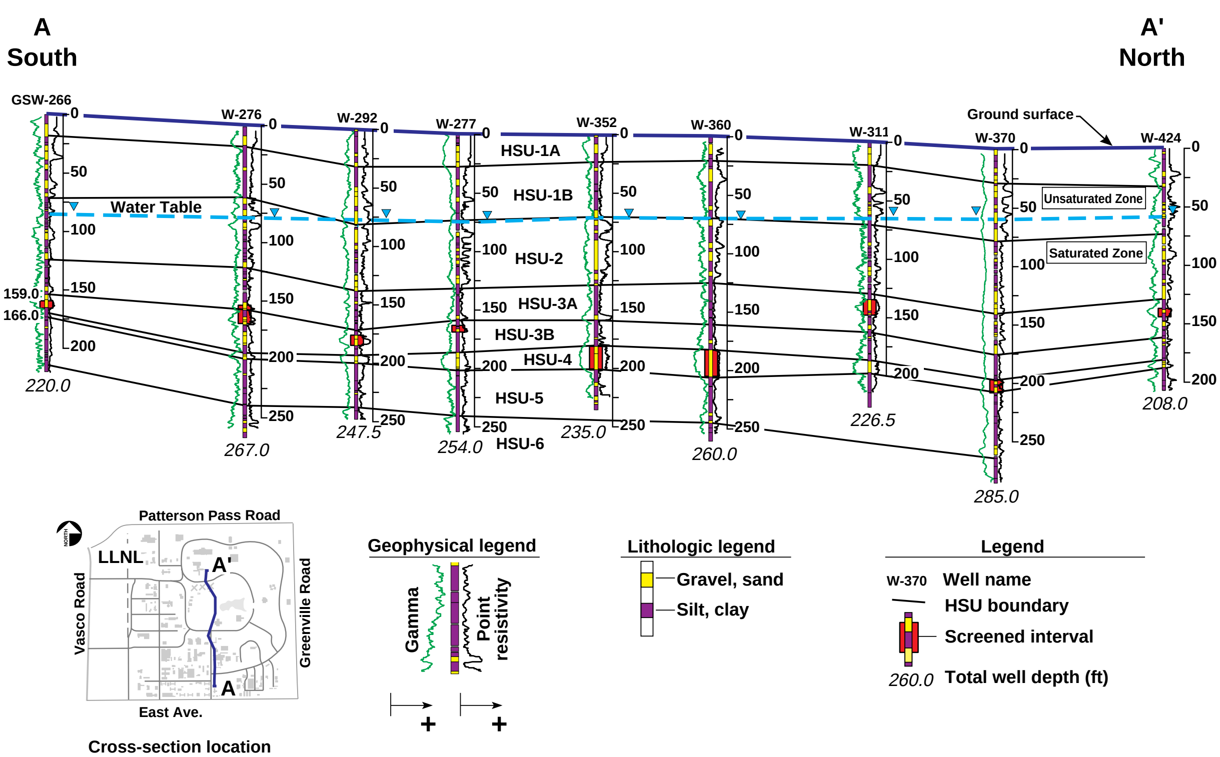


Figure 11. Typical hydrogeologic cross section prepared for the LLNL Remediation Investigation report in 1990. While the cross section accurately portrays the heterogeneity of the subsurface, it does not depict the hydraulic communication between permeable layers containing VOCs beneath the site. Additional characterization was required to implement cost-effective cleanup at the site. Compare with Figure 12.

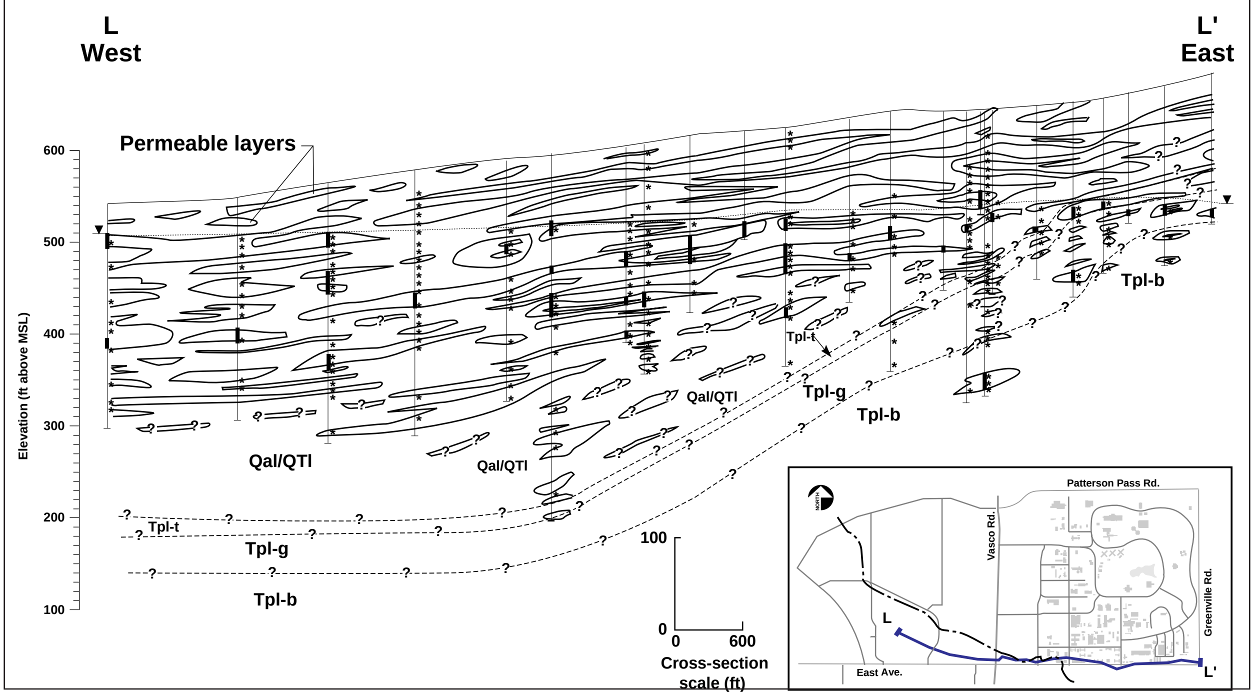
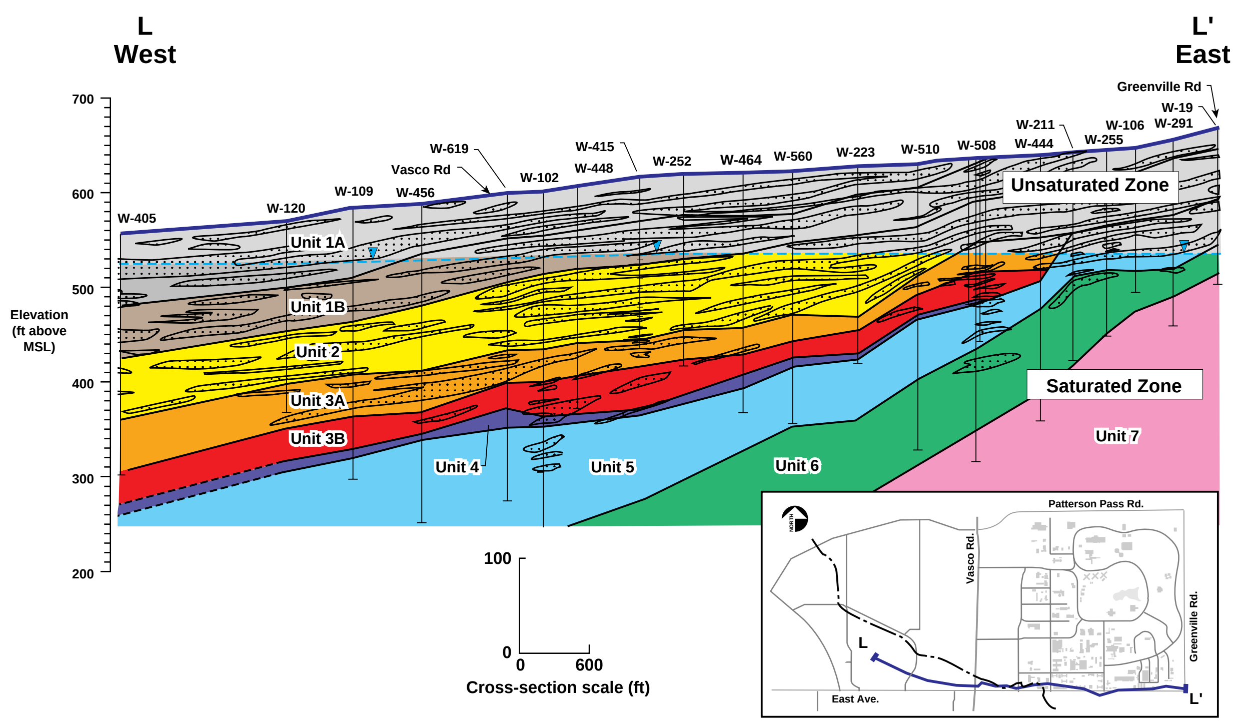


Figure 12. Hydrostratigraphic cross section constructed using the methodology described above. The heterogeneous sequence depicted in Figure 11 has been subdivided into hydrostratigraphic units whose constituent permeable layers are hydraulically interconnected. This eliminates the need to complete extraction wells in each individual permeable unit containing VOCs.



REMEDIATION PERFORMANCE

Remediation History

The LLNL Livermore Site ground water treatment program is currently being implemented. Treatment facilities A,B,C, and D have operated with some of the planned extraction wells since their startup. As the wellfields are completed, hydraulic control and mass removal goals are being realized (Figures 6, 8, 15, and 16). Vapor Treatment Facility 518 (VTF518) began operation in September 1995. Treatment facility performance information gathered to date is presented in the following "Performance" subsections.

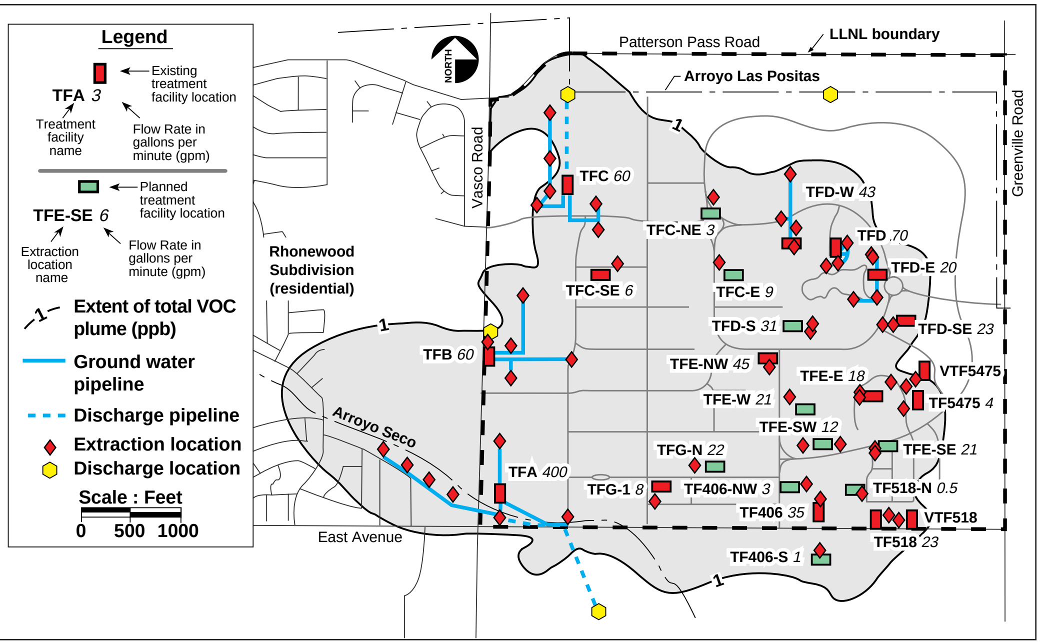
Performance Criteria

The environmental cleanup at the LLNL Livermore Site is designed to satisfy numerous chemical-specific, location-specific and action-specific requirements. The primary goals for cleanup are the Federal and California Maximum Contaminant Levels (MCLs) for drinking water. The MCL for the primary contaminants, PCE and TCE, is 5 ppb. The project is also designed to reduce existing risks by:

- Preventing migration of contaminated ground water to nearby offsite water-supply wells.
- Cleaning up offsite plume components.
- Achieving cleanup goals in minimum time and at minimum cost.

Extraction Well Network & Treatment Facility Locations

Figure 13. LLNL site map showing treatment facilities, extraction locations, and associated pipelines. Portable Treatment Units (PTUs) supplement the treatment facilities and will be deployed as needed.



The extraction well and treatment facility network is a combination of fixed treatment facilities (TFA, TFB, TFC, and TFD) with pipelines to extraction wells, portable treatment units (PTU), mini-PTUs (MTU), granular activated-carbon treatment units (GTU) and solar-powered water activated-carbon treatment units (SWATs) near extraction wells.

Fixed treatment units are used for hydraulic capture of contaminant plumes at the border of the site. Other treatment units are used to remediate areas near sources and can be moved to adapt to changing plume configurations. Treated ground water is discharged to a recharge basin, recharge well or to drainage ditches that empty into a local creek (Arroyo Las Positas). Treated ground water can also be used for irrigation or facility cooling systems.

Existing fixed treatment facilities TFA, TFB, TFC, and TFD are designed to accommodate additional pipelines, if needed. Nine PTUs, one MTU, and one SWAT unit are operating for hydraulic source area control and isolation, and VOC mass removal (Figure 14, and Tables 1 and 2). Additional treatment units will be constructed to control all sources and collapse the plumes. A soil vapor extraction (SVE) system is in place at TF518 and an additional unit is planned for the Trailer 5475 Area. Catalytic Reductive Dehalogenation (CRD) is being used for *in situ* destruction of VOCs by hydrogen and a palladium catalyst without bringing tritium to the surface. The first CRD reactor is being deployed and additional units are planned. The locations of current and planned extraction locations and treatment facilities are shown in Figure 13.

Figure 14. LLNL-designed and constructed Portable Treatment Units (PTUs) allow project managers to cost-effectively modify extraction well and treatment facility networks to target changing VOC plume configurations.

Treatment System Overview

Table 1. Ground water and soil vapor treatment systems in use at the Livermore Site.

Treatment Type	Treatment facility	Primary target contaminants	Startup date	Total design flow rate (gpm)
Fixed Facility Treatment by air stripping followed by ion exchange to remove chromium, if necessary	TFA	PCE, 1,1-DCE	1989	350
	TFB	TCE, CCl_4, PCE	1990	50
	TFC	TCE, Cr, Freon 113, PCE	1993	60
	TFD	TCE, Cr, Ni	1989	350
PTU Treatment by air stripping followed by ion exchange to remove chromium, if necessary	TFC SE	TCE, 1,1-DCE, Cr	1996	6
	TFD W	TCE, CCl_4	1997	21
	TFD E	TCE, PCE, 1,1-DCE, 1,2-DCA	1997	19
	TFD SE	TCE, PCE, 1,1-DCE, CCl_4	1998	23
	TFE E	TCE, PCE, 1,1-DCE	1996	18
	TFE NW	TCE, PCE, 1,1-DCE	1998	45
	TF 406	TCE, CCl_4, PCE, 1,1-DCE	1996	27
	TFG -1	TCE, PCE, 1,1-DCE, CCl_4	1996	8
MTU Treatment by air stripping followed by ion exchange to remove chromium, if necessary	TF 518	TCE, PCE, 1,1-DCE, CCl_4	1998	23
SWAT Treatment by granular activated carbon	SWAT -1	TCE, PCE, 1,1-DCE, 1,2-DCA	1997	5
Soil Vapor Extraction Soil vapor extraction with treatment by granular activated carbon	VTF 518	TCE, PCE, 1,1-DCE	1995	30 CFM

Legend

Treatment facility → TFA	← Primary target contaminants: PCE, 1,1-DCE
Startup date → 1989	← Total design flow rate (gpm): 350

Adaptive Pump and Treat

The development of portable pump and treat systems has allowed for the implementation of an adaptive pump and treat strategy for the Livermore Site. Without PTUs, MTUs, and SWATs, cost-effective EPC cleanup of the site would not be possible. These portable pump and treat systems can be easily re-deployed to new locations, ensuring continued optimal mass removal (Table 3) and hydraulic control as VOC plume configurations change over time.

Treatment Performance

Table 2. Current treatment facility influent concentrations at the Livermore Site.

Treatment Facility Design Concentrations

	Average influent concentration (ppb)													Treated effluent discharge limits (ppb)	
	TFA	TFB	TFC	TFD	TFC SE	TFD W	TFD E	TFD SE	TFE E	TFE NW	TFG-1	TF406	TF518	NPDES	LWRP
TCE	7	300	20	875	82	117	368	357	325	122	38	41	90	–	–
PCE	280	40	5	28	–	–	39	189	80	7	13	2	10	4	–
1,1-DCE	12	10	2	11	31	–	27	30	49	9	11	2	7	–	–
1,2-DCE (total)	4	3	–	1	–	–	–	–	–	–	–	–	–	–	–
1,1,1-TCA	5	1	–	–	–	–	–	–	–	–	3	–	–	–	–
1,1-DCA	5	5	–	1	–	–	2	2	–	–	–	–	–	–	–
1,2-DCA	–	1	–	20	–	–	11	4	1	1	–	–	–	–	–
Chloroform	10	10	3	1	2	1	4	13	6	2	15	–	1	–	–
CCl4	–	2	–	148	–	4	8	2	1	2	7	3	5	–	–
Freon 113	5	10	100	–	59	–	1	7	37	1	7	5	38	–	–
Freon 11	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–
Total VOCs	328	382	130	1,110	174	123	459	604	499	143	99	53	150	5	1,000
Cr6+	–	20	30	11	35	12	11	12	11	15	21	22	10	-/22	–
Total Cr	–	20	30	11	35	12	11	12	11	15	21	22	10	50/-	620

NOTE: "-" = not part of design basis; negligible anticipated influent
NPDES = National Pollutant Discharge Elimination System permit. Metals limits vary by season; values are dry season (4/1-11/30) / wet season (12/1-3/31)
LWRP = Livermore Water Reclamation Plant permit

Operational/Treatment Performance

Effects on Plume

Current agreements specify that all treatment facilities will be operated until *in situ* ground water VOC concentrations are below MCLs for 2 years. Final closure is discussed in the Compliance Monitoring Plan.

Influent Contaminant Concentrations vs Time

At TFA, influent PCE concentrations have been reduced from about 900 ppb to <50 ppb since startup in 1989.

Table 3. Influent Contaminant Mass Removal.

Information on the total volume of VOCs removed by each treatment facility is being continuously collected and updated. From start of operation through May 1998, mass removal has been:

Treatment Facility	VOC mass removed (kg)	Extracted ground water (Mgal)	Average extraction rate (gpm)
TFA	98.2	421	200
TFB	28.0	73	50
TFC	18.8	45	22
TFD	100.8	83	8
TFE	22.42	13.5	18
**TFF	*10,200	1.6	50
TFG	1.0	5.6	8
TF406	1.9	6.8	32
TF518	0.7	1.8	20
TF5475	0.2	0.2	1

* Gallons of liquid equivalent gasoline
** Facility closed in 1996

Figure 15. Cumulative mass removal of VOCs at TFA over time. Since 1992, TFA has consistently treated VOCs in ground water at a higher rate than that predicted by 2-D modeling.

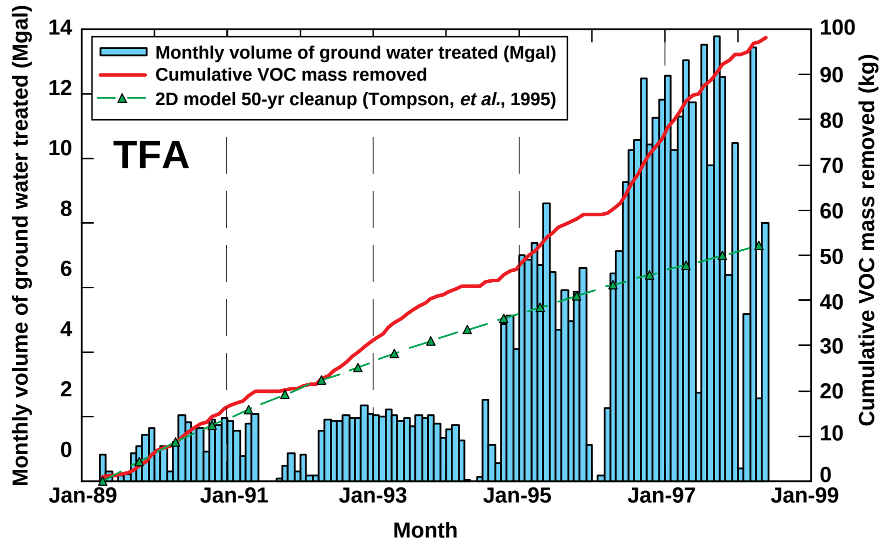
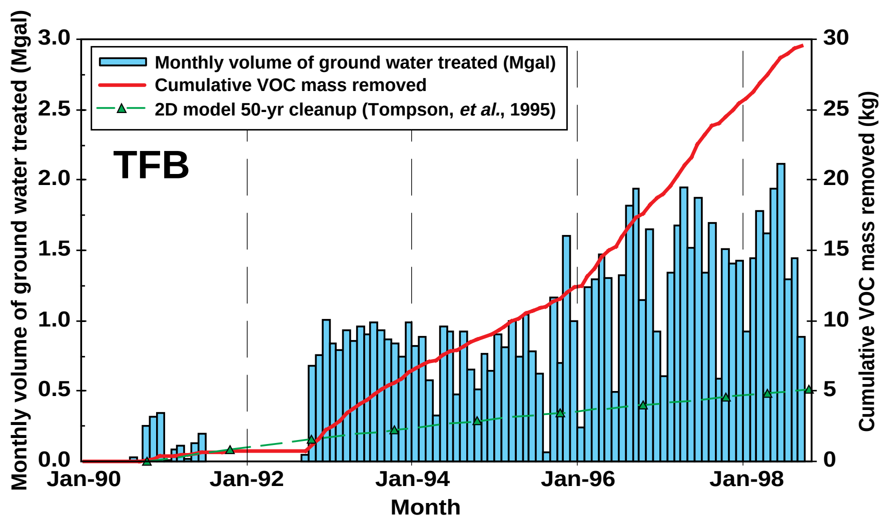


Figure 16. Cumulative removal of VOCs at TFB over time. Since June 1994, TFB has also treated VOCs in ground water at a significantly higher rate than that predicted by 2-D modeling.



TFA and TFB have now established hydraulic control over most of the western offsite portion of the VOC plumes (Figures 6-9). Modeling efforts anticipate the creation of complete hydraulic capture when all treatment facilities are fully operational.

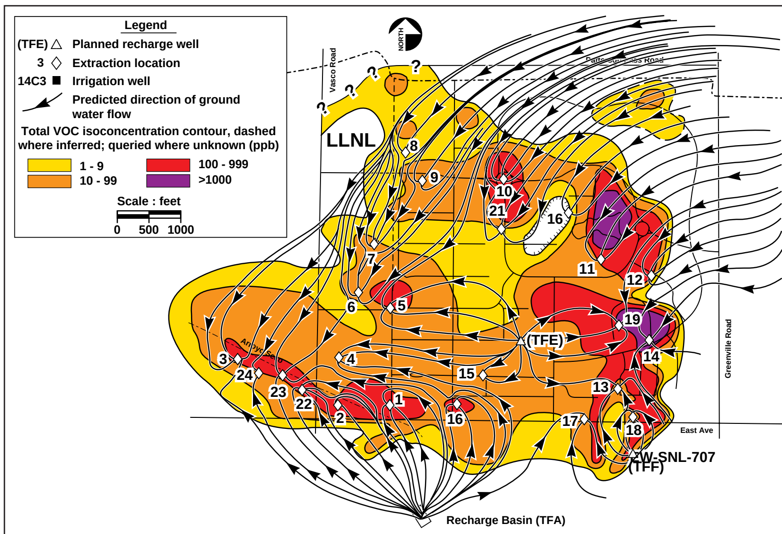


Figure 17. Map showing predicted hydraulic capture zones and recharge well locations for the 24 initial extraction locations specified in the Record of Decision using 2-D modeling.

COST

Operating and Capital Costs

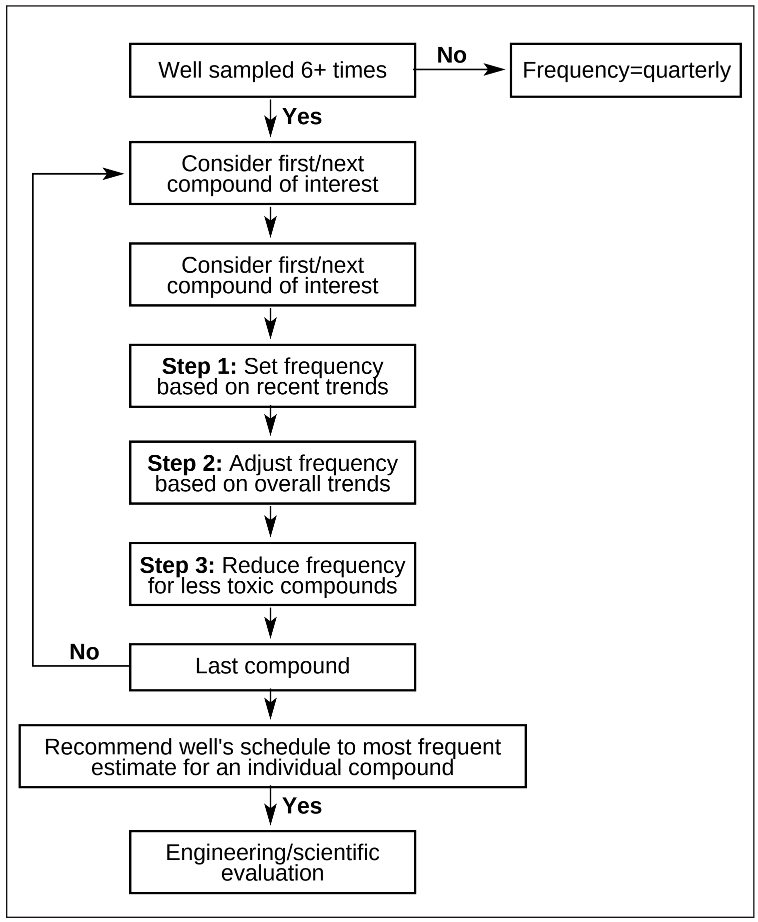
Facility	Capital (K$)*	Operating (K$/yr)
TFA	896	500
TFB	446	400
TFC	1,628**	450
TFD	1,589**	470
PTU	250	250

* Capital costs do not include well installation or all pipelines
** Includes ion exchange unit for metals

Cost-Effective Sampling

- Cost-Effective Sampling (CES) is a new method developed at LLNL for estimating the lowest frequency sampling of monitor wells for remediation and compliance-related decision making.
- Statistical analysis provides trends and outliers observed in the sampling. These data yield essential compliance information with fewer samples. CES is also being used at the Savannah River Site and is under consideration by other DOE sites.
- CES has resulted in a 40% reduction in the number of samples taken for analysis for VOCs from monitor wells at the Livermore Site.

CES views the need for sampling in terms of the rate at which change is occurring in the measured concentrations of contaminant in an individual well, tempered by the degree of uncertainty associated with the change. Rates of change are translated into broad scheduling categories: quarterly, semiannual, annual, and biannual. Variability is combined with rate of change information to adjust the frequency to the appropriate rate. CES was implemented at LLNL in 1992 and subsequently approved by local regulatory agencies. Annual cost savings due to CES over that last five years are estimated to be about $400 thousand.



The CES program is a statistical analysis tool. As with any data analysis tool, CES relies on the quick and accurate retrieval of good quality data. CES retrieves data from the data base maintained by the ERD Information Systems Management Group (ISMG).

INFORMATION SYSTEMS MANAGEMENT

The Information Systems Management Group (ISMG) of the Environmental Restoration Division at LLNL provides integrated sample and data management services that support planning, collection, tracking, verification, validation, reporting, interpretation and use of data produced in characterization, remediation, self-monitoring, and surveillance monitoring (Tables 4 and 5). This system has been in use at LLNL since 1986.

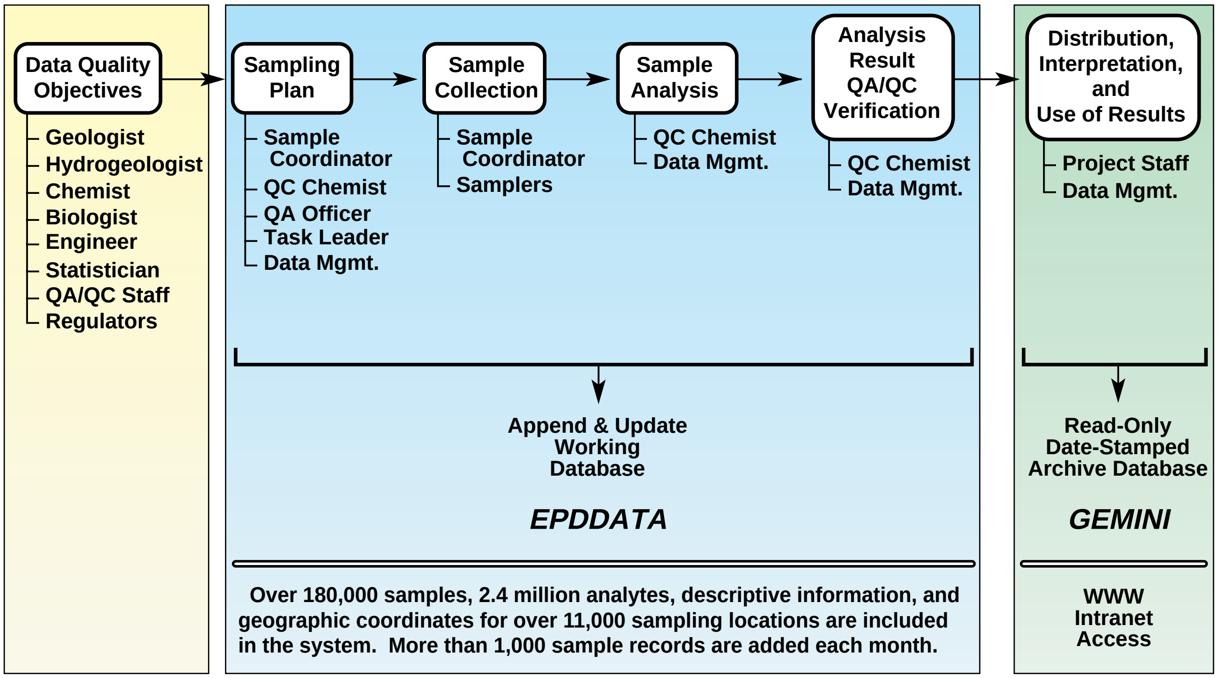
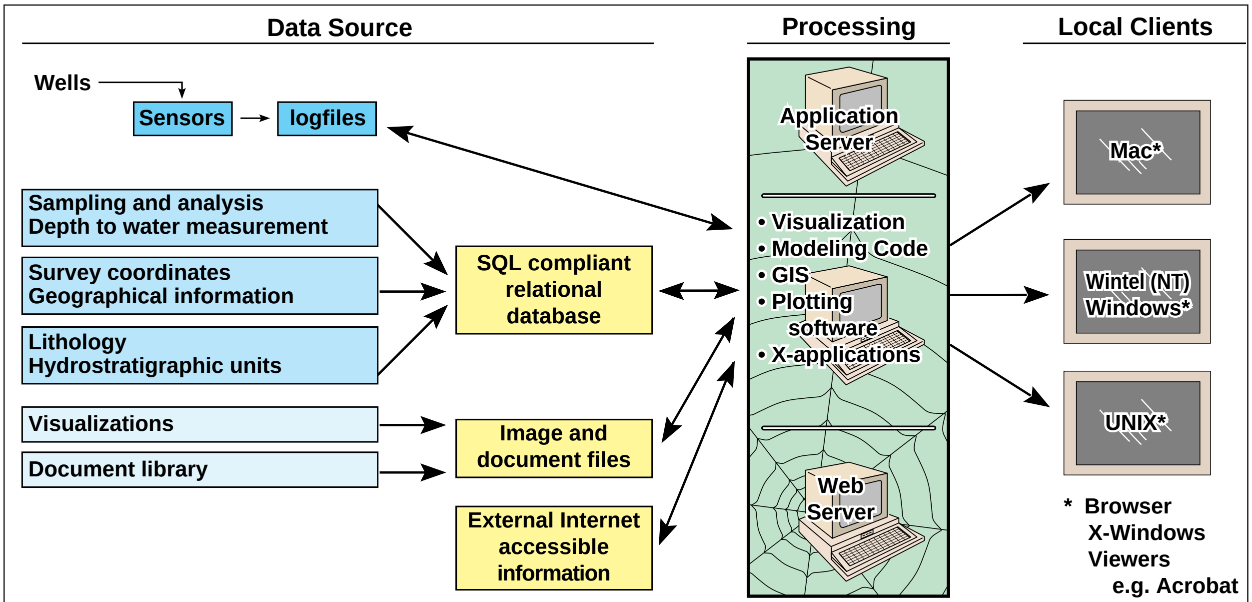


Table 4. Flow chart of ISMG data management at the Livermore Site.

The ISMG software tools are linked to the World Wide Web database access, have decreased labor-intensive overhead in the site study, and have increased the efficiency of the Ground Water Project.



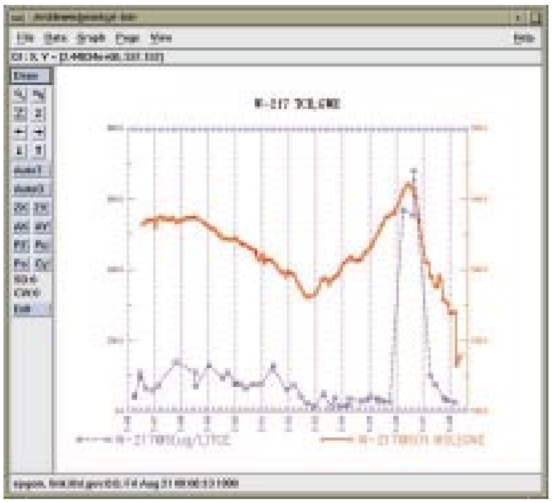
Rapid data access tools have been developed to assist project staff, DOE, and regulators. Tools and data are served via a controlled access intranet.

Table 5. ISMG data management allows for rapid client access to Livermore Site data.

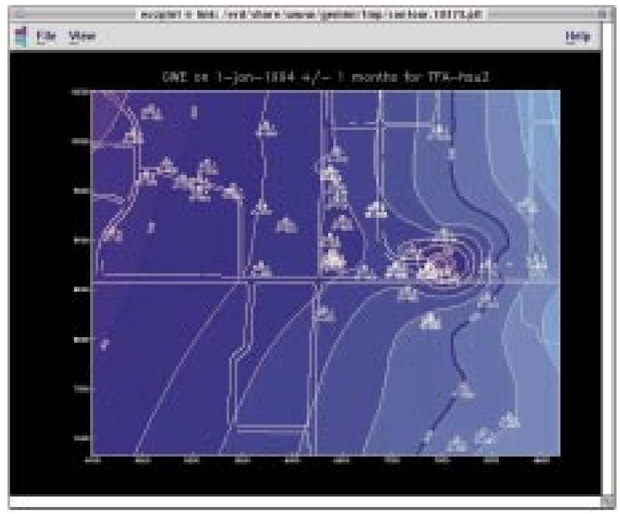
ERD and the World-Wide-Web

ERD has developed innovative new uses of the emerging world-wide-web (WWW) technology. In addition to the traditional use of providing access to static documents, reports, images, and product and technology overviews, our webserver also provides division personnel and DOE with dynamic access to project status by allowing form-based statistical processing, database access, and cost-estimating tools. Tools and data are served via a controlled access intranet. These new capabilities have demonstrated estimated cost savings on the order of $500 thousand per year, and for the first time, have made the enormous amount of collected data available to scientists on their desk top in a timely fashion and in a form immediately useful for analysis and interpretation.

Examples of data display generated with ERD Web tools.

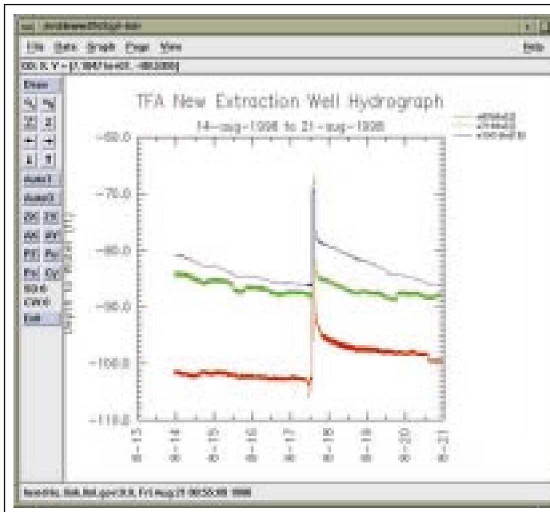


TCE and ground water elevation plot.



Ground water elevation contour map.

Real-time treatment facility status.



Extraction well hydrograph.

Ground Water and Vadose Zone Modeling

Modeling contaminant transport fulfills several project needs to:
- Estimate future VOC concentrations and risk to human health and the environment.
- Optimize remediation design to save time and money.
- Provide insight to understanding the complex contaminant hydrogeology.
- Evaluate methods to mitigate the impact of source areas to plume growth.
- Evaluate the effectiveness of innovative cleanup technologies at specific sites.

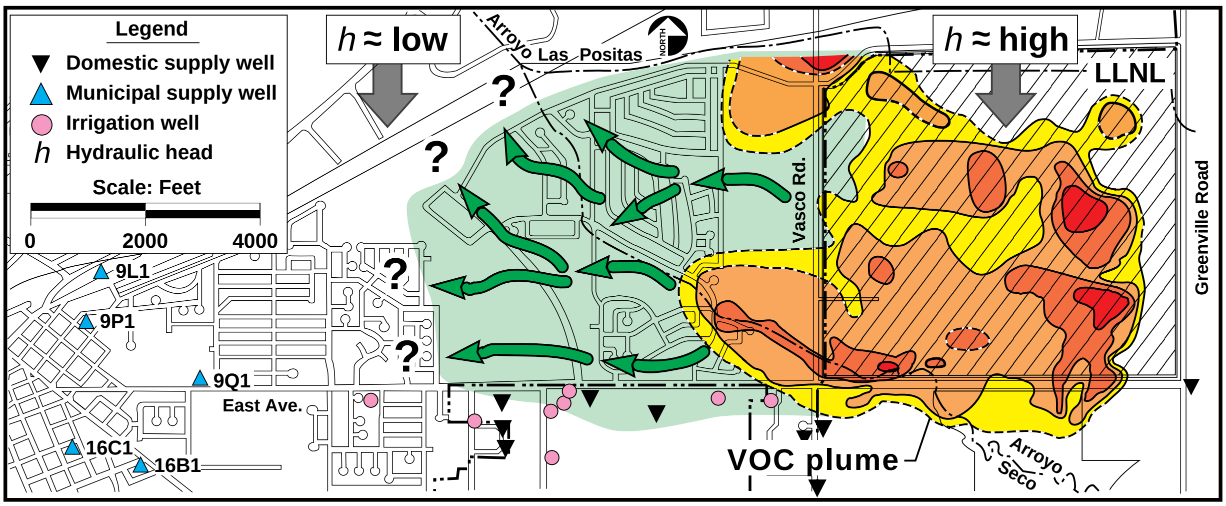


Figure 18. Contaminants migrate to high-risk receptors at uncertain rates and along unknown pathways.

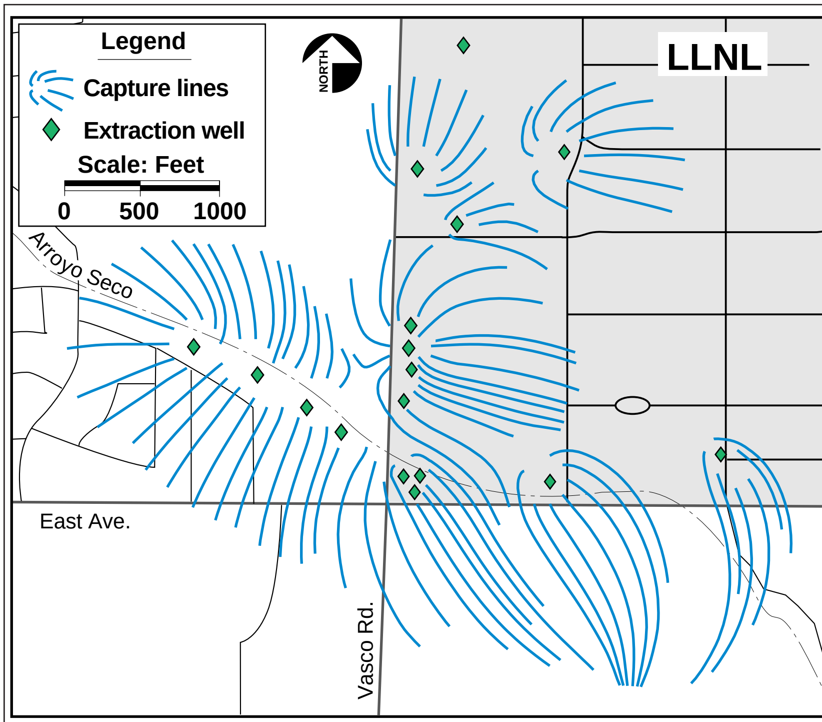


Figure 19. The complex flow paths of large wellfields are evaluated using models to simulate the capture zones of each extraction well. As new pumping wells are added, they alter the capture zones for the entire remediation system. Wellfield management is required to optimize the system efficiency. Models are used to manage remediation wellfields by:
- Capture zone analysis.
- Evaluating remediation alternatives before implementation.
- Providing wellfield design and planning recommendations.
- Incorporating local ground water resource agency plans into our remediation strategy.

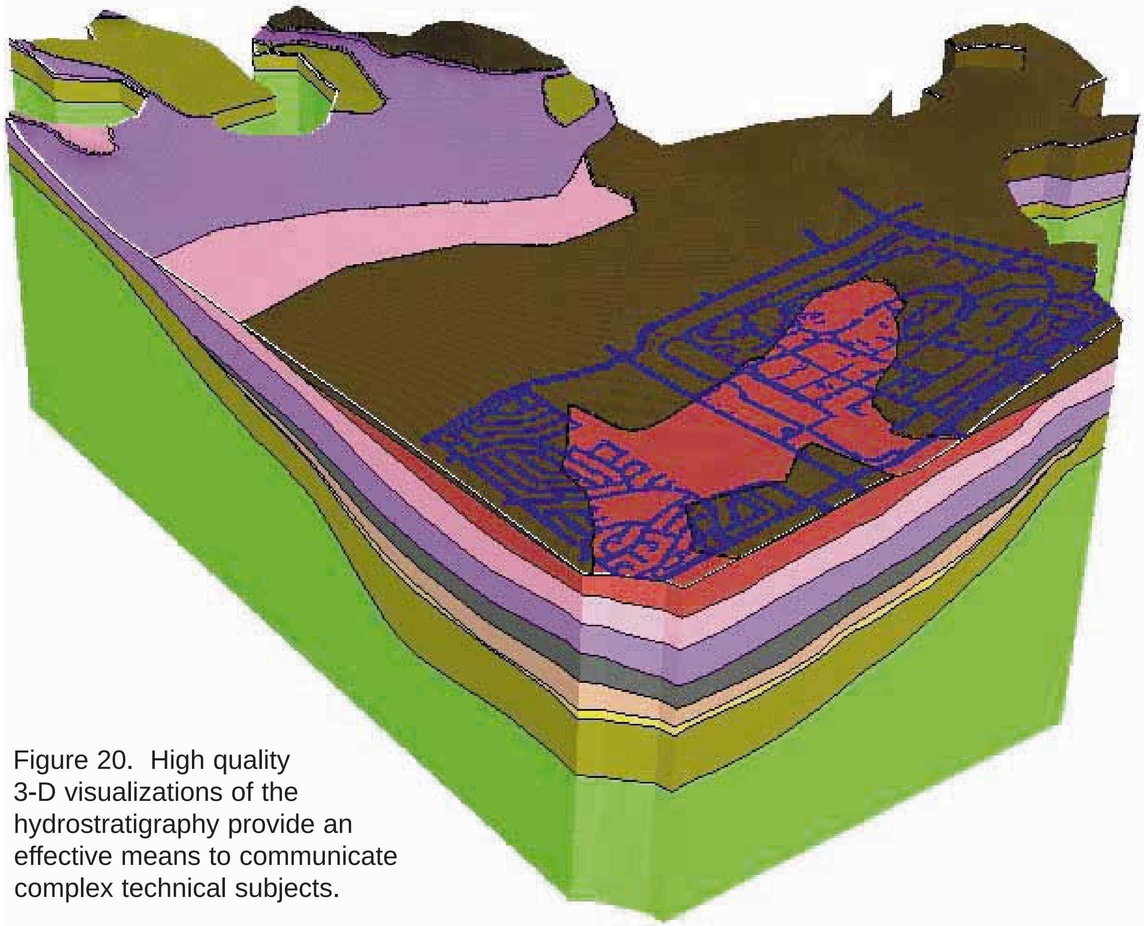


Figure 20. High quality 3-D visualizations of the hydrostratigraphy provide an effective means to communicate complex technical subjects.

The use of sophisticated three-dimensional visualization software such as Earthvision™ allows hydrogeologists to increase their understanding of contaminant distribution and potential migration pathways. Once constructed, these "models" can be directly input into highly detailed, predictive, numerical fate and transport models to aid in the placement of extraction and monitor wells.

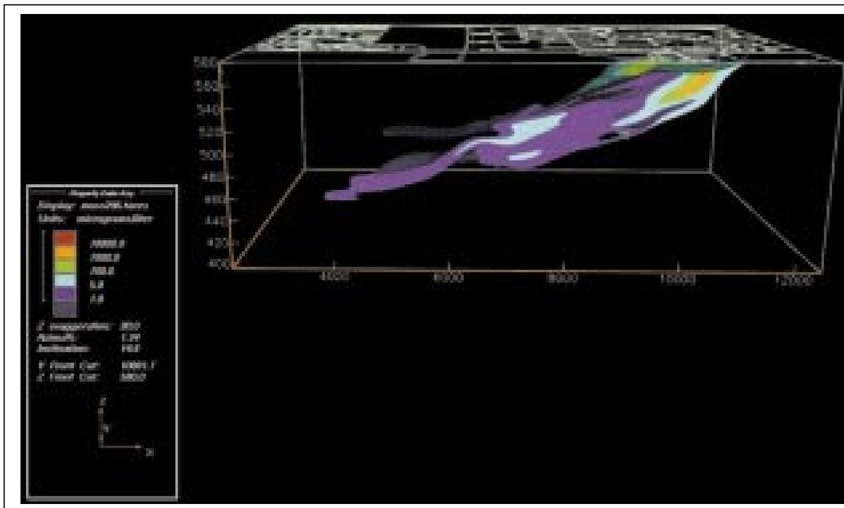


Figure 21. The first step in the Phased Source-Area Remediation strategy to cleanup source areas is to understand the impact of the geologic heterogeneity on contaminant distribution. The 3-D visualization of plumes provide insight into the distribution of complex plumes and their relationship to source areas. These data can then be input into detailed numerical models to evaluate remediation in source areas.

The time to ultimate site cleanup is largely controlled by the rate that VOCs in fine-grained sediments diffuse into more permeable sediments in the source areas. The proper application of certain innovative technologies to address this issue would significantly decrease the time of cleanup. Modeling is a cost-effective means to evaluate and design these expensive innovative technologies prior to implementation to decrease cost and improve their effectiveness.

REGULATORY/INSTITUTIONAL ISSUES

• All treatment facilities comply with the Bay Area Air Quality Management District standards for VOC emissions. Ground water discharges to the storm sewer are controlled by substantive requirements of a former National Pollutant Discharge Elimination System (NPDES) permit. Ground water discharges to the LLNL Recharge Basin (currently from TFA) are controlled by the San Francisco Bay Regional Water Quality Control Board (RWQCB) Waste Discharge Order Requirements.

• An active and ongoing public involvement program conducted through the Livermore Valley Community Work Group (CWG), and through an EPA technical assistance grant, has served to coordinate discussions and commentary from the interested local population.

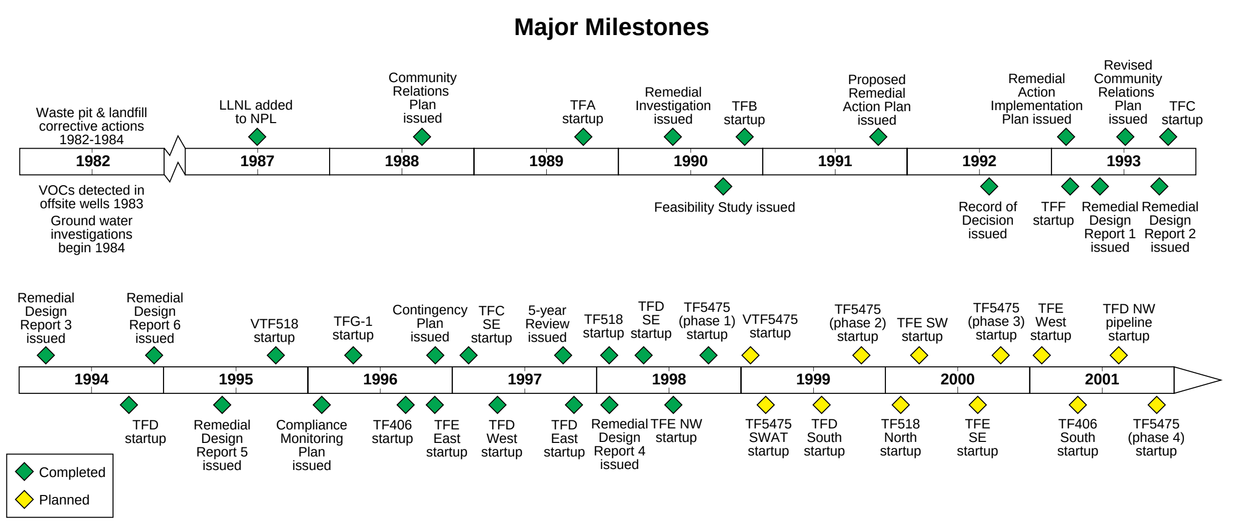
• An extensive and detailed quantitative risk assessment involving contaminant fate and transport modeling was completed for the Livermore Site. The "best estimate" of noncarcinogenic risk produced a Hazard Index (HI) of 1.6E-3 indicating little potential for chronic health effects. However, an EPA health conservative (worst case) risk assessment method produced cancer risks as high as 1E-3 and HIs equalling 1, which exceeds EPA's acceptable cancer risk range at Superfund sites of 1E-4 to 1E-6 and indicates the potential for chronic health effects. The best estimate of the maximum incremental risk of developing cancer was 2E-7 from a lifetime exposure to VOCs in downtown Livermore well water. No members of the public are currently exposed to VOCs from the use of water-supply wells near LLNL.

• Successful interactions with regulatory agencies include: (1) renegotiated project milestones for efficiency and cost effectiveness, (2) negotiated reduced reporting requirements, (3) negotiated approval to install downgradient extraction systems to ensure hydraulic control of offsite plumes, (4) modified the Record of Decision based on regulatory acceptance of three Explanations of Significant Differences, (5) received regulatory decisions of closure and No Further Action for fuel hydrocarbons in the vadose zone and saturated zone, respectively, at TFF, and (6) received approval of an emergency removal action for removal and disposal of capacitors and soil containing polychlorinated biphenyls.

Cleanup Criteria

Currently, treatment systems will be operated until ground water concentrations of target contaminants are below MCLs for two years. Site monitoring, reporting, and closure were described in the Compliance Monitoring Plan and contingencies were discussed in the Contingency Plan.

SCHEDULE



Chronology of events in the LLNL Livermore Site environmental cleanup.

Accomplishments

- The LLNL ground water remediation systems are effectively capturing and remediating the western margin offsite plumes and are beginning to clean up ground water VOC plumes within the interior of the site.
- Advanced characterization methods using hydrostratigraphic analysis are optimizing placement of extraction wells to maximize contaminant mass removal rates and providing hydraulic control of plumes. The methodology provides short-term cost savings by reducing the number of required wells, and long-term savings by decreasing the time to site closure.
- Renegotiation of CERCLA milestones with State and Federal regulators has reduced costs and enhanced cleanup. Additional cost savings are being realized as planned fixed treatment facilities are replaced by portable treatment units.
- LLNL-designed and constructed treatment facilities are successfully treating VOCs in ground water by air stripping and metals by ion exchange. VOCs mixed with tritium are treated *in situ* by catalytic reductive dehalogenation.
- The LLNL-designed integrated data and information management system allows for quick access to characterization and remediation information needed for cost-effective decision support.
- Cost-effective sampling techniques developed at LLNL have resulted in a 40% reduction in the number of ground water samples collected from monitor wells for VOC analysis.
- Effective use of the World Wide Web is allowing for rapid access and analysis of data to evaluate hydraulic capture, contaminant trends, data validation, and facility performance. This allows critical remediation decisions to be made in minutes rather than weeks.

Lessons Learned

- The HSU characterization methodology has allowed LLNL to develop a site-wide working hydrogeologic model necessary for targeting specific contaminant plumes and leading to accelerated VOC mass removal and optimization of the cleanup.
- Advanced 3-D ground water and vadose zone fate and transport modeling techniques developed at LLNL allow for in-depth analysis and optimization of various regulatory cleanup objectives and remediation alternatives.
- Carefully planned, phased implementation of treatment facilities using HSU analysis and modeling has allowed the project to optimize remediation actions and meet cleanup objectives.
- Integration of hydrogeologic modeling with engineering design was essential for implementing the LLNL Livermore Site cleanup plan in a cost-effective manner.
- Conducting pilot-scale and field demonstrations proved useful in the design and construction of effective treatment systems.
- The deployment of portable treatment units allows project managers to adapt to changes in ground water and vadose zone conditions due to ongoing plume migration and/or changes in contaminant concentrations. This results in lower costs than are required for a fixed treatment system.
- The Livermore Valley Community Work Group and technical assistance grant maintains a high level of community and regulatory communication and understanding of project goals and objectives. LLNL personnel share all data and discuss work-in-progress with regulators and the community during regularly scheduled meetings as well as at seminars and workshops convened on an as-needed basis. This approach has secured early concurrence from the regulatory agencies and the public during ongoing technology-related decision making.
- Ground water extraction and treatment continues to be effective at the Livermore Site due to Engineered Plume Collapse, which incorporates “smart pump-and-treat”, HSU analysis, PTU technology, and active wellfield management to achieve plume capture and retraction, and to maximize contaminant mass removal.
- Low hydraulic conductivity fine-grained materials tend to adsorb contaminants onto clay and silt particles. These fine-grained materials serve as a long-term source of contaminants to ground water in coarse-grained materials. If the contaminants in these source areas are not removed, the distal parts of plumes will continue to grow and a cost-effective remediation will not be achieved.
- Developing or evaluating new technologies is important for achieving the cleanup goals at the site. Technologies such as electro-osmosis, and vapor extraction can enhance VOC removal from fine-grained material at the source areas and expedite cleanup. Technologies such as catalytic reductive dehalogenation will allow treatment of VOCs *in situ* in areas that also contain tritium, which will minimize the amount of ground water brought aboveground, and thus meet a strong community and regulatory desire.
- Although ultraviolet UV oxidation destroys VOCs, UV oxidation technology drawbacks include: less effective destruction of single carbon-to-carbon bonds, safety hazards associated with handling of hydrogen peroxide, and the electrical power costs required to operate the system.
- Undocumented landfills and buried hazardous waste may be encountered during excavation and drilling operations. However, with a properly trained staff of environmental scientists available, removal of the undocumented waste can be performed quickly and safely without a threat to human health or the environment.
- Re-evaluation of NPDES sampling frequency and discharge limits resulted in cost reduction while remaining protective of the environment.

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Environmental Restoration Division monitor well installation at the LLNL Livermore Site.