Cost and Performance Report

General Services Area Operable Unit

Lawrence Livermore National Laboratory Site 300

September 1997

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U.S. DEPARTMENT OF ENERGY

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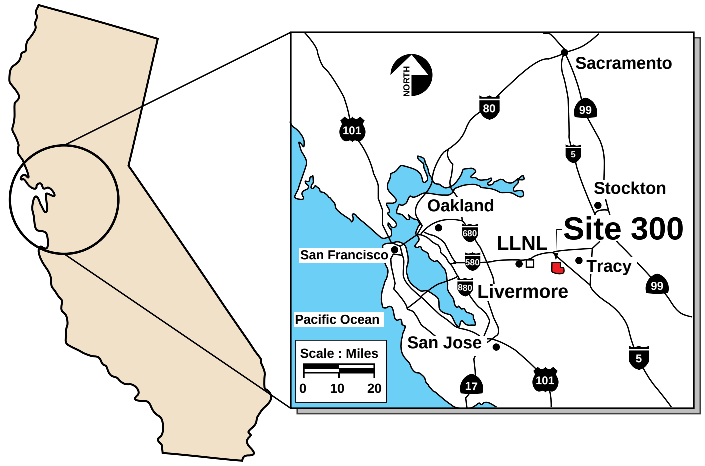
1. SUMMARY

This report summarizes cost and performance data for ground water and soil vapor extraction and treatment at the General Services Area (GSA) Operable Unit (OU) at Lawrence Livermore National Laboratory (LLNL) Site 300. Solvents containing volatile organic compounds (VOCs), primarily trichloroethene (TCE), were released to the ground as a result of past activities in the craft shops and equipment fabrication and repair facilities.

Remediation began in 1991 as a removal action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). A Record of Decision (ROD) is in place (DOE, 1997), and the cleanup has moved into the remedial action phase. The ROD specifies Maximum Contaminant Levels (MCLs) as the ground water cleanup standards.

DOE/LLNL is currently operating two ground water extraction (GWE) wellfields and one soil vapor extraction (SVE) system. A total of 93 million gallons of ground water have been extracted and treated using air stripping or granular activated carbon (GAC). Approximately 40.4 kilograms of VOCs have been removed from the subsurface as of July 1997, most of which was TCE. In the eastern GSA, the primary objective of ground water extraction is to control migration of the contaminant plume. The length of the offsite TCE plume exceeding MCLs has been reduced from 4,500 to 200 feet, and the maximum ground water TCE concentration is now below 13 µg/L. At the central GSA, where the objective of the removal action is source control, maximum TCE concentration in ground water has been reduced from 240,000 µg/L to 10,000 µg/L. TCE concentration in extracted soil vapor has dropped from over 1,000 $ppm_{v/v}$ to 2 $ppm_{v/v}$. Future remedial actions will expand the extraction well field.

The total actual and projected costs for investigation and remediation in the GSA OU are estimated at $38.6M. Modeling predicts that to meet cleanup standards soil vapor extraction will need to continue for 10 years, and ground water extraction for 55 years.



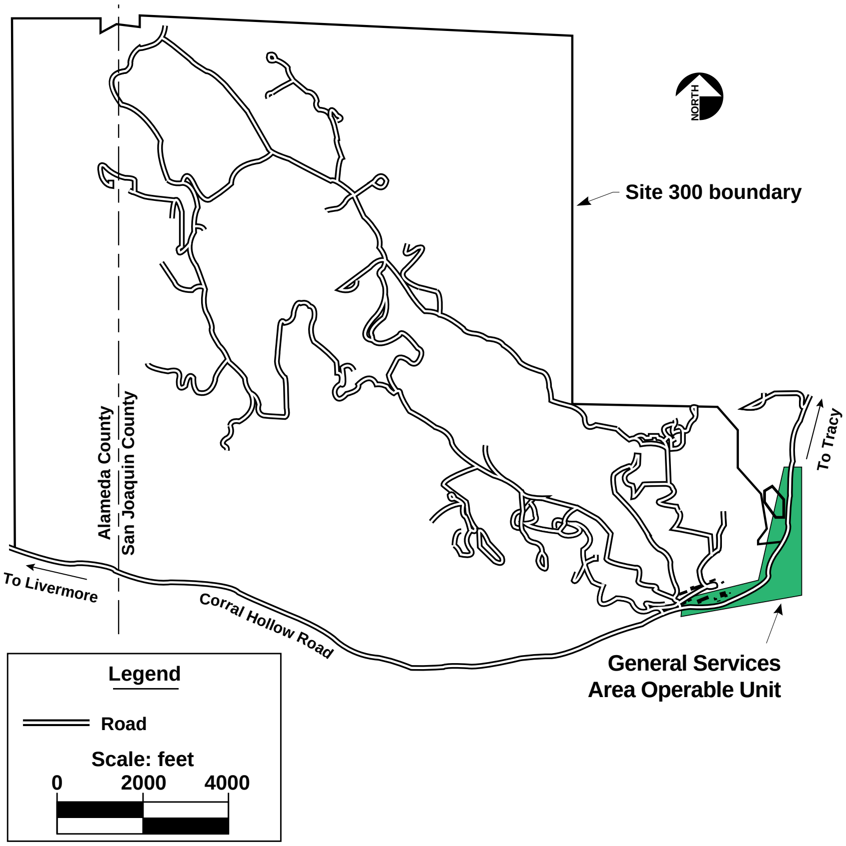
Location of LLNL Site 300.

Central GSA extraction wells.

2. SITE INFORMATION

Identifying Information

- Facility: Lawrence Livermore National Laboratory, Site 300.
- Operable Unit: General Services Area (OU 1).
- Regulatory Drivers: CERCLA, Record of Decision, Site 300 Federal Facility Agreement.
- Type of Action: Ground water and soil vapor extraction and treatment.
- Period of Operation: Ongoing since June 1991.



Location of the General Services Area Operable Unit at Site 300.

Prior to the ROD, DOE/LLNL used CERCLA removal actions to remediate VOCs in the subsurface through ground water and soil vapor extraction. Due to the success of these removal actions, the remedial action will continue this strategy and expand the extraction wellfield to 1) capture more contaminated ground water, 2) address additional source areas, and 3) shorten cleanup time.

Central GSA soil vapor extraction manifold.

Technology Application (cont.)

Remediation technology application in the GSA OU (July 1997).

Treatment system	Startup date (length of operation)	Volume of media treated	Mass of VOCs removed
Eastern GSA ground water	1991 (6 yrs)	93,000,000 gal of ground water	5.1 kg
Central GSA ground water	1993 (4 yrs)	787,000 gal of ground water	4.8 kg
Central GSA soil vapor	1994 (3 yrs)	399,000 cubic feet of soil vapor	30.5 kg
Total			**40.4 kg**

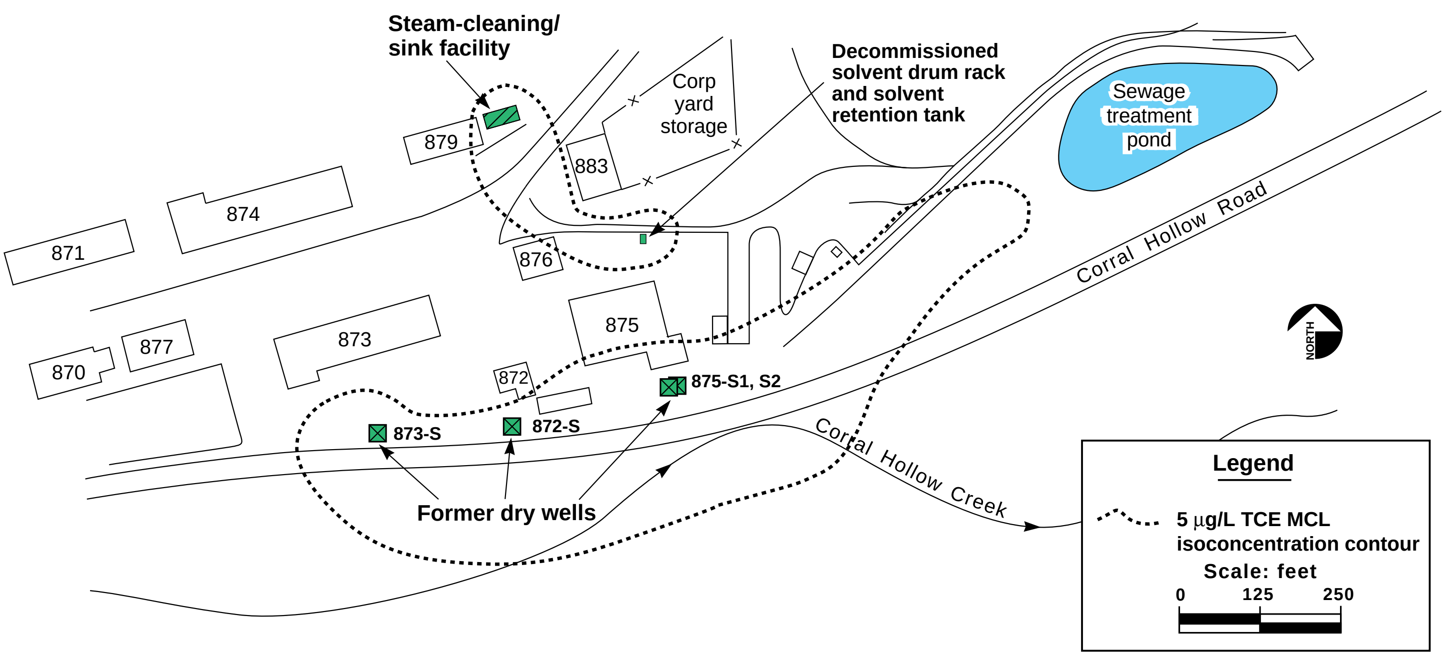
In the eastern GSA, craft shop debris containing TCE was buried in shallow trenches. Test pits were excavated and trace concentrations of VOCs found in soil and bedrock.

Solvents containing VOCs were commonly used in the central GSA craft shops as a degreasing agent. Rinse water from these operations were disposed in dry wells. The dry wells at the GSA typically were gravel-filled excavations about 3 to 4 feet deep and 2 feet across. Piping from floor drains in the shops led to the dry wells. All dry wells have been excavated.

Environmental investigations began in 1982. Almost 100 ground water monitor wells have been installed. Other site characterization methods include soil sampling, soil vapor surveys, hydraulic testing, colloidal borescope investigations, and geophysical surveys. These investigations identified six release sites, but central GSA dry wells 875-S1 and 875-S2 and the eastern GSA debris burial trench are the primary contributors to subsurface contamination.

Documents prepared for the GSA OU include the Site-Wide Remedial Investigation report (Webster-Scholten, 1994), a Feasibility Study (Rueth and Berry, 1995), a Proposed Plan (DOE, 1996), a Record of Decision (DOE, 1997), and a draft Remedial Design report (Rueth et al., 1997).

All releases in the GSA OU fall under SIC code 9631A.



Contaminant release sites in the central GSA.

Site Background and History (cont.)

Contaminant releases in the GSA.

Contaminant release site	Mechanism
Dry wells 875-S1 and 875-S2	Rinse water containing solvents from a parts dipping tank and steam - cleaning/equipment washdown area in Building 875 was disposed during the 1960s and 1970s.
Dry well 872-S	Rinse water containing solvents from a cascade water spray area and equipment rinse down area in Building 872 was discharged during the 1960s and 1970s.
Dry well 873-S	Rinse water containing solvents from a paintbrush cleaning pad in Building 873 was discharged during the 1970s.
Decommissioned solvent drum rack and underground solvent retention tank	Solvent spills from a drum rack and tank occurred during 1970s and 1980s.
Building 879 steam-cleaning/sink facility	Waste water containing oil and grease and minor amounts of solvents was discharged to unlined drainage ditch during 1960s and 1970s.
Debris burial trenches	Craft shop debris contaminated with solvents was disposed in shallow trenches during the 1960s.

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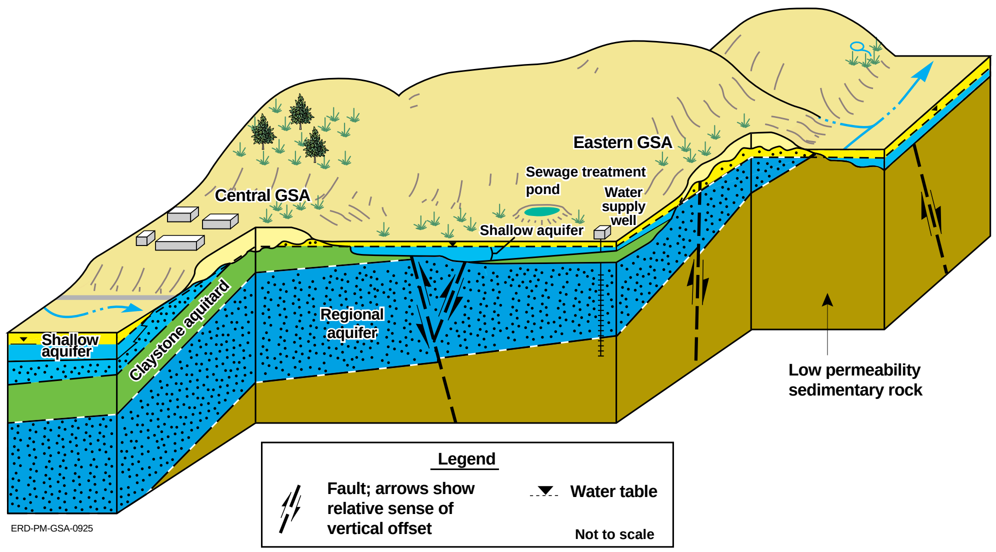
3. MATRIX AND CONTAMINANT DESCRIPTION

VOC-contaminated ground water and soil vapor are extracted from the subsurface and treated by the GSA remediation systems. VOCs have been detected in the vicinity of the dry wells 875-S1 and 875-S2 at concentrations indicative of Dense Non-Aqueous Phase Liquids (DNAPLs). High concentrations of VOCs have also been detected in soil vapor samples collected from the vicinity of these dry wells.

Hydrogeology

Eastern GSA: Depth to ground water is approximately 10 to 15 feet. Ground water flow in the alluvial valley fill (Qal) and shallow bedrock is eastward, turning north to follow the trend of the valley. Ground water flow velocity is estimated to be about 0.5 to 3 feet per day. This shallow aquifer is in hydraulic communication with the deeper regional aquifer ($Tnbs_1$).

Central GSA: Depth to water is approximately 10 to 20 feet. Ground water flow is south-southeast with an estimated flow velocity of 0.05 to 0.10 feet per day. The shallow aquifer occurs in terrace alluvium (Qt) and underlying fractured sandstone ($Tnbs_2$). Ground water in this aquifer is hydraulically isolated from the $Tnbs_1$ regional aquifer by a 60- to 80-foot-thick aquitard ($Tnsc_1$) in most of the central GSA. The shallow aquifer is also referred to as the Qt-$Tnsc_1$ hydrogeologic unit. The regional aquifer is encountered 35 to 145 feet below ground surface under confined to semi-confined conditions. Ground water flow in the regional aquifer is south-southeast at a velocity of 0.3 feet per day.



Conceptual hydrogeologic model of the GSA Operable Unit.

Contaminant physical properties.

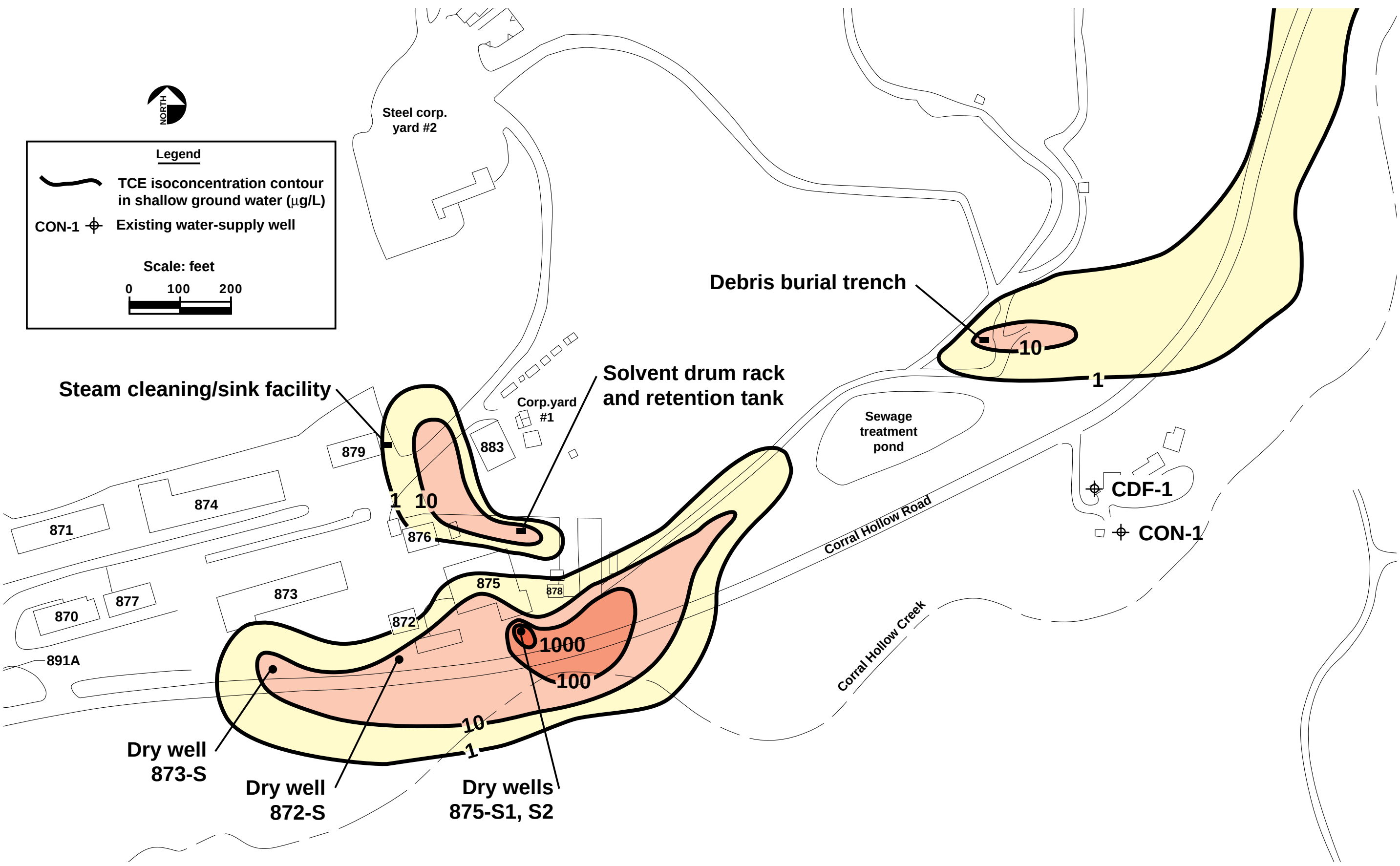
Contaminant	Vapor pressure (mm Hg)	Henry's Law constant (atm-m^3/mol)	Density constant (g/cm^3)	Water solubility (mg/L)	Kow	Koc
Benzene	9.52E+01	5.40E-03	0.8680	1.75E+03	131.83	87.10
Bromodichloromethane	3.75E-01	1.60E-03	1.97	6.73E+03	123.03	74.13
Chloroform	1.60E+02	3.23E-03	1.4890	8.00E+03	79.43	43.65
1,1-Dichloroethene	5.91E+02	1.80E-02	1.2180	2.25E+03	69.18	64.57
trans-1,2-Dichloroethene	2.65E+02	7.20E-03	1.2565	6.30E+03	123.03	58.88
1,1,1-Trichloroethane	1.00E+02	1.62E-02	1.3390	1.55E+03	295.12	151.36
Tetrachloroethene	1.40E+01	1.53E-02	1.6227	1.50E+02	398.11	263.03
Trichloroethene	5.78E+01	9.10E-03	1.4642	1.10E+03	338.84	107.15

Vapor Pressure: The higher the vapor pressure, the more volatile.
Henry's Law Constant: Compounds with constants greater than 1E-3 readily volatilize from water; compounds with constants less than 1E-5 are not as volatile.
Density: Compounds with a density greater than 1 have a tendency to sink (i.e., DNAPLs); compounds with a density less than 1 have a tendency to float (i.e., LNAPLs).
Water Solubility: Highly soluble chemicals can be rapidly leached from wastes and soils and are mobile in ground water; the higher the value, the higher the solubility.
Octanol-Water Partition Coefficient (K_{ow}): Used in estimating the sorption of organic compounds on soils (high K_{ow} tends to adsorb more easily).
Organic Carbon Partition Coefficient (K_{oc}): Indicates the capacity for an organic chemical to adsorb to soil because organic carbon is responsible for nearly all adsorption in most soils (the higher the value, the more it adsorbs).

Nature and Extent of Contamination

In the eastern GSA, the highest TCE concentrations in ground water (up to 74 µg/L) occur in alluvium near the debris burial trench area release site. TCE has also been detected in the underlying bedrock regional aquifer at maximum concentrations of 62 µg/L. A ground water plume extends eastward from the debris burial trench area and has migrated northward in the Corral Hollow alluvium. Very low VOC concentrations (up to 0.19 mg/kg) have been detected in soil at the debris burial trenches.

In the central GSA, the highest pre-remediation TCE concentrations in soil or bedrock (up to 360,000 µg/kg) were detected below the Building 875 dry wells. TCE at concentrations up to 1,100 $ppm_{v/v}$ has also been reported in vadose zone soil vapor samples. A ground water plume, consisting primarily of TCE at historic concentrations up to 240,000 µg/L, extends into the Corral Hollow Creek alluvium. The bulk of contamination is present in the $Tnbs_2$ sandstone, approximately 35 feet below the surface. There is a smaller ground water plume with significantly lower TCE concentrations to the north associated with the drum storage rack and steam cleaning release sites.



Distribution of TCE in ground water (1997).

Matrix Characteristics

Matrix characteristics: ground water (Eastern GSA).

Matrix characteristic	Potential effects on cost or performance
Depth to ground water: 10 to 15 ft below ground surface (bgs)	The bulk of contamination is concentrated in the Qal, therefore extraction wells are relatively shallow. However, if pumping of source area in the Qal does not adequately remediate the underlying $Tnbs_1$, deeper extraction wells may be necessary.
Saturated thickness: Qal: 0 to 22 ft Total unit: 150 to 170 ft	
Hydraulic condition: Unconfined	None.
Hydraulic conductivity (K): 10^{-1} cm/sec (maximum)	High K results in high flow volume to treatment system. As a result, the VOC mass removal rate per volume of water treated is relatively low.
Ground water flow direction and gradient: E-NE to N with a gradient of 0.003 to 0.009	Strategic placement of extraction wells prevents further offsite migration of contaminated ground water.
Typical well yields: <0.5 to 50 gpm	Relatively high well yields necessitate continuous operation of treatment facility for hydraulic control.

Matrix characteristics: ground water (Central GSA).

Matrix characteristic	Potential effects on cost or performance
$Qt\text{-}Tnsc_1$ hydrogeologic unit (shallow aquifer)	
Depth to ground water: 20 to 30 ft bgs	The depth to ground water in this unit allows for the installation of relatively shallow extraction wells.
Saturated thickness: 80 ft	The bulk of contamination in this hydrogeologic unit is in the $Tnbs_2$ sandstone, which is approximately 18 to 25 ft thick.
Hydraulic condition: Unconfined	None.
Hydraulic conductivity: 10^{-3} to 10^{-4} cm/sec	The relatively low hydraulic conductivity in this unit has contributed to the limited migration of contaminants in ground water from the source areas.
Ground water flow direction and gradient: S-SE with a gradient of 0.04	Strategic placement of extraction wells prevents further offsite migration of contaminated ground water.
Typical well yields: <0.5 to 5 gpm	Low well yields from this unit necessitates batch treatment of contaminated ground water in the treatment facility.
Relationship to adjacent hydrogeologic units: Conformably overlies, but is hydraulically isolated from the $Tnbs_1$ regional aquifer except in the vicinity of the sewage treatment pond.	The $Tnsc_1$ confining layer, where present, prevents the migration of contaminants into the $Tnbs_1$ regional aquifer, eliminating the need for remediation of this aquifer in most of the central GSA.
$Tnbs_1$ regional aquifer	
Depth to ground water: 35 to 145 ft bgs	The contaminated portion of the $Tnbs_1$ is at a relatively shallow depth where this unit subcrops beneath the Qal to the east. Therefore, the planned extraction well for this unit will be relatively shallow.
Saturated thickness: 285 to 320 ft	
Hydraulic condition: Semi-confined to confined	The confined portion of this unit is uncontaminated and does not require remediation.
Hydraulic conductivity: 10^{-4} cm/sec	The relatively low hydraulic conductivity of this unit has limited the migration of contaminated ground water.
Ground water flow direction and gradient: S-SE with a gradient of 0.09	A downgradient $Tnbs_1$ reinjection well was included as part of the central GSA wellfield to help prevent further contaminant migration in this unit.
Typical well yields: <0.5 to 40 gpm	The central GSA treatment facility was designed to handle ground water pumped from one $Tnbs_1$ extraction well.
Relationship to adjacent hydrogeologic units: Conformably underlies, but is hydraulically isolated from the $Qt\text{-}Tnsc_1$ hydrogeologic unit in most of the central GSA.	Where the overlying $Tnsc_1$ confining layer is not present, contaminants have migrated into the $Tnbs_1$ aquifer resulting in the need for deeper extraction wells.

Matrix Characteristics (cont.)

Matrix characteristics: vadose zone soil or bedrock (Central GSA).

Matrix characteristic	Potential effects on cost or performance
Tnbs$_2$ sandstone	
Lithology: The Tnbs$_2$ sandstone, in which SVE is conducted, consists of a massive fine- to medium-grained sandstone with interbedded siltstone and claystone. Fractures have been observed in cores from this unit.	Although SVE is typically utilized in soil applications, combined SVE and GWE has proven more effective in remediating VOCs in the subsurface in the central GSA Building 875 dry well pad area than the use of GWE alone.
Range of Thickness: Approximately 25 ft thick in the vicinity of Building 875 where SVE efforts are concentrated.	SVE and GWE efforts are focused in the lower Tnbs$_2$ where the bulk of the contamination was identified.
Porosity: 0.36	Porosity of the Tnbs$_2$ bedrock was sufficient to implement SVE successfully.
Moisture Content: Saturated	This unit is purposely dewatering by ground water extraction so SVE can be used.

4. REMEDIATION SYSTEM DESCRIPTION

Treatment technology types.

Location	Soil/bedrock	Ground water
Eastern GSA	None	Extraction and *ex situ* treatment with aqueous-phase carbon adsorption
Central GSA	Soil vapor extraction with *ex situ* vapor-phase carbon adsorption	Extraction and *ex situ* treatment with air stripping and vapor-phase carbon adsorption

Central GSA soil vapor treatment system.

Key Design Criteria

Eastern GSA Ground Water Extraction and Treatment System

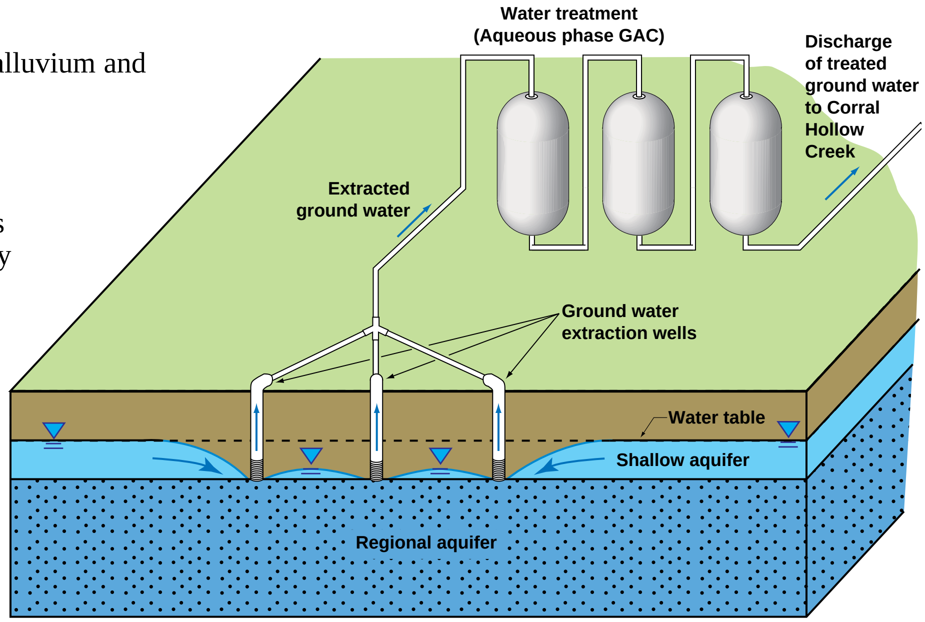
- Three extraction wells completed in the alluvium and shallow bedrock.
- Submersible electric pumps.
- Water distribution piping.
- 5-micron particulate filtration system.
- Three 1,000-lb aqueous-phase GAC units connected in series with a design capacity of 50 gpm.

Central GSA Ground Water Extraction and Treatment System

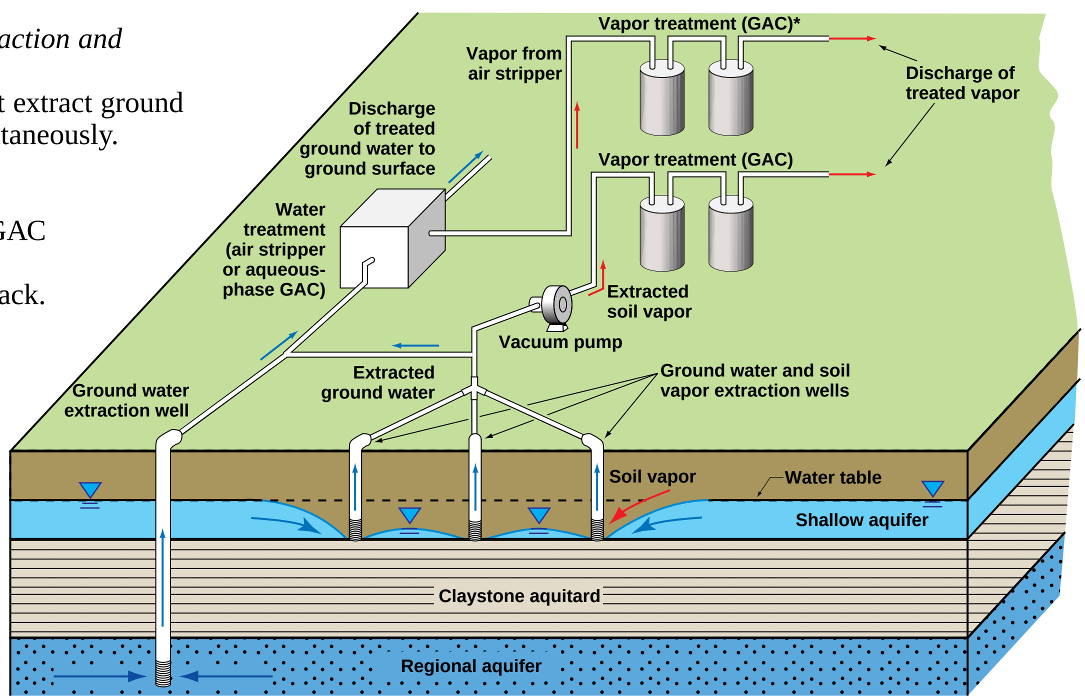
- Nineteen extraction wells completed in the alluvium, shallow bedrock, and regional aquifers.
- Submersible electric and pneumatic pumps.
- Water distribution piping.
- Shallow tray air stripper with a design capacity of 50 gpm, 5-micron particulate filter, two 140-lb vapor-phase GAC units, and air emissions stack housed in a Portable Treatment Unit (PTU).
- Pre- and post-treatment storage tanks.

Central GSA Soil Vapor Extraction and Treatment System

- Seven extraction wells that extract ground water and soil vapor simultaneously.
- Vapor distribution lines.
- 2-hp vacuum pump.
- Four 140-lb vapor-phase GAC units connected in series.
- Treated vapor discharge stack.



Schematic of the eastern GSA remediation system.



* Treatment of vapor from ground water treatment system is not necessary if aqueous-phase GAC is used.

Schematic of the central GSA remediation system.

Treatment System Operating Parameters

Eastern GSA GWE system.

Operating parameters	EGSA Ground water extraction and treatment system	Potential effects on cost or performance
Operating time	Continuous operation; 24 hrs/day, 7 days/wk	Continuous operation is more cost effective for contaminant mass removal at this time. Cyclic operation may be considered in the future to eliminate potential stagnation zones.
Pumping rate	45 gpm combined flow from 3 extraction wells	Modeling indicated that increasing the pumping rate and/or number of extraction wells did not significantly increase mass removal or enhance plume capture.
System throughput	45 gpm for a total monthly throughput of 1.5 to 2 million gallons	Combination of low flow rate and low influent VOC concentration allowed use of aqueous-phase GAC treatment technology.
pH	System influent: 7.5 System effluent: 8.1	NPDES permit discharge require 6.5<pH<8.5; significant increases in effluent pH could necessitate control measures.
VOC concentrations	System influent: 4 to 10 µg/L System effluent: <0.5 µg/L	Combination of low flow rate and low influent VOC concentration allowed use of aqueous-phase GAC treatment technology.
Mass removal rate	28 grams VOCs/month	Although the mass removal rate is low for the volume of ground water treated, monitoring data indicate a significant reduction in plume size as a result of this remediation strategy.

Central GSA GWE system.

Operating parameters	CGSA Ground water extraction and treatment system	Potential effects on cost or performance
Operating time	Continuous extraction. Batch treatment: approximately 10 to 20 days/month	Continuous extraction has resulted in dewatering of the bedrock, exposing a greater volume of contaminants to soil vapor extraction. This results in higher mass removal rates than could be achieved through GWE alone.
Pumping rate	0.3 gpm combined flow from 7 extraction wells. With expanded extraction wellfield: 15 gpm from 19 wells	Modeling indicated that increasing the pumping rate and/or number of extraction wells over that proposed in the Remedial Design document did not significantly increase mass removal or enhance plume capture.
System throughput	Currently 10 gpm during batch treatment for a total monthly throughput of approximately 1,000 gallons. With expanded extraction wellfield: up to 15 gpm	The ground water treatment system was designed to allow for increased capacity due to the planned wellfield expansion.
pH	System influent: 7.0 to 8.4 System effluent: 7.0 to 7.2	Substantive Requirements for waste discharge require 6.5<pH<8.5; significant increases in effluent pH could necessitate control measures.
Additives	Anti-scaling prevention agents: JP-7 or CO_2 pH control: CO_2, if necessary.	It has been necessary to inject anti-scaling agents to control scale buildup with the treatment system to prevent clogging of treatment units and discharge lines. Scale buildup could result in ineffective treatment and discharge limit violations.
VOC concentrations	System influent: 700 to 3,000 µg/L (seasonal variations) System effluent: <0.5 µg/L	The air stripping/vapor-phase GAC was determined to be effective in reducing VOC influent concentrations to meet discharge requirements. More innovative technologies will continue to be evaluated to identify more cost-effective remediation measures.
Air flow	Air stripper: 300 cfm Vapor-phase GAC: 450 cfm	Air flow rate in the air stripper was designed to establish the air-to-water mixing ratio necessary to reduce VOC concentrations to effluent limits.
Mass removal rate	Approximately 100 grams VOCs/month	Although the mass removal rate through ground water extraction is relatively low, the primary objective is to dewater the contaminated bedrock to maximize mass removal through SVE.

Treatment System Operating Parameters (cont.)

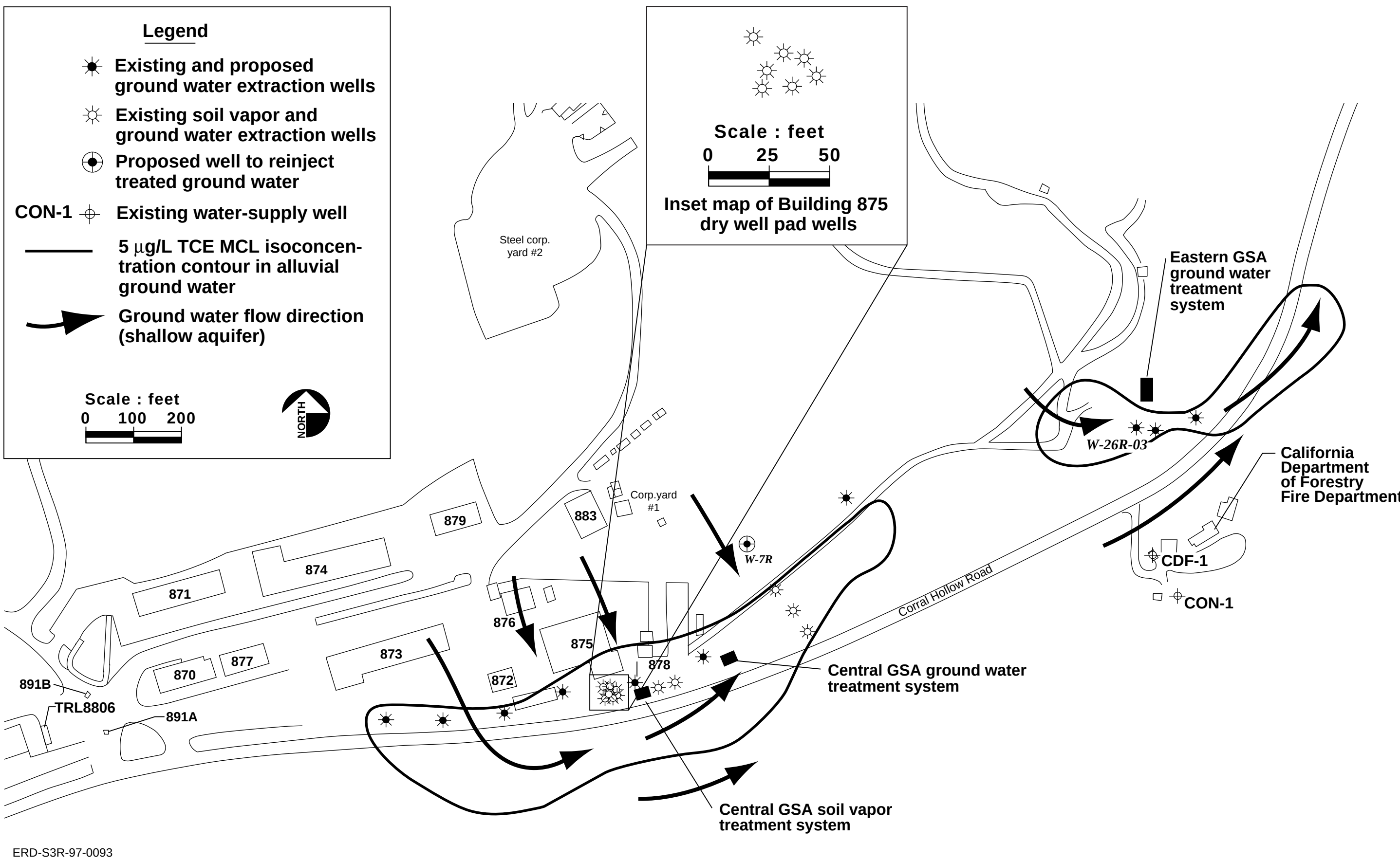
Central GSA SVE system.

Operating parameters	CGSA Soil vapor extraction and treatment system	Potential effects on cost or performance
Operating time	Continuous extraction; cyclic operation may be utilized to maximize contaminant mass removal	In general, a higher mass removal rate is achieved through continuous operation of SVE; however, cyclic operation may be more cost-effective. Cyclic operation allows VOCs to reequilibrate in soil vapor possibly resulting in the same mass removal during shorter operating periods. In addition, cyclic operation can eliminate stagnation zones.
Extraction rate	Approximately 15 scfm	SVE testing indicated that more efficient mass removal was achieved using lower flow rates.
Moisture control	Water knockout drum	The water knockout drum was installed to reduce the moisture content in soil vapor prior to GAC treatment. A high moisture content in vapor can reduce the efficiency of vapor-phase GAC treatment.
VOC concentrations	System influent: 2 to 100 $ppm_{v/v}$ System effluent: <6 $ppm_{v/v}$	Although SVE has been effective in mass removal in the central GSA, more innovative technologies will continue to be evaluated to identify remediation measures which could significantly reduce cleanup time.
Air flow rate	15 scfm	See "Extraction Rate" discussion.
Mass removal rate	510 grams VOCs/month	SVE is a cost-effective method of remediating VOCs in the subsurface with a mass removal rate over 5 times that achieved through GWE.

Central GSA ground water treatment system (1993–1997).

Eastern GSA extraction wells and treatment system.

Treatment System Operating Parameters (cont.)



Existing and proposed extraction wells, reinjection well, and treatment systems.

Each facility has a designated Facility Operator who has been trained in the safe and efficient operation of the treatment facility. To qualify as a Facility Operator, personnel must attend appropriate Facility Operator and Health and Safety training courses and undergo facility operation training in the field under the direction and supervision of a qualified Facility Operator. Total onsite Operation and Maintenance (O&M) personnel requirements for both the eastern and central GSA facilities average approximately 60 hours per month. These O&M activities include water and vapor facility compliance sampling, flow measurements, permit compliance documentation, daily inspections, GAC replacement, and well and treatment system maintenance.

5. REMEDIATION SYSTEM PERFORMANCE

Cleanup Objectives

- Reduce VOC concentrations in ground water to levels protective of human health and the environment.
- Reduce VOC concentrations in soil vapor to meet ground water cleanup standards.
- Mitigate VOC inhalation risk inside Building 875.

Soil vapor remediation will continue until: 1) it is demonstrated that VOC removal from the vadose zone is no longer technically and/or economically feasible in order to meet ground water cleanup standards sooner, more cost effectively, and more reliably, and 2) the additive VOC inhalation risk inside Building 875 is adequately managed.

Ground water remediation will be conducted to reduce VOC concentrations to MCLs in all contaminated ground water. Modeling indicates that ground water cleanup standards should be reached in 10 years in the eastern GSA and in 55 years in the central GSA.

Ground water cleanup standards.

Contaminant of concern	EPA Cancer group[a]	Federal MCL (µg/L)	State MCL (µg/L)
Benzene	A	5	1
Bromodichloromethane	B2	100[b]	100[b]
Chloroform	B2	100[b]	100[b]
1,1-DCE	C	7	6
cis-1,2-DCE	D	70	6
PCE	B2-C	5	5
1,1,1-TCA	D	200	200
TCE	B2-C	5	5

[a]From Integrated Risk Information System (IRIS) database maintained by the U.S. Environmental Protection Agency: A = known carcinogen; B2 = probable carcinogen; C = possible carcinogen; D = noncarcinogen.
[b]Total trihalomethanes.

To monitor the progress of subsurface soil remediation, soil vapor concentrations will be monitored at dedicated soil vapor sampling points and at SVE wells through the life of remediation. The demonstration that the vadose zone cleanup has been achieved to the point that the remaining vadose zone VOC contaminants no longer cause concentrations in the leachate to exceed the aquifer cleanup levels will be made through contaminant fate and transport modeling, trend analysis, mass balance, or modeling. In addition, VOC concentrations in soil vapor will be monitored to ensure that the inhalation risk inside Building 875 is adequately managed.

As specified in the ROD, ground water cleanup in the GSA will continue until cleanup standards are achieved. Ground water will be monitored throughout the life of remediation to: 1) determine the effectiveness of the remedial action in achieving cleanup standards, 2) re-evaluate and improve the remediation plans, 3) determine when cleanup standards as stipulated in the ROD have been achieved, and 4) determine when active remediation should cease. When VOC concentrations in ground water are below negotiated cleanup standards, selected wells will be sampled for five years as part of post-closure monitoring. Remediation will be considered complete when contaminant concentrations remain below the cleanup standards for five years. If concentrations rise above cleanup standards, extraction will resume at the appropriate wells.

Monitoring

VOC concentrations in GSA ground water and soil vapor are monitored regularly to evaluate the performance of the remedial action in meeting cleanup standards.

Ground water sampling and analysis program.

Area	No. of wells sampled	Analyses conducted	Sampling frequency
Central GSA	54	EPA Method 601	Semi-annual
	2	EPA Method 601	Quarterly
	12	EPA Method 602	Annually
	2	Dissolved drinking water metals	Annually
	15	Dissolved drinking water metals	Every 2 years
QA/QC	14 (10% of total)	EPA Method 601 EPA Method 602 Dissolved drinking water metals	Annually
Eastern GSA	34	EPA Method 601	Semi-annually
	5	EPA Method 601	Quarterly
	2	EPA Method 601	Monthly
QA/QC	12	EPA Method 601	Annually

- The eastern and central GSA ground water extraction and treatment systems have been operating since 1991 and 1993, respectively, as CERCLA removal actions. Based on the performance evaluation and the progress of these removal actions in remediating ground water, the existing extraction and treatment systems will continue to be used as part of the long-term remedial action.

- The focus of the central GSA removal action has been source control at the Building 875 dry well release area. In the remedial action, the wellfield will be expanded to address additional contaminant releases and to capture much of the contaminated ground water. The estimated time to cleanup may be significantly reduced by the addition of strategically placed extraction wells and by using cyclic pumping to address stagnation zones that may develop in the subsurface.

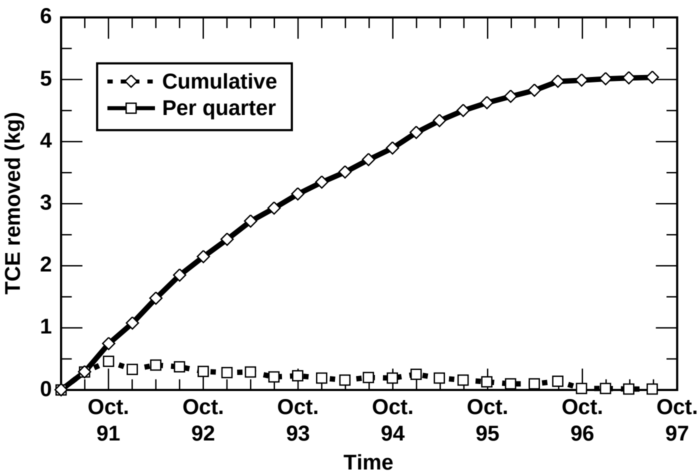
- In July 1994, soil vapor extraction for source control began in the central GSA Building 875 dry well area as part of a CERCLA removal action. Based on the performance evaluation and the progress of the removal action in remediating soil vapor in the central GSA, the existing soil vapor extraction and treatment system will continue to be used as part of the long-term remedial action.

- Ground water monitoring will be performed throughout the predicted 55 years of remediation or until ground water cleanup standards are met plus 5 years of post-remediation monitoring. Soil vapor concentrations will be monitored periodically from soil vapor extraction wells and soil vapor monitoring points during the predicted 10 years of SVE or until soil vapor cleanup standards are met.

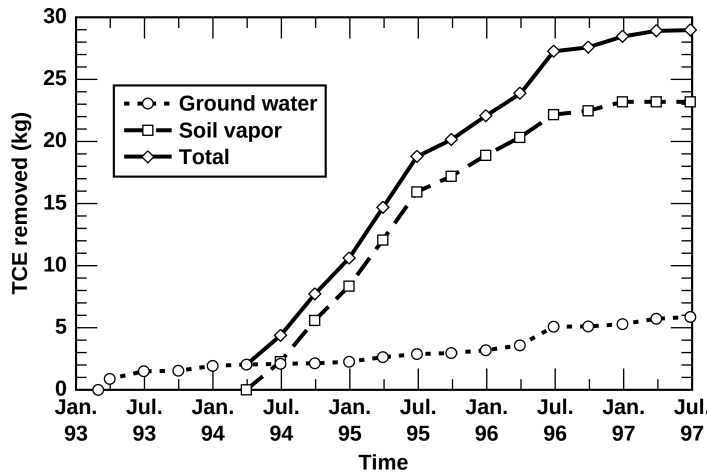
- Administrative controls will be implemented to prevent human exposure to contaminants, if necessary. These controls may include access restrictions and procedures for construction in areas where possible exposure to contaminated media may occur.

- Point-of-use (POU) treatment systems may be required at offsite water-supply wells if VOC concentrations in these wells exceed MCLs. The POU treatment system design consists of two gravity-flow aqueous-phase GAC canisters mounted on a double-containment skid.

Remediation Plan (cont.)



Mass of TCE removed from ground water at the Eastern GSA.



Cumulative mass of TCE removed from ground water and soil vapor at the Central GSA.

Central GSA Portable Treatment Unit (since 1997).

Treatment Facility Sampling and Analysis Program

Treatment facility sampling and analysis program.

Monitoring program	Type of samples collected	Sampling frequency	Analytical methodology	QA/QC
EGSA GWTS NPDES Permit	Influent/Effluent	Bi-monthly	EPA Method 601, TDS, pH	10% of total no. of samples collected
	Receiving Waters	Weekly when creek is flowing	EPA Method 601, pH, turbidity.	
CGSA GWTS Substantive Requirements	Influent/Effluent	Monthly	EPA Method 601 & 602, pH, spec. conduct.	10% of total no. of samples collected
CGSA SV Treatment System Air Discharge Permit	Effluent	Weekly	Monitored with an OVA.	OVA calibrated before each use

Volume of contaminated media treated and mass of contaminants removed (July 1997).

Treatment system	Operation mode	Average flow rate	Volume treated to date	VOC mass removed to date
Eastern GSA GWTS	Continuous	45 gpm	93,000,000 gal	5.1 kg
Central GSA GWTS	Batch	12,000 gal/month	787,000 gal	4.8 kg
Central GSA SVTS	Continuous	15.3 scfm	399,000 cf	30.5 kg
			GSA Total:	**40.4 kg**

Approximately 1,100 lbs of VOC-laden GAC residual is generated by the central GSA treatment system annually. Based on contaminant concentration and flow rates, it is estimated that the 1,000-lb aqueous-phase GAC canisters from the eastern GSA ground water treatment system will need to be replaced approximately every two to three years. All spent GAC canisters are packaged, labeled for shipment, manifested, and temporarily stored onsite for up to 90 days before being transported offsite for regeneration or disposal.

Untreated and Treated Contaminant Concentrations

Contaminant concentrations prior to and during remediation.

Media	Area	Pre-remediation maximum TCE concentrations	Maximum TCE concentrations (May 1997)	Cleanup standards
Shallow ground water	Central GSA (Bldg. 875 dry well pad)	240,000 μg/L	10,000 μg/L	5 μg/L
Regional aquifer ground water	Central GSA (West of sewage treatment pond)	58 μg/L	33 μg/L	5 μg/L
Shallow ground water	Eastern GSA (Debris burial trench area)	74 μg/L	13 μg/L	5 μg/L
Soil/bedrock	Central GSA (Bldg. 975 dry well pad)	360 mg/kg	Not measured	Not applicable
Soil/bedrock	Eastern GSA (Debris burial trench area)	0.19 mg/kg	Not measured	Not applicable
Soil vapor	Central GSA (Bldg. 875 dry well pad)	450 $ppm_{v/v}$	2 $ppm_{v/v}$	0.36 $ppm_{v/v}$

Contamination concentration prior to and following treatment (May 1997).

Constituent	Discharge limits	Average untreated media concentration (treatment system influent)	Average treated media concentration (treatment system effluent)
CGSA ground water treatment system			
Total VOCs	Monthly median: 0.5 μg/L	1,500 μg/L	Monthly median: <0.5 μg/L
EGSA ground water treatment system			
Total VOCs	Monthly median: 0.5 μg/L	7 μg/L	Monthly median: <0.5 μg/L
CGSA soil vapor treatment system			
TCE	6 $ppm_{v/v}$	2 $ppm_{v/v}$	0 $ppm_{v/v}$

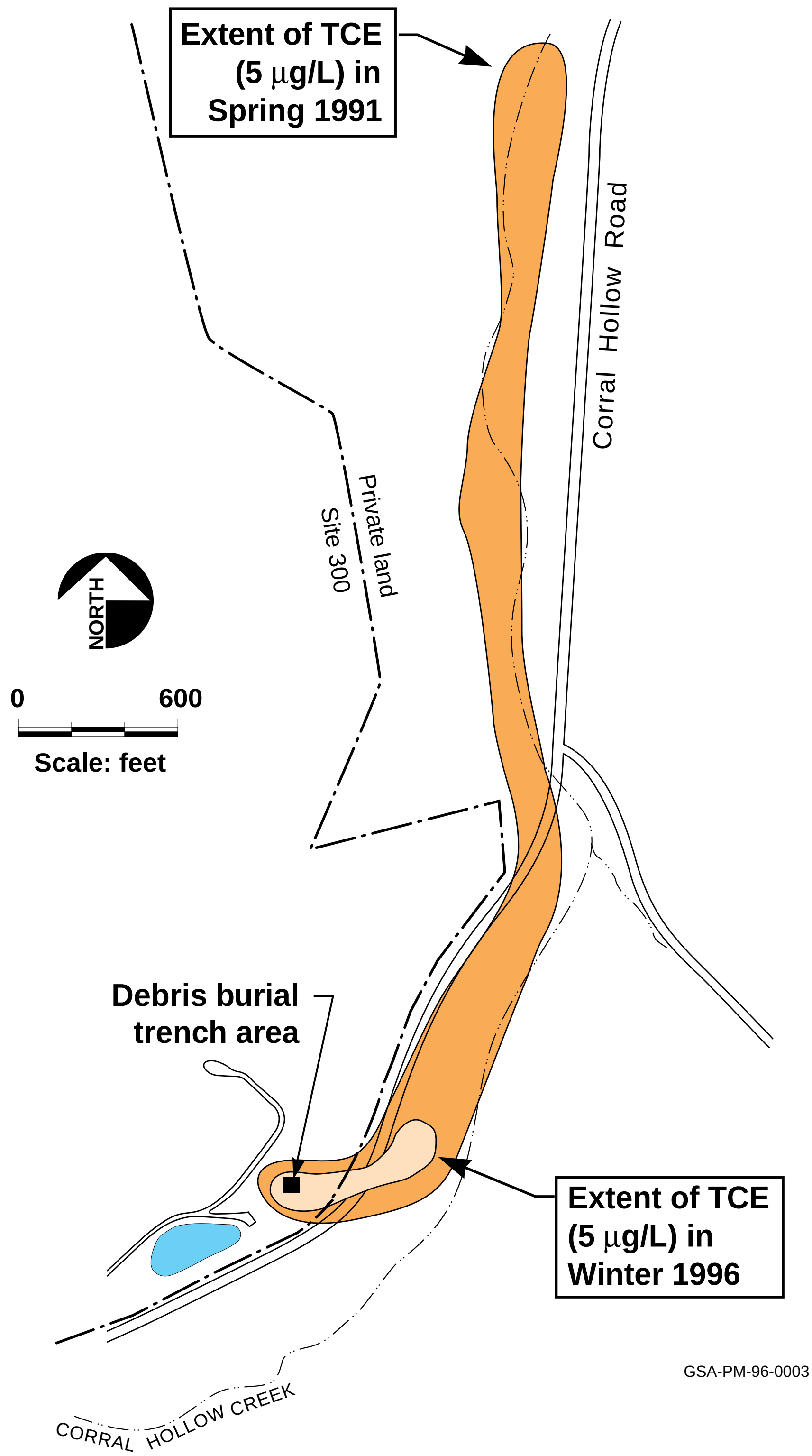
Comparison with Cleanup Objectives

After six years of ground water remediation in the eastern GSA, the maximum VOC concentrations in ground water have been reduced from a historical pre-remediation maximum of 74 µg/L to a maximum concentration of 13 µg/L as of second quarter 1997. Only five of the 42 monitor wells in the eastern GSA currently contain TCE in concentrations that exceed the cleanup standard of 5 µg/L. All other contaminants of concern in the eastern GSA have been remediated to below their respective cleanup standards (MCLs).

Prior to remediation of the eastern GSA VOC plume, the portion of the TCE plume in which concentrations exceed the cleanup standards for TCE (MCL of 5 µg/L) extended approximately 4,500 feet offsite. The TCE plume with concentrations exceeding the MCL now extends less than 200 feet from the site boundary.

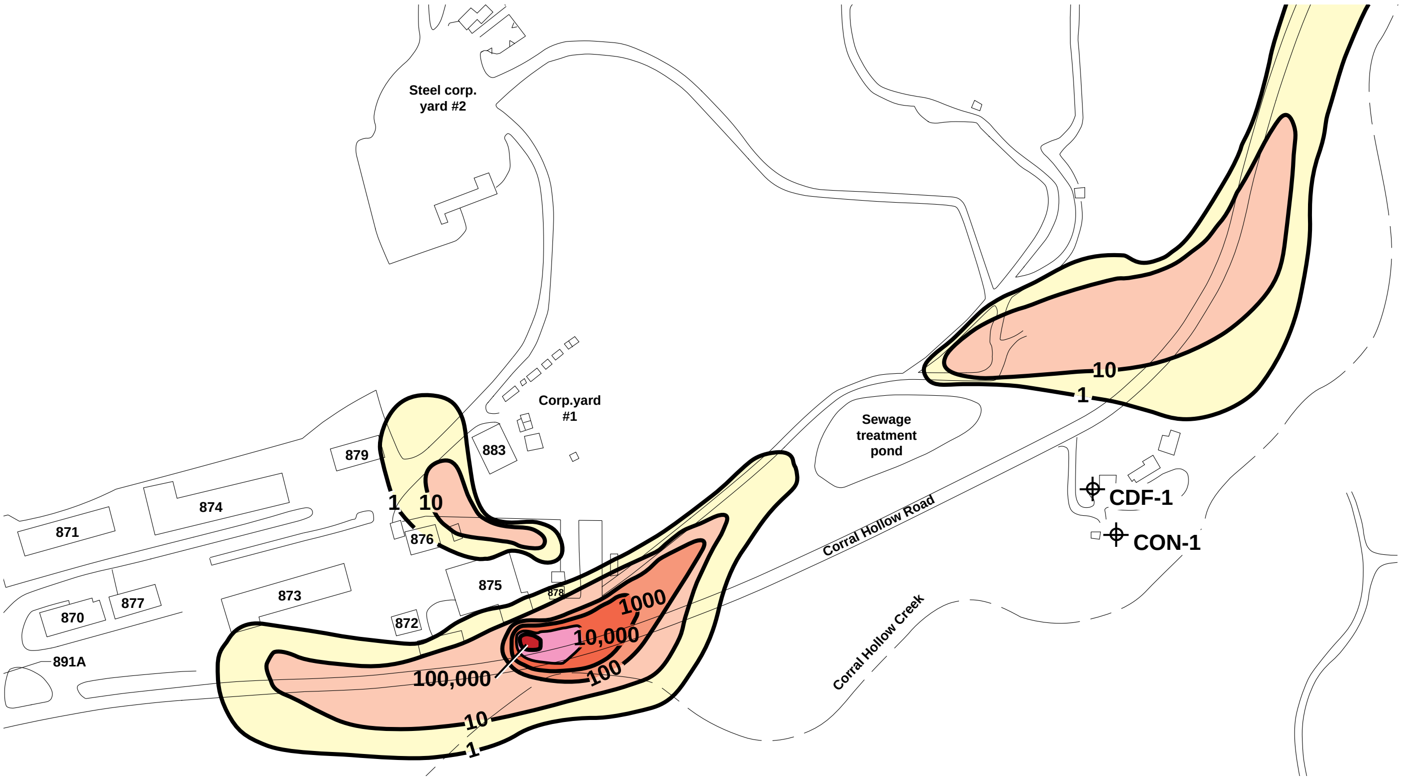
In the central GSA, maximum TCE concentrations detected in ground water prior to remediation were 240,000 µg/L. The maximum TCE concentration detected in ground water as of the fourth quarter of 1996, after approximately three years of source area remediation, was 10,000 µg/L. Of the eight VOCs identified as contaminants of concern in the central GSA, currently only TCE and PCE are detected in wells in concentrations which exceed the cleanup standards (MCLs). The actual mass removal achieved by the central GSA ground water treatment system is similar to the mass removal rate predicted by modeling.

Following two years of soil vapor extraction and treatment in the central GSA, TCE concentrations in soil vapor have been reduced from a pre-remediation concentration of 1,000 $ppm_{v/v}$ to 2 $ppm_{v/v}$.

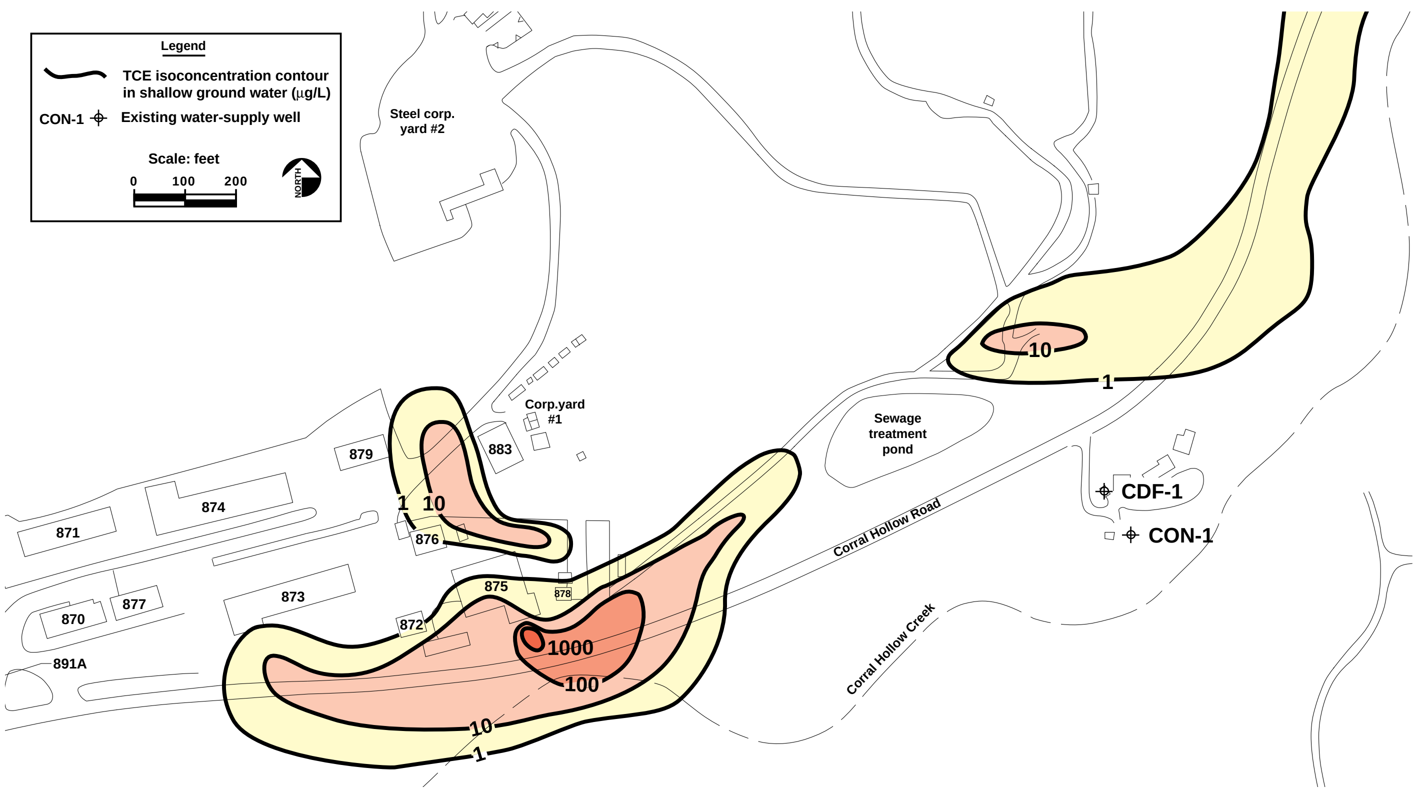


Eastern GSA pre-remediation and current plume configurations.

Comparison with Cleanup Objectives (cont.)

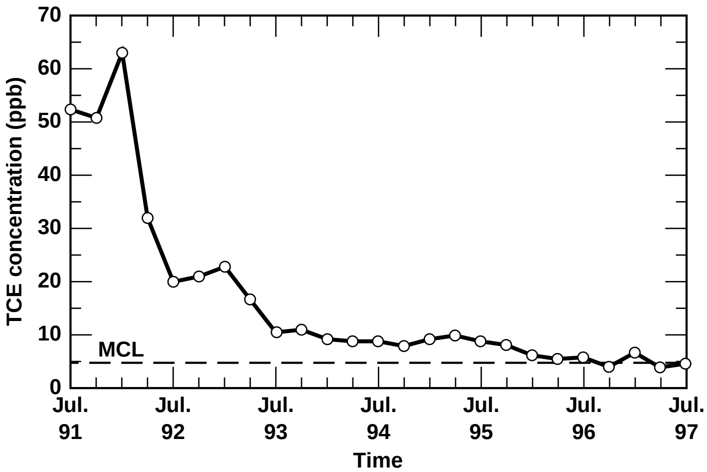


Distribution of TCE in ground water (1991).

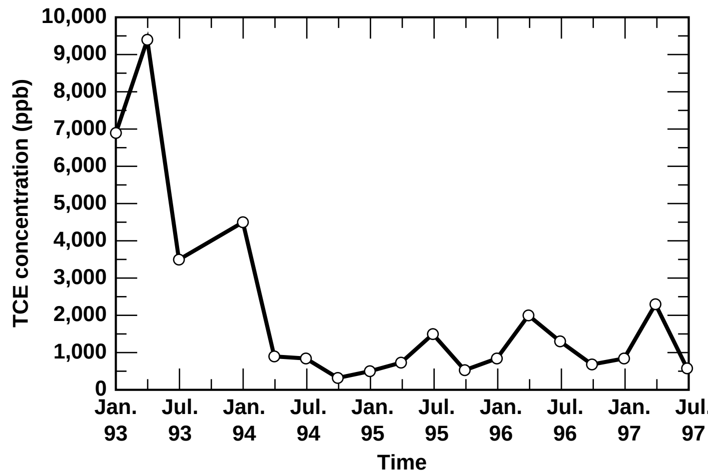


Distribution of TCE in ground water (1997).

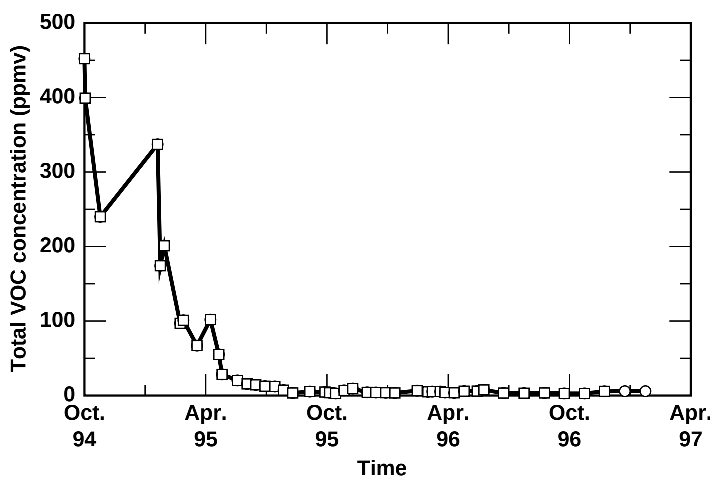
Comparison with Cleanup Objectives (cont.)



TCE concentration in ground water treatment system influent at the eastern GSA.



TCE concentration in ground water treatment system influent at the central GSA.



VOC concentration in soil vapor extraction system influent at the central GSA.

Risk Reduction

The GSA baseline risk assessment identified two exposure routes that could potentially result in unacceptable risk to the community and workers on site: 1) ingesting contaminated ground water, and 2) inhaling TCE vapor inside Building 875.

The calculated excess cancer risk for potential residential use of ground water in the vicinity of the eastern GSA debris burial trenches or at offsite wells is about 1 in 100,000 (10^{-5}). Existing offsite water-supply wells are monitored monthly for VOCs, however no VOCs have ever been detected in these wells at concentrations above MCLs. Water from these existing wells is used primarily for livestock watering and non-drinking water domestic purposes.

The excess cancer risk for use of ground water from a hypothetical well that could potentially be installed at the site boundary near Building 875 was calculated to be approximately 7 in 100 (7×10^{-2}). No water-supply wells currently exist at the site boundary location, and ground water in the area is not used for drinking water.

The excess human cancer risk from inhalation of TCE vapor inside Building 875 in the GSA was calculated to be 1 in 100,000 (10^{-5}). However, current VOC concentrations are likely lower due to ongoing soil vapor remediation.

6. COST SUMMARY

All preliminary activities and removal actions were conducted and associated costs incurred prior to the signing of the Final GSA ROD in February 1997. The worth of pre-1997 costs is based on the year incurred. The remaining activities presented are post-ROD with the exception of monitor well installation and removal action construction and operation and maintenance (O&M) costs.

Projected costs (post 1997) are present worth as estimated in the Feasibility Study and Remedial Design Documents. Costs presented for post-ROD remedial action activities have been calculated based on the projected life of the project. The total actual and projected investigation and remediation cost for the GSA Operable Unit is $38.6 M.

Cost Elements

Cost Elements for Eastern GSA.

General activity areas (WBS)	WBS 2nd level cost elements (WBS)	Cost items (WBS)	Costs ($K)	Subtotal ($K)
Preliminary/ Preconstruction Activities (32)	• RI/FS (32.02)	• Field Investigations (32.02.06)	545	1,845
		• Remedial Investigation - Data Evaluation (32.02.11) - Risk Assessment (32.02.12) - RI Document (32.02.13)	437	
		• Feasibility Study: - Alternative Evaluation (32.02.14) - FS document (32.02.16)	430	
		• Proposed Plan/ROD (32.02.03)	92	
		• Sampling and Analysis (32.02.08)	215	
	• Remedial Design (32.03)	• Removal Action Design (32.03.20)	9	
		• Remedial Design Report (32.03.20)	117	
Construction Activities (33)	• Monitoring, Sampling, Testing, and Analysis (33.02)	• Monitor Well Installation/Soil Sampling (57 wells) (33.02.09, 33.02.06)	271	688
		• Ground Water Sampling and Analysis (33.02.05)	39	
	• GW Collection and Control Construction (33.06) • Physical Treatment Construction (33.13)	• Removal Action Construction: GWE: - Air Stripping System Construction (33.13.07) - GAC-vapor systems (2) (33.13.19) - Extraction Wellfield Construction (33.06.01)	173	
		• Remedial Action Construction: GWE: - GAC-Liquid System Construction (33.13.20)	205	
Post-Construction Operations and Maintenance (O&M): Removal Action (34)	• Monitoring, Sampling, Testing, and Analysis (34.02)	• Removal Action Monitoring, Sampling, Testing, and Analysis: - Air Monitoring (34.02.03) - Monitor Well O&M (34.02.04) - Ground Water/Treatment Facility Sampling (34.02.05) - Lab Chem. Analysis (34.02.09)	215	1,190
	• GW Collection and Control (34.06) • Physical Treatment O&M (34.13)	• Removal Action Ground Water Extraction and Treatment System O&M: - Extraction Well O&M (34.06.01) - Air Stripping System O&M (34.13.07) - Carbon Adsorption-Gas System O&M (34.13.19)	816	
	• Other: Treatment Facility Compliance Reporting (34.90)	• Removal Action TF Compliance Reporting (34.90.01)	159	
Post-Construction Operations and Maintenance (O&M): Remedial Action (34)	• Monitoring, Sampling, Testing, and Analysis (34.02)	Remedial Action Monitoring, Sampling, Testing, and Analysis: • Air Monitoring (34.02.03) • Monitor Well O&M (34.02.04) • GW/Facility Sampling (34.02.05) • Lab Chem. Analysis (34.02.09)	580	2,490
	• GW Collection and Control (34.06) • Gas/Vapor Collection and Control (34.07) • Physical Treatment O&M (34.13	• Remedial Action O&M - GWE: - Extraction/Injection O&M (34.06.01) - GAC-Liquid O&M (34.13.20)	1,600	
	• Other: Treatment Facility (TF) Compliance Reporting (34.90)	• Remedial Action Compliance (34.90.02)	310	
		Total Eastern GSA		**$6,213K**

Cost Elements (cont.)

Cost elements for Central GSA.

General activity areas (WBS)	WBS 2nd level cost elements (WBS)	Cost items (WBS)	Costs ($K)	Subtotal ($K)
Preliminary/ Preconstruction Activities (32)	• RI/FS (32.02)	• Field Investigations (32.02.06) • Remedial Investigation - Data Evaluation (32.02.11)/ Risk Assessment (32.02.12)/ RI Document (32.02.13) • Feasibility Study: - Alternative Evaluation (32.02.14) - FS document (32.02.16) • Proposed Plan/ROD (32.02.03) • Sampling and Analysis (32.02.08)	731 437 430 92 82	1,973
	• Remedial Design (32.03)	• Removal Action Design • Remedial Action Design (32.03.20)	75 126	
Construction Activities (33)	• Monitoring, Sampling, Testing, and Analysis (33.02)	• Monitor Well Installation/Soil Sampling (57 wells) (33.02.09, 33.02.06) • GW Sampling and Analysis (33.02.05)	374 55	1,987
	• GW Collection and Control Construction (33.06) • Air Pollution/Gas Collection and Control (33.07) • Physical Treatment Construction (33.13)	• Removal Action Construction (GWE) - Air Stripping System Construction (33.13.07) - GAC-vapor systems (2) (33.13.19) - Extraction Wellfield Construction (33.06.01) • Removal Action Construction(SVE) - GAC-vapor System (33.13.19) - SVE System (33.13.23) - Extraction Wellfield Construction (33.06.01) • Remedial Action Construction: 1) GWE: - Air Stripping System Construction (33.13.07) - GAC-vapor System Construction (33.13.19) 2) SVE: • Extraction wellfield expansion (33.06.01) • Extraction/Instrumentation - Equipment/Pipeline Construction (33.06.07)	506 123 296 347 286	
Post-Construction Operations and Maintenance (O&M): Removal Action (34)	• Monitoring, Sampling, Testing, and Analysis (34.02)	Removal Action Monitoring, Sampling, Testing, and Analysis: • Air Monitoring (34.02.03) • Monitor Well O&M (34.02.04) • GW/Treatment Facility Sampling (34.02.05) • Lab Chem. Analysis (34.02.09)	334	1,689
	• GW Collection and Control (34.06) • Gas/Vapor Collection and Control (34.07) • Physical Treatment O&M (34.13)	• Removal Action O&M (includes equipment and labor for TF and extraction wellfield O&M): - Extraction Well O&M (34.06.01) - Air Stripping System O&M (34.13.07) - GAC-vapor O&M (34.13.19) - SVE O&M (34.13.23)	883	
	• Other: Treatment Facility (TF) Compliance Reporting (34.90)	• Removal Action TF Compliance Reporting (34.90.01)	472	
Post-Construction Operations and Maintenance (O&M): Remedial Action (34)	• Monitoring, Sampling, Testing, and Analysis (34.02)	• Remedial Action Monitoring, Sampling, Testing, and Analysis: - Air Monitoring (34.02.03) - Monitor Well O&M (34.02.04) - Ground Water/Treatment Facility Sampling (34.02.05) - Lab Chem. Analysis (34.02.09)	10,230	26,790
	• GW Collection and Control (34.06) • Gas/Vapor Collection and Control (34.07) • Physical Treatment O&M (34.13)	• Remedial Action O&M - GWE - Extraction/Injection Wellfield O&M (34.06.01) - Air stripping System O&M (34.13.07) - Carbon Adsorption-Gas O&M (34.13.19) • Remedial Action O&M - SVE: - GAC-vapor O&M (34.13.19) - SVE System O&M (34.13.23)	12,375 1,050	
	• Other: Facility Compliance Reporting (34.90)	• Remedial Action TF Compliance Reporting (34.90.02)	3,135	
		Total Central GSA		**$32,439K**

7. REGULATORY ISSUES

Regulatory agencies overseeing the GSA cleanup include the: 1) U.S. EPA, 2) Central Valley Regional Water Quality Control Board, and 3) California Department of Toxic Substances Control.

The driver for ground water cleanup is based on VOC concentrations in GSA ground water that exceed MCLs. Ground water in the GSA OU is considered a potential drinking water source by the state and federal regulatory agencies who require restoration of ground water to protect beneficial uses.

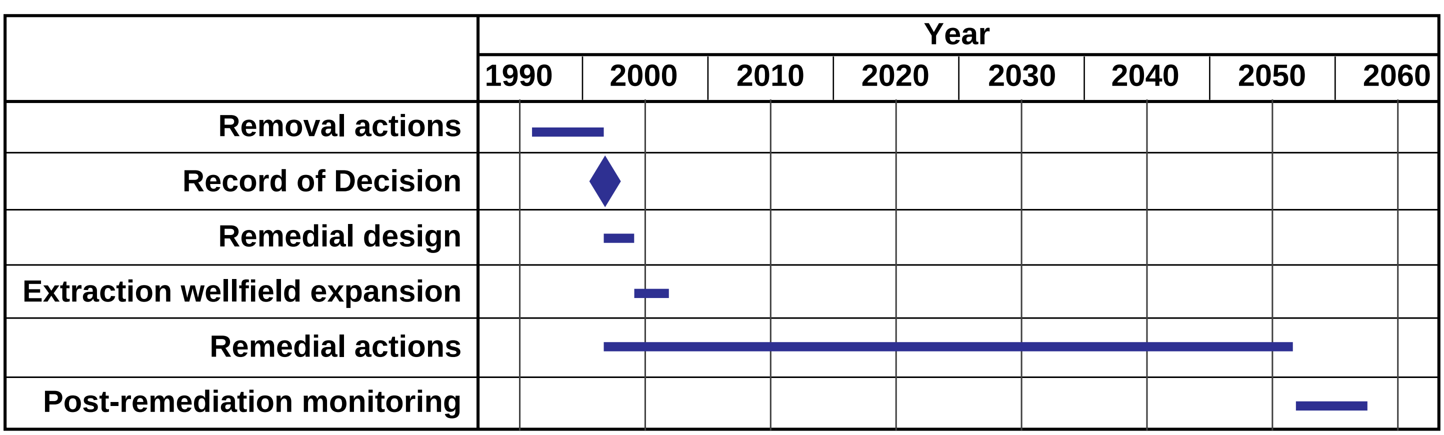
The driver for soil vapor cleanup is based on VOC concentrations in soil vapor in the central GSA Building 874 dry well pad area that are estimated to impact ground water in excess of drinking water standards and result in an inhalation risk inside Building 875 requiring risk management.

The state regulatory agency requires that discharges from the central and eastern GSA ground water treatment systems be treated for VOCs to meet a discharge limit of <0.5 µg/L VOCs. This standard is met by treating ground water with an air-stripping system in the central GSA and an aqueous-phase GAC system in the eastern GSA. The existing waste discharge permits and Record of Decision allow these treatment technologies to be readily supplemented by innovative treatment/destruction technologies if a more cost-effective method of treating contaminated ground water is identified. Treated water is discharged under a NPDES permit in the eastern GSA and under Substantive Requirements for Waste Discharge in the central GSA.

The local air regulatory agency requires that emissions to air from the central GSA soil vapor treatment system and ground water air-stripping system be treated for VOCs to meet a 6 $ppm_{v/v}$ discharge limit. Currently, this standard is met by treating emissions with vapor-phase GAC. The existing permit and Record of Decision allow the GAC to be readily supplemented by innovative treatment/destruction technologies if a more cost-effective method of treating contaminated vapor is identified.

In the GSA ROD, the state and federal regulatory agencies did not concur with the selection of MCLs as the cleanup standard for chloroform and bromodichloromethane because the MCL for total trihalomethanes is based on the economics of chlorinating a municipal water supply to remove pathogens and the agencies stated that the MCL did not adequately protect the beneficial uses of a drinking water source that has not been, and may not be, chlorinated. The modeling performed for the GSA Feasibility Study predicted that, in the course of remediating TCE to MCLs, chloroform and bromodichloromethane would be remediated to the taste and odor threshold levels desired by the regulatory agencies. However, the ROD states that if remediation does not show that cleanup of these compounds is proceeding as predicted, the cleanup standards for chloroform and bromodichloromethane will be revisited.

8. SCHEDULE



9. LESSONS LEARNED

Implementation Considerations

Soil vapor extraction and treatment in the central GSA Building 875 dry well pad area may continue past the 10 year estimated time to cleanup if it is demonstrated that it will expedite ground water cleanup in a cost-effective manner.

As VOC concentrations in ground water decreased in the eastern GSA, the air sparging system was replaced with aqueous-phase GAC. Using GAC will incur lower operation and maintenance costs and eliminated the need for an air discharge permit and associated compliance monitoring.

Carbonate scale buildup in both the central and eastern GSA treatment systems resulted in a reduction in treatment system efficiency and clogging of the discharge lines. To correct this problem, scale control agents (JP-7 and CO_2) are injected into the water stream. CO_2 injection can also be used to control the pH of the treatment system effluent to meet NPDES permit waste discharge requirements.

In the central GSA Building 875 dry well pad area, ground water extraction was used to dewater bedrock and create an “artificial” vadose zone. Simultaneous soil vapor and ground water extraction dramatically increased VOC mass removal rates from those obtained by ground water extraction alone.

Cyclic pumping (e.g. alternating periods when the extraction system is on and off) is used to maximize VOC mass removal efficiency from both ground water and soil vapor. During the pump-off cycles, VOCs desorb from solids into ground water and soil vapor, increasing the mass removal rate when the extraction system is turned back on. Cyclic pumping is also used to minimize or eliminate stagnation zones that develop due to competition between extraction wells.

The central GSA ground water treatment system is housed in a portable treatment unit (PTU). Using a PTU will:
1) prevent UV degradation of system components,
2) be significantly less costly than a permanent facility,
and 3) allow the treatment system to be moved to another areas at LLNL if a more effective treatment technology is employed at the central GSA.

The ability to restore ground water to MCLs using active pumping is unlikely at many sites. If the stakeholders determine that extraction is technically and economically infeasible to reduce VOCs in ground water to the cleanup levels established in the ROD, the selected technologies may be re-evaluated. Low well yields (<0.5 gpm) in the central GSA may limit the effectiveness of pump and treat for ground water restoration and source control. Long-term ground water extraction in the central GSA Building 875 dry well pad area will be considered as a technique to enhance soil vapor extraction for the purposes of source removal.

Innovative technologies will be considered for the GSA throughout the process of remediation to shorten cleanup time, improve cleanup efficiency, and reduce cost.

If technologies that enhance contaminant mobility are used (e.g. surfactants) it may be necessary to implement hydraulic controls near source areas to prevent further plume migration.

10. REFERENCES

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11. VALIDATION

Signatories:

"This analysis accurately reflects the current performance and projected costs of the remediation."

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U. S. Department of Energy

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12. ACKNOWLEDGMENTS

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