Cost and Performance Summary Report

Groundwater Pump and Treat, Air Sparging, and Soil Vapor Extraction at the Cascade Corporation Site, Troutdale Gravel Aquifer, East Multnomah County Groundwater Contamination Site, OU 2, Gresham, Oregon

Background [1, 2, 3, 5, 6]

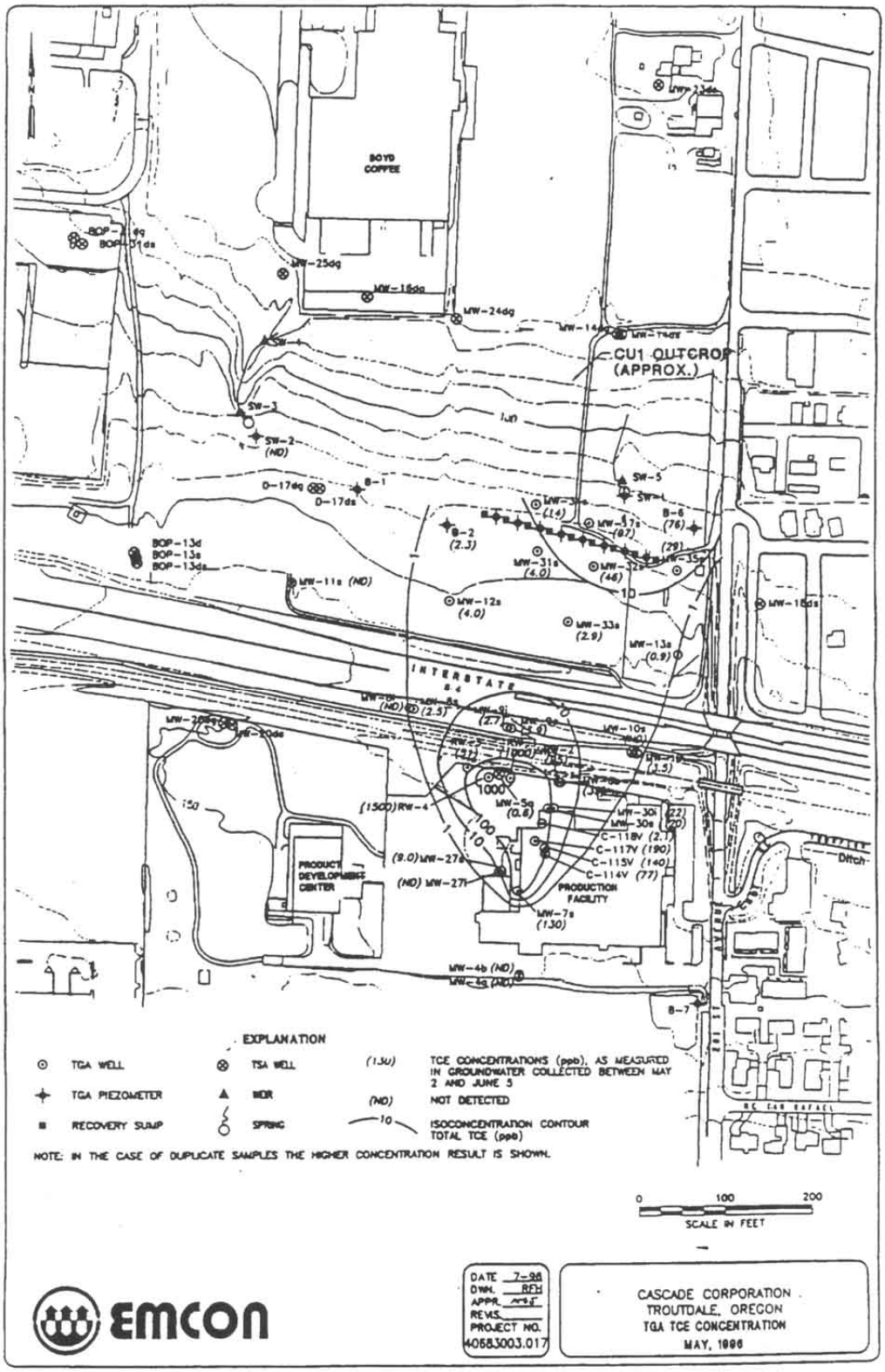
The East Multnomah County (EMC) Groundwater Contamination site covers three square miles in Multnomah County, east of Portland, Oregon, and includes contaminated groundwater plumes from multiple facilities. The Cascade site (OU 2), located within the EMC Groundwater Contamination site, is in Gresham, Oregon, and consists of those portions of Cascade Corporation's property containing soil or groundwater contamination at levels requiring remedial action, and is the focus of this report.

Cascade Corporation manufactures forklifts and has operated at the site since 1956. Operations include a paint booth, a parts and hydraulic cylinders assembly area, a maintenance shop, nickel and chrome electroplating, and vapor degreasing. Underground storage tanks (USTs) had been used to store waste coolants and cutting oils. Soil and groundwater at the site are contaminated with chlorinated solvents, primarily tetrachloroethene (PCE), trichloroethene (TCE) and cis-1,2-dichloroethene (cis-1,2-DCE). Volatile organic compounds (VOCs) were detected in soil at concentrations as high as 0.09 mg/kg (PCE), 5.5 mg/kg (TCE), and 10 mg/kg (1,2-DCE), and in soil vapors at concentrations as high as 8.9 mg/m^3 (PCE), 584 mg/m^3 (TCE), and 554 mg/m^3 (1,2-DCE). VOCs in groundwater were detected at concentrations as high as 920 µg/L (PCE), 11,000 µg/L (TCE), 13,000 µg/L (1,2-DCE), and 106 µg/L vinyl chloride (VC). Chromium was detected in groundwater at concentrations as high as 172 µg/L. In addition, the presence of light non-aqueous phase liquids (LNAPL) were noted at the site. Figure 1 shows the concentrations of TCE in the groundwater as of May 1996.

There are several aquifers beneath and in the vicinity of the Cascade site. The Troutdale Gravel Aquifer (TGA) is the shallowest aquifer at the site. An on-site interim removal action measure (IRAM) for the TGA, consisting of groundwater extraction and treatment, began operation in June 1991. The IRAM system consisted of 5 extraction wells spaced approximately 50-100 ft apart, located along the northern property boundary, and an air stripping tower. Through December 1995, the IRAM system had removed and treated more than 27 million gallons of TGA groundwater containing approximately 380 pounds of VOCs.

In addition, an off-site IRAM consisting of a 400-ft long trench with the bottom keyed into a confining unit, was installed approximately 600-ft north of the Cascade site. The trench was designed to intercept the off-site contamination plume in TGA groundwater and treat extracted groundwater in an air stripper prior to discharge to the municipal sewer. The trench began operation in December 1995. In addition to the trench, the off-site plume is being treated by phytoremediation using poplar trees, according to the Oregon Department of Environmental Quality (DEQ).

Figure 1. TCE Concentration Contours as of May 1996 – Cascade Corp. TGA [2]



A Record of Decision (ROD) was signed for OU 2 in December 1996, addressing soil and groundwater contamination in the TGA at the Cascade site. A separate ROD was signed for OU 1, also in December 1996 that addressed contamination in a deeper aquifer at the site. The selected remedy for OU 2 included soil vapor extraction (SVE) with destruction of VOCs using catalytic oxidation or equivalent; continued operation of on- and off-site IRAMs pump and treat (P&T); expansion of the off-site IRAM; extraction of LNAPL by co-pumping LNAPL and groundwater; additional on-site groundwater extraction using existing and new wells; and air sparging using approximately 25 on-site wells.

CERCLIS ID	ORD987185030
Lead	Potential Responsible Party (PRP) – Cascade Corporation
Oversight	Oregon Department of Environmental Quality

Timeline [2, 6]

Date	Activity
June 1991 – February 1998	On-site IRAM operated (Groundwater P&T)
December 1995	Off-site IRAM (extraction trench) operation began
December 1996	ROD signed for OU 2
March 1998	Phase 1 Remedial Action (RA) began
March – October 1998	Initial operating period for Phase 1 RA – documented in 1998 Performance Evaluation
May 11, 1998 – October 1998	Air sparging pilot test performed
October 1998 – December 2002	Ongoing remedy operation, including source area, perimeter, and control trench groundwater extraction, source area LNAPL extraction, and source area soil vapor extraction
March 2000 – Present (March 2004)	Planting and maintenance of 850 poplar trees for phytoremediation of VOCs in groundwater
December 2002	SVE terminated
December 2002 – Present (March 2004)	Ongoing control trench and on-site perimeter groundwater extraction, pulse pump operation of source area extraction wells, and planning for source area bio-augmentation pilot testing in 2004

Matrix Characteristics Affecting Treatment Cost or Performance [2, 6]

Hydrologic units beneath the site, in order of increasing depth, are the Troutdale Gravel Aquifer (TGA), confining unit 1 (CU1), the Troutdale Sandstone Aquifer (TSA), confining unit 2 (CU2), and the Sand and Gravel Aquifer (SGA). TGA consists of gravel with sand, silt, and clay, and is approximately 50 ft thick on-site. Upper TGA materials consist primarily of unconsolidated silty, sandy gravel with cobbles and boulders. The lower TGA is typically an indurated sandstone.

Matrix Characteristic	Value
Soil Classification	Gravel with sand, silt, and clay
Clay Content and/or Particle Size Distribution	10% fines, 30% sand, 60% gravel
Depth to Groundwater	Approx. 10 – 20 ft, varying spatially and seasonally
Hydraulic Conductivity (Saturated Zone)	1.7 ft/day (source: Remedial Investigation (RI) Report, EMCON 1995)
Air Permeability (Vadose Zone)	Information not provided
Porosity (Vadose Zone)	25%

Technology Design and Operation [3, 6]

The 1996 ROD included groundwater P&T, dual-phase extraction (DPE) (for groundwater and soil vapor), total fluid extraction (TFE) (for groundwater, LNAPL, and SVE), air sparging, and SVE, as shown in Figure 2. Groundwater was extracted from 5 recovery wells (RW-1 through RW-5) and 13 DPE wells. LNAPLs were extracted using TFE in one source area. Air sparging was performed in 2 test wells in the same source area as the TFE wells. SVE was performed using 8 SVE wells and the 13 DPE wells.

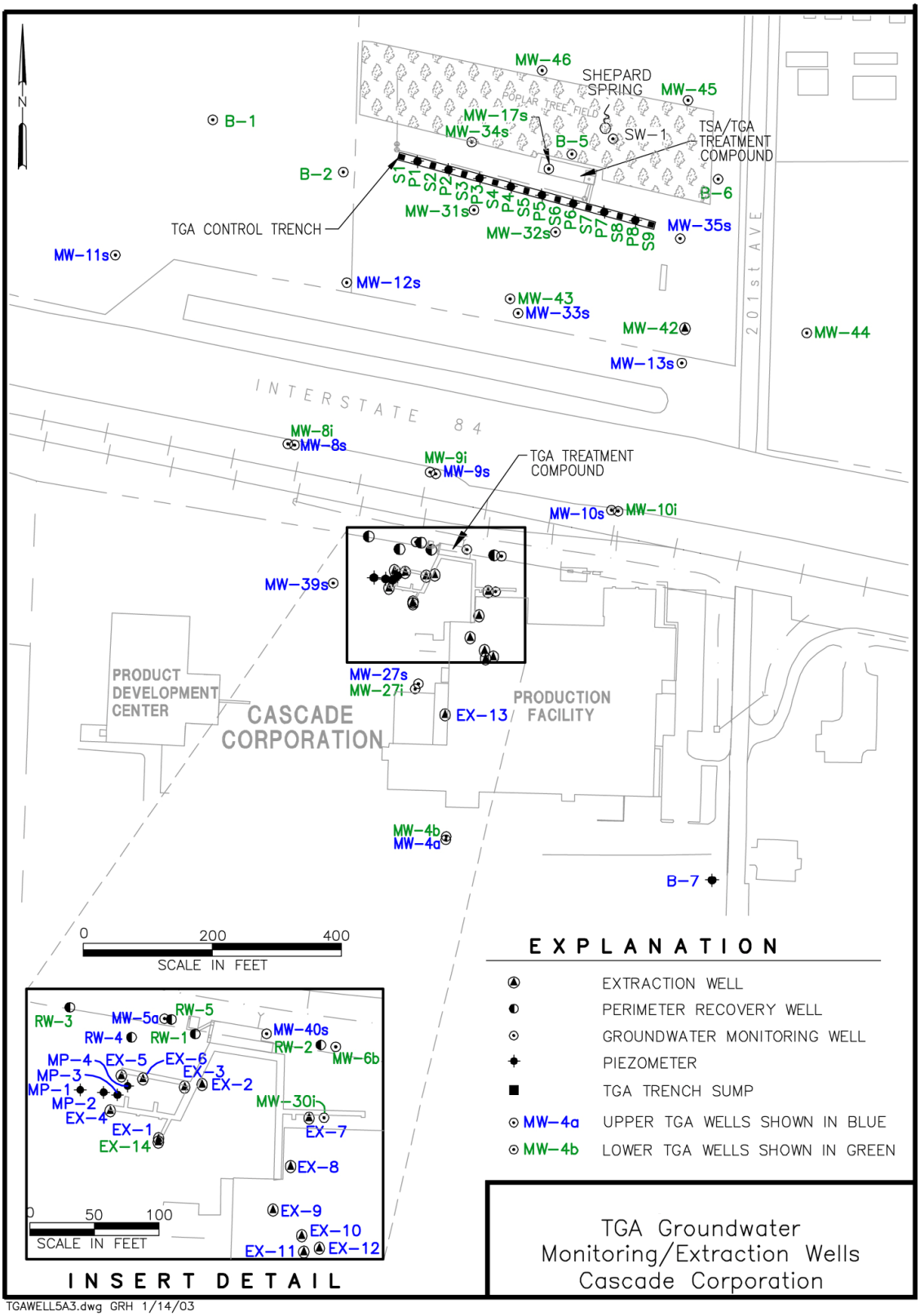
The groundwater monitoring network consists of 26 monitoring wells, 20 piezometers, 18 recovery wells, 18 extraction wells, 9 recovery trench sumps, and 5 spring locations, as shown in Figure 2.

The P&T, air sparging, and SVE systems were designed to operate 24 hours per day and 7 days per week, on an automatic basis

Groundwater Remediation

The groundwater pump and treat system was operated from 1991 to 1998. In 1998, extraction rates for individual on-site wells ranged from 0.01 to 5 gallons per minute (gpm), with a total groundwater extraction rate estimated to range from 8 to 11 gpm (420,000 to 550,000 gallons per month). These relatively low rates were attributed to the shallow depths of the extraction wells (15 at <27 ft, 3 at >35 ft, and 2 at >40 ft), limited available drawdown, and TGA characteristics.

Figure 2. Well Locations – Cascade Corporation [6]



The five on-site perimeter extraction wells were aligned perpendicular to the plume axis, and were designed to intercept contaminated groundwater at the Cascade facility boundary and to protect against off-site migration. The source area DPE wells were designed to shorten contaminant travel and cleanup times and to protect against off-site migration. The off-site control trench was designed to intercept the TGA plume upgradient of the TGA erosional truncation to protect surface water and the underlying Troutdale Sandstone Aquifer.

Perimeter extraction wells were phased into operation beginning in 1991. The control trench began operating in late 1995. In March 1998, source area DPE wells and LNAPL fluid extraction began. LNAPL extraction was terminated in October 1999 when there was no longer recovery of measurable levels of LNAPL. Source area groundwater extraction continued through 2002, at which time pulse pump operation began to cyclically desorb contaminants from the soil matrix during off-cycles and extract contaminants during on-cycles.

The Cascade Corporation planted 850 poplar trees in 2000 for future use in treating VOCs in groundwater north of the control trench. The trees will be incorporated into the remedy after sufficient root growth has occurred for groundwater interception and uptake.

Soil Vapor Extraction

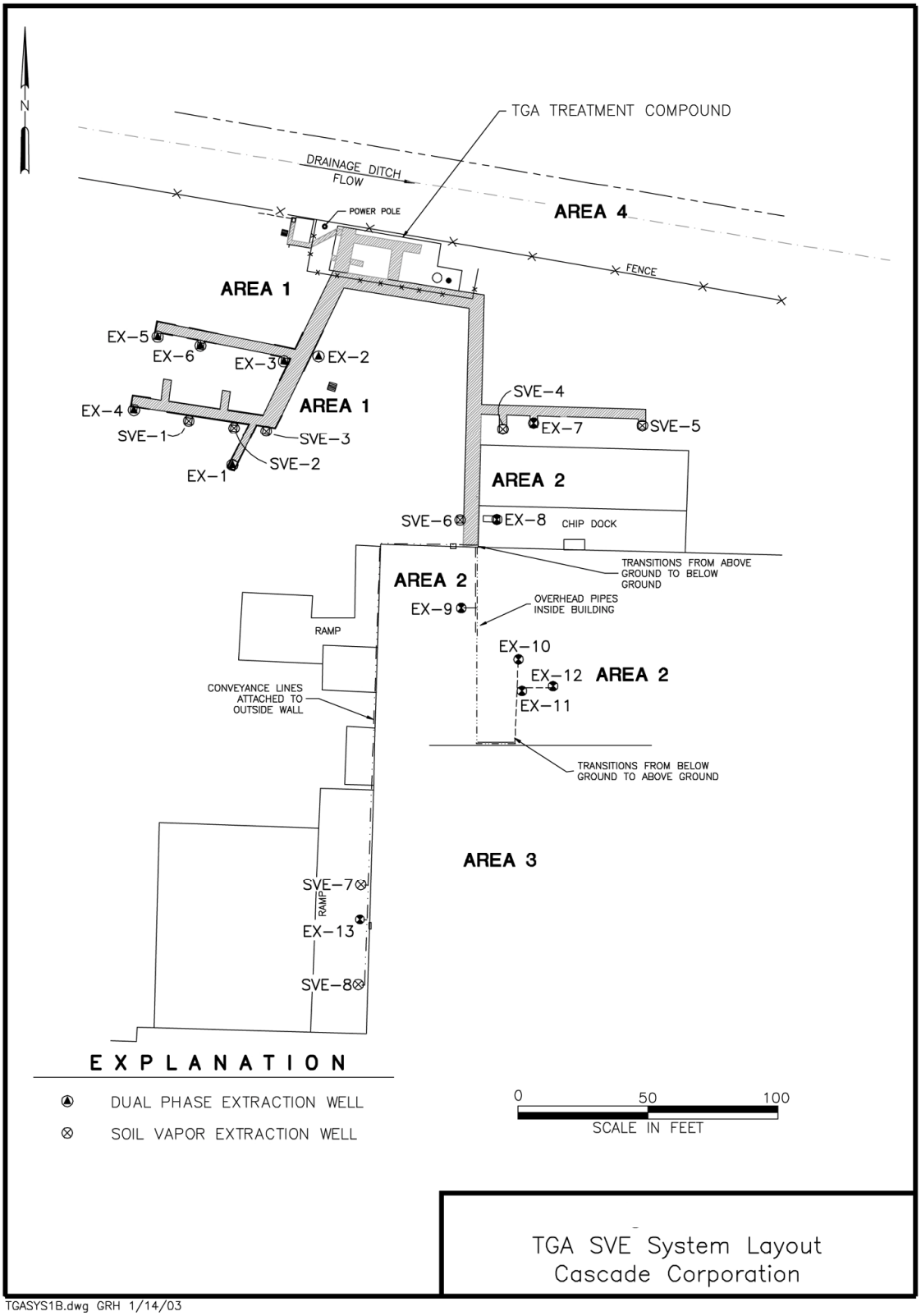
The SVE system began operating in March 1998 with vapor removal from 21 SVE and DPE source area wells, as shown in Figure 3. Extracted vapors were conveyed to a manifold system and a moisture separator, then a rotary positive blower, and finally discharged through a stack. Vapor extraction operated concurrent with air sparging through February 1999, at which time air sparge operation ceased. An SVE pilot shutdown and concentration rebound test was performed from March to October 1999, followed by seasonal SVE shutdown from October 1999 to May 2000. The system operated during the 2000 and 2001 summer/fall seasons and permanently ceased operation in December 2001. Shutdown vapor monitoring ceased in December 2002, based on the compliant mean concentration for total constituents of concern in vapor using the 90 percent upper confidence limit.

Air Sparging

Air sparging was performed as a pilot test using two air sparge wells (shown as AS-2 and AS-3 in Figure 2) from March 1998 through February 1999. The objectives for the test were to determine if sparging would enhance volatilization of VOCs from TGA groundwater, enhance SVE mass removal rates, and enhance the oxygen levels in groundwater and unsaturated soil to support the biodegradation of petroleum hydrocarbons. The sparge test was designed to operate while the groundwater extraction and SVE systems were operating, and began approximately 2 weeks after startup of the groundwater extraction and SVE systems.

Sparge pressures ranged from 1-6 pounds per square inch (psi) in the 2 wells, with flow rates ranging from 13 to 30 cubic feet per minute. Dissolved oxygen (DO) levels ranged from 1.2 to 12.2 mg/L in 4 extraction wells.

Figure 3. SVE/DPE System Layout [6]



Operating Parameters Affecting Treatment Cost or Performance [3]

Operating Parameter	Value
Groundwater extraction flow rate	8 to 11 gallons per minute
Air sparging injection air flow rate	13 to 30 cubic feet per minute
SVE extraction air flow rate	550 – 690 cubic feet per minute
SVE extraction vacuum level	Area 1: 35 – 70 inches water Areas 2 and 3: 3 – 20 inches water

Treatment Performance [2, 3, 6]

The ROD for OU 2 identifies the cleanup levels shown in Table 1 for groundwater and soil in the TGA.

Table 1. Cleanup Levels for Groundwater and Soil in TGA [2]

Chemical	Groundwater Cleanup Level (µg/L)	Soil Cleanup Level (mg/kg)
PCE	5	0.3
TCE	5	0.4
Cis-1,2-DCE	70	4.0
Vinyl Chloride	2	0.008
Chromium (VI)	100	(a)

NOTE:

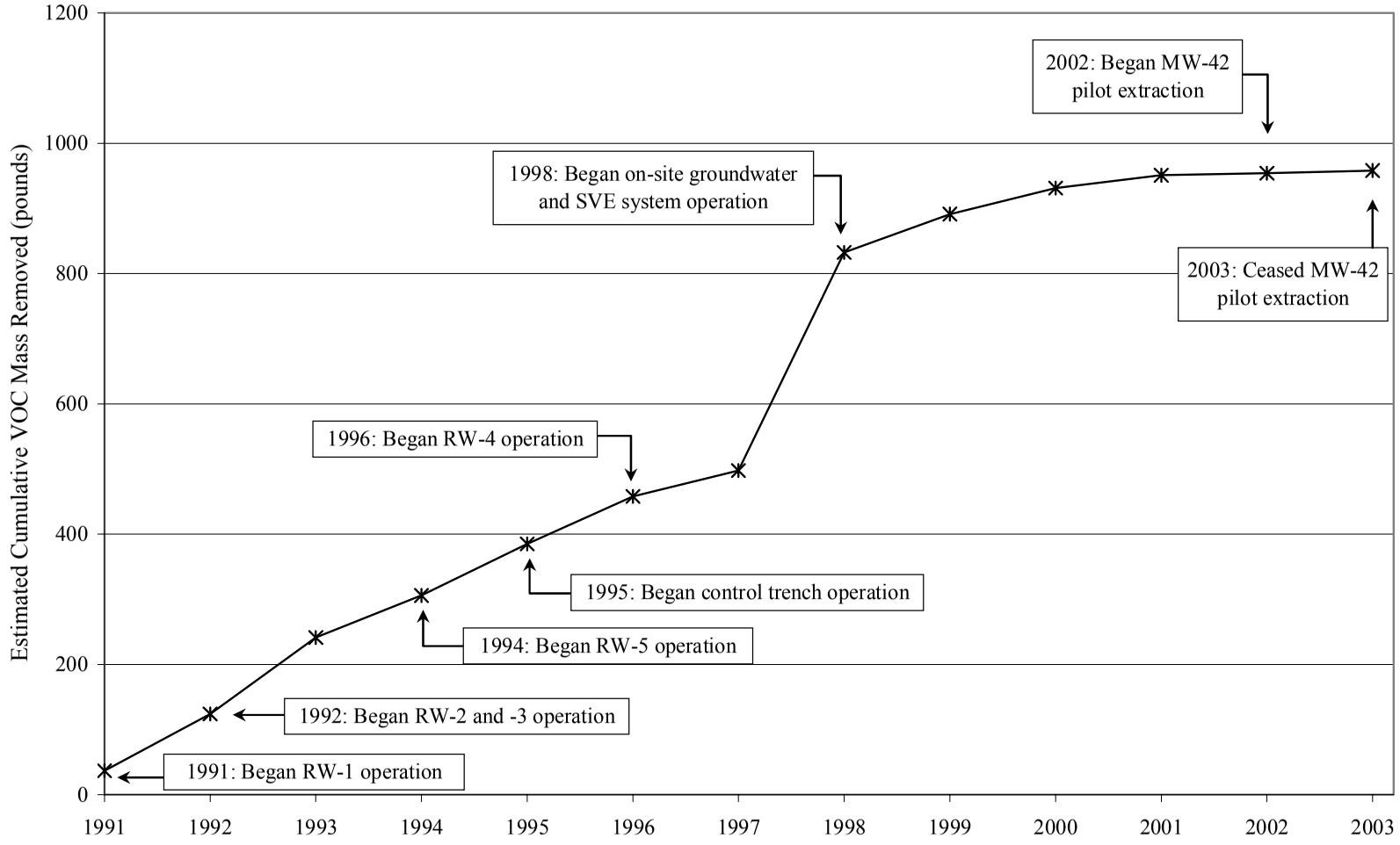
(a) Soil cleanup levels for Chromium (VI) shown as 1,500 mg/kg total waste analysis and as 0.86 mg/L Toxic Characteristic Leaching Procedure (TCLP)

In addition, the ROD indicated that the SVE system was to be operated until soil gas VOC concentrations were reduced to a concentration of 5 parts per million by volume (ppmv) in SVE extraction wells.

Performance data are available for the period from 1991 through 2003, in terms of annual VOC mass removed from groundwater, soil, and as LNAPL. As shown in Figure 4, a total of 958 pounds of VOCs were removed over that 13 year period, consisting of 561 pounds removed from groundwater, 377 pounds removed from soil, and 20 pounds removed as LNAPL.

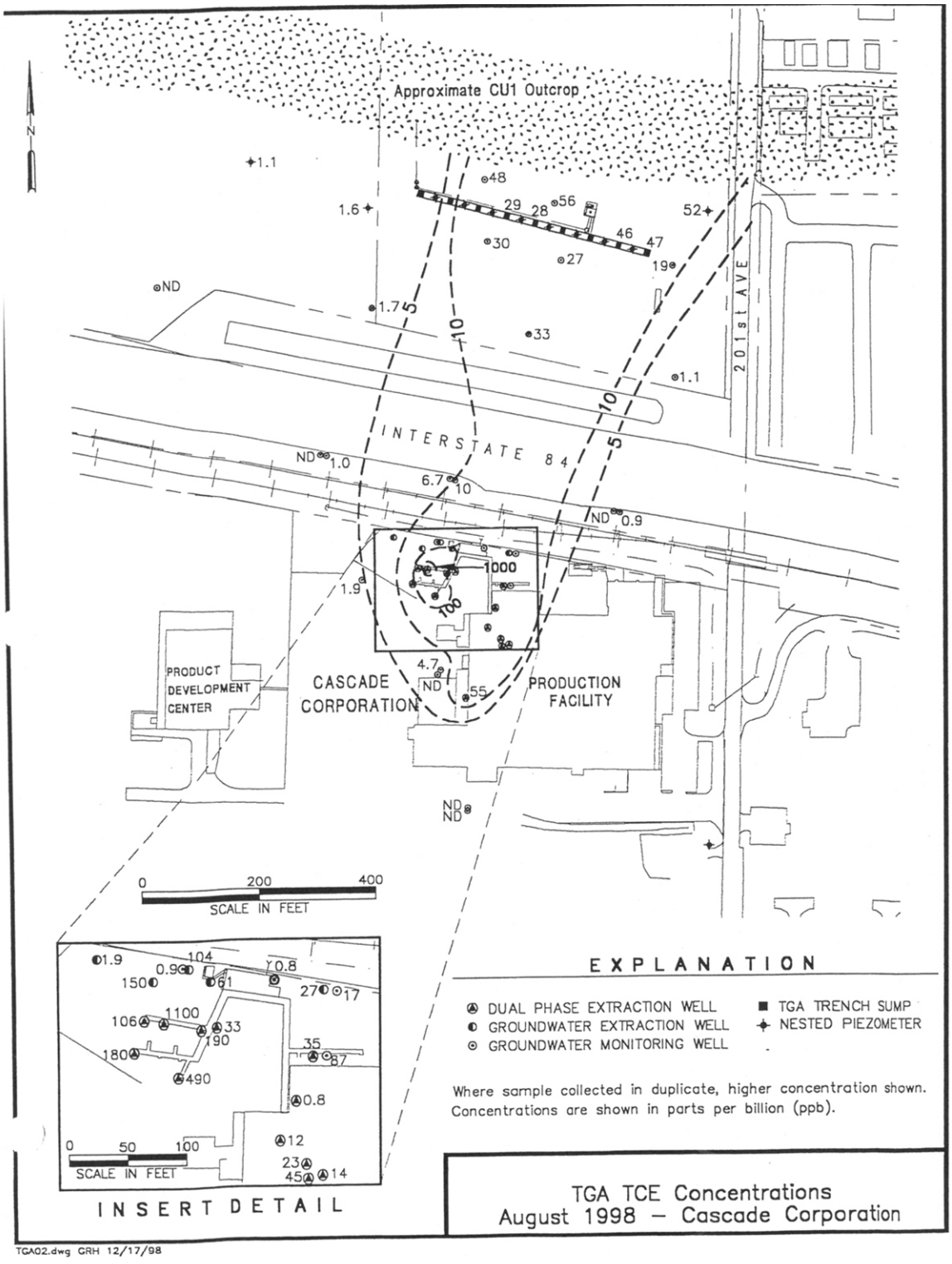
Figure 5 shows the extent of the TCE plume in the TGA groundwater as of August 1998 (5 months after RA system start-up). This figure does not show substantial change in the overall extent, size, and shape of the TCE plume, when compared with the data from 1996 shown in Figure 1.

Figure 4. Cumulative Remedy VOC Mass Removed – 1991 through 2003
Cascade Corporation TGA Remedy [6]



NOTE: Data shown represents VOC mass removed for LNAPL, groundwater, and soil vapor, and does not include soil removal actions.

Figure 5. TCE Plume in TGA Groundwater – August 1998 [3]



The extent of the TCE plume in TGA groundwater as of February and August 2003, as shown in Figures 6 and 7, respectively, shows significant on-site plume size and concentration reductions, compared with the 1996 data shown in Figure 1. The most pronounced reductions have occurred in Source Area 1 wells (source areas are shown on Figure 3), as reflected by the Area 1 1998 annual average TCE concentration of 1,530 µg/L and the Area 1 2003 annual average TCE concentration of 58 µg/L. 2003 annual average TCE concentrations in other source areas ranged from 7.8 to 39 µg/L. Annual average cis-1,2-DCE concentrations in Source Areas 1 through 4 ranged from 3.3 to 83 µg/L in 2003, with highest concentrations in Source Area 1. PCE concentrations are highest in Source Area 3 and show little restoration progress since remedy startup. The 2003 annual average PCE concentration in Area 3 was 158 µg/L, compared with the 1998 annual average of 94 µg/L. Other source area annual average PCE concentrations in 2003 ranged from 1.7 to 7.9 µg/L. Vinyl chloride annual average concentrations have remained below the cleanup level since 1999. Chromium concentrations have remained below the cleanup level since remedy startup in 1998.

TCE is the primary constituent of concern that is present at concentrations above the cleanup level in off-site wells. Off-site 2003 annual average TCE concentrations in the TGA range from 8.9 µg/L upgradient of the control trench to 26 µg/L downgradient of the control trench. These compare with annual average concentrations of 13 and 63 µg/L, respectively, in 1998. Highest off-site TCE concentrations are present in wells screened across the Lower TGA and portions of the underlying siltstone transition zone that grades downward into Confining Unit 1.

On-Site Groundwater Treatment System

From April to November 1998, the on-site groundwater treatment system removed a total of approximately 28 pounds of VOCs (Figure 8). During this time, a total of 4 million gallons of groundwater were extracted. The majority of VOCs extracted were TCE and cis-1,2-DCE, with lesser amounts of PCE and negligible amounts of vinyl chloride. TCE concentrations ranged from 61 to 280 µg/L, DCE from 140 to 420 µg/L, PCE from 5.2 to 10 µg/L, and VC less than 0.5 µg/L. These data show that the concentrations of TCE, DCE, and PCE were higher than their respective cleanup goals through November 1998. During this same time period, the off-site TGA control trench removed a total of approximately 1.8 pounds of VOCs from nearly 5 million gallons of extracted groundwater.

On-site annual mass removal rates have declined since 1998, with approximately 1.73 pounds of TCE, cis-1,2-DCE, PCE, and VC removed in 2003. Approximately 2.35 pounds of these contaminants of concern (COCs) was removed through off-site control trench extraction in 2003.

Chromium concentrations in groundwater have remained consistently below the cleanup level since remedy startup in 1998. Chromium analyses were therefore discontinued in 2002.

Figure 6. TGA TCE Concentrations – February 2003 [6]

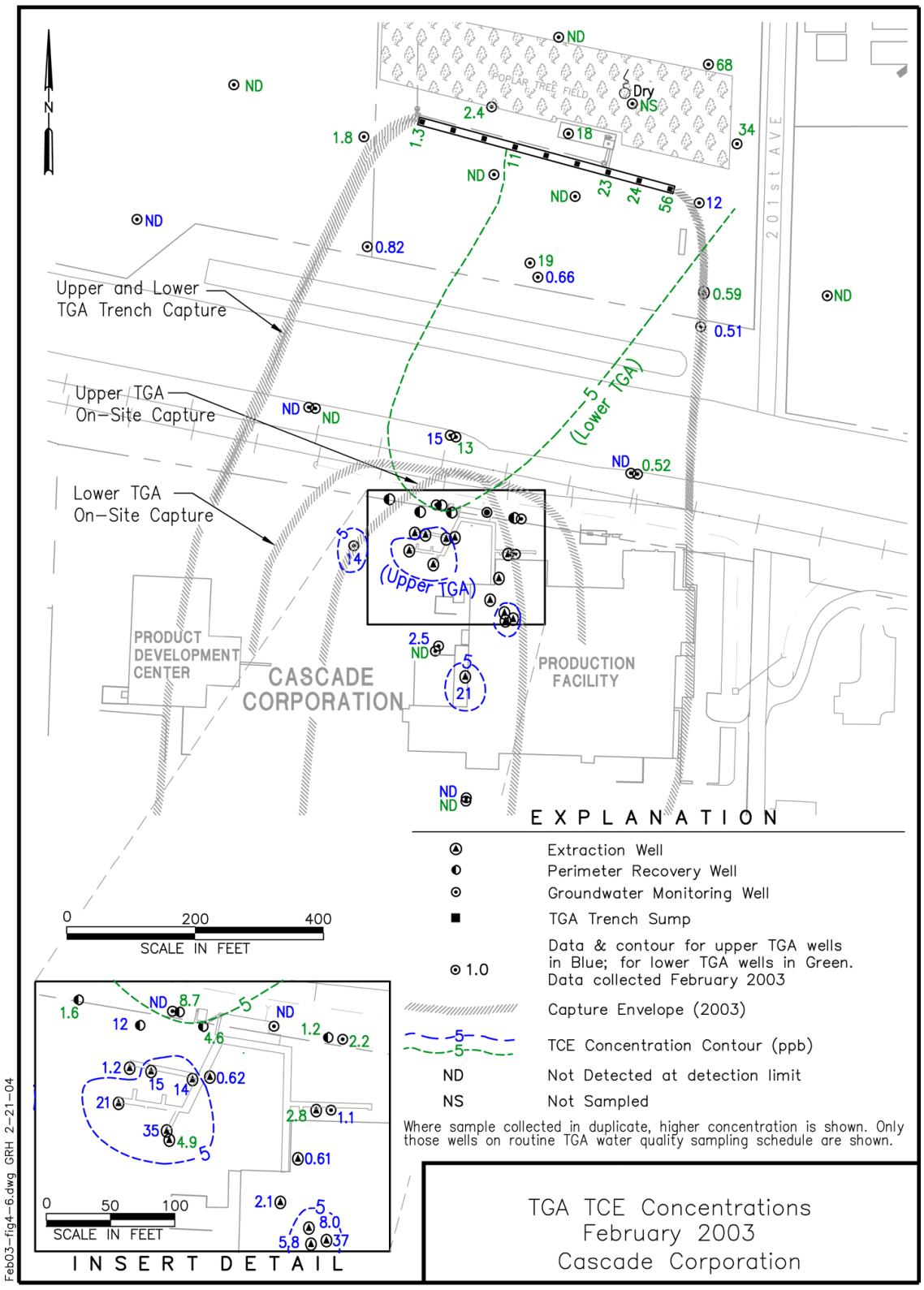


Figure 7. TGA TCE Concentrations - August 2003 [6]

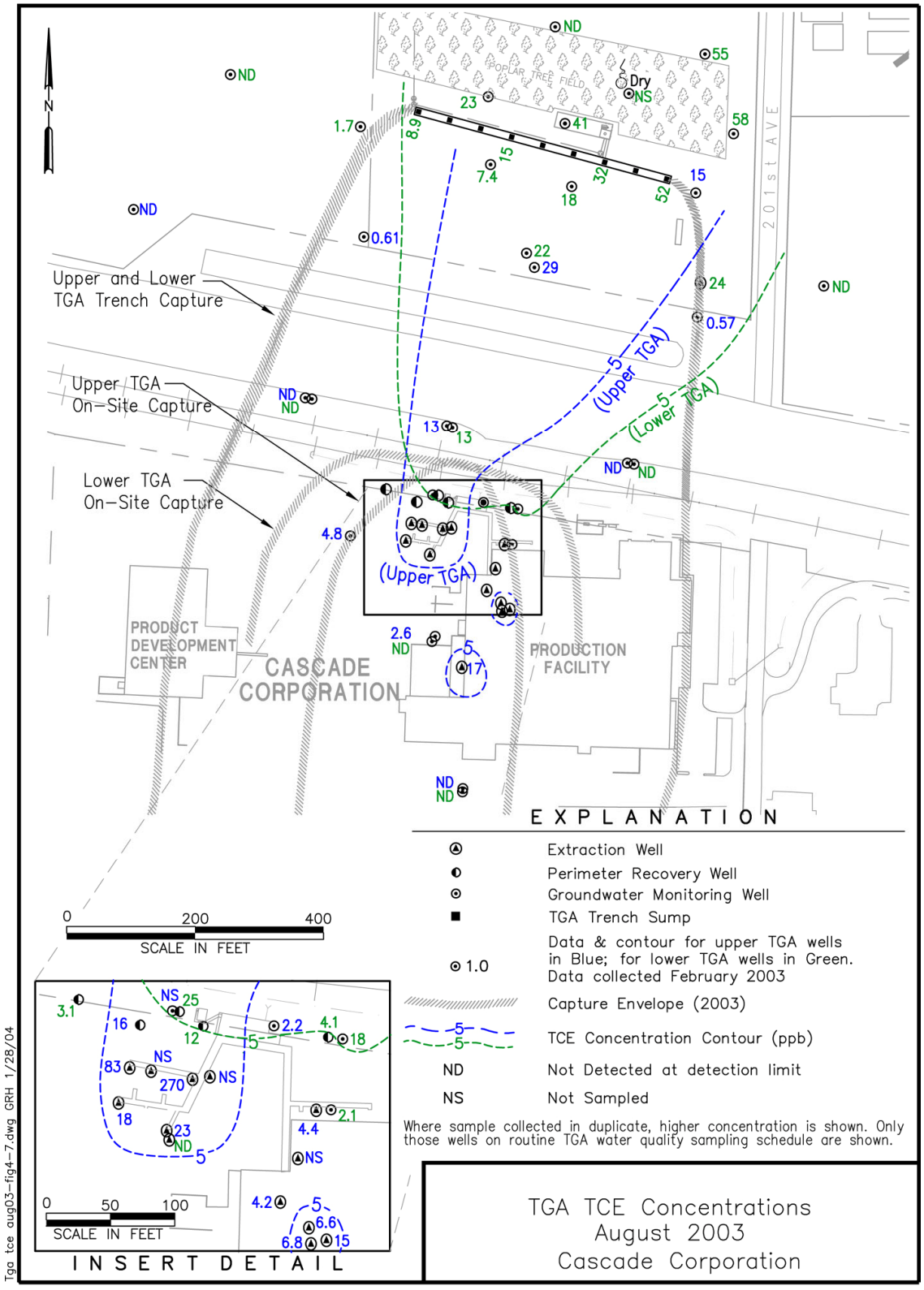
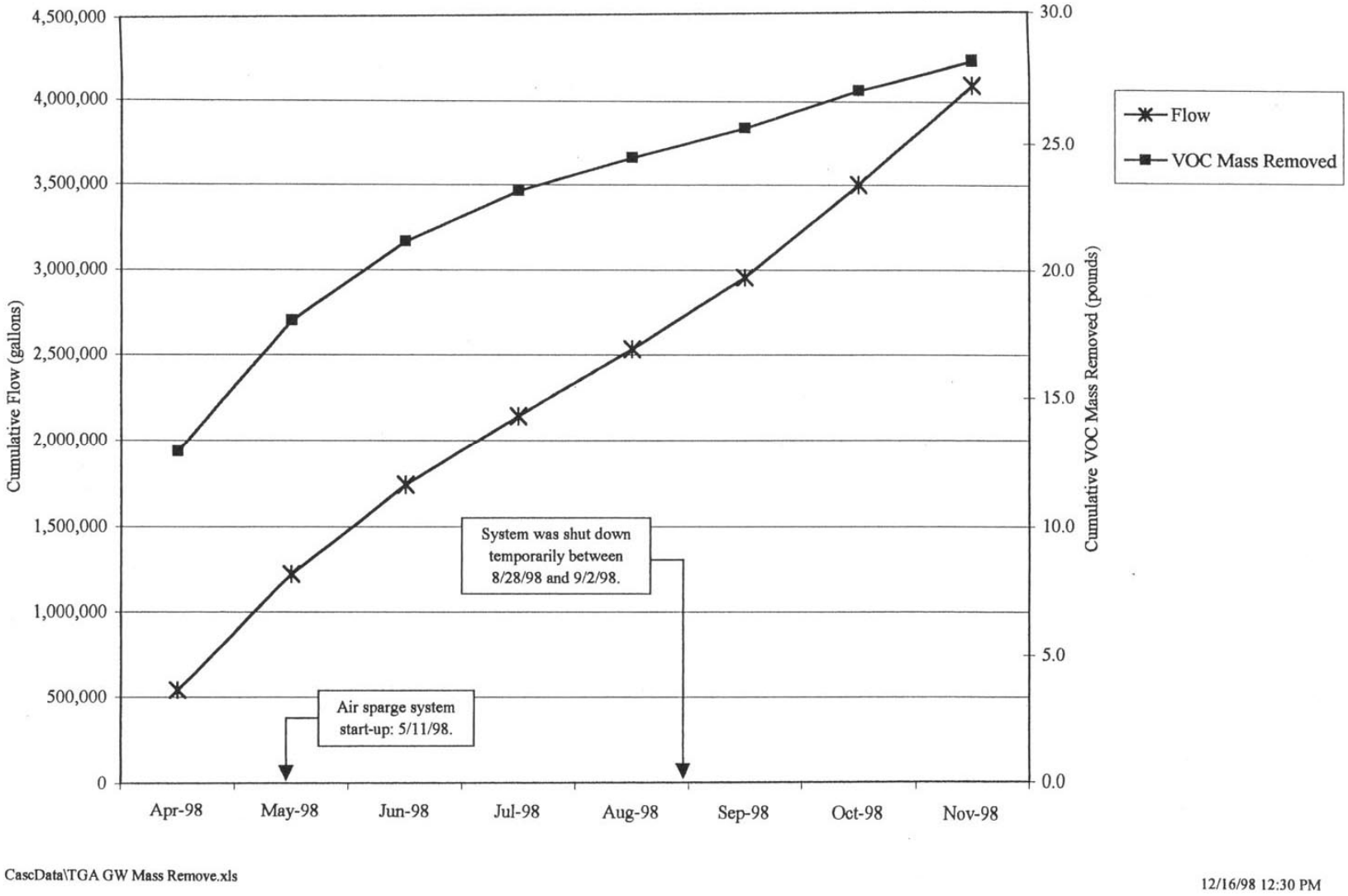


Figure 8. On-Site Groundwater Treatment System Results - April to November 1998 [3]



Soil Vapor Extraction System

From April to November 1998, the SVE system removed a total of approximately 310 pounds of total VOCs (Figure 9). TCE and cis-1,2-DCE had the highest concentrations of the constituents measured, with TCE ranging from 420 to 4,200 parts per billion by volume (ppbv) and DCE from 71 to 2,100 ppbv. Total VOCs ranged from less than 1 ppmv to 2.7 ppmv (using Method TO-14) or to 13.1 (using a PID). According to the site contractor, VOC concentrations in most vapor extraction wells had decreased to less than 5 ppmv, the ROD goal.

The vapor cleanup level was revised downward in 2000 to 0.5 ppmv (500 ppbv), based on re-evaluation of previous groundwater protection analyses. 2002 vapor sample results were used to calculate the 90 percent upper confidence limit of the mean concentration for total COCs after system shutdown in December 2001. The calculated mean concentration was 0.257 ppmv for 2002, below the revised cleanup level.

Air Sparging Pilot Test

Results of the pilot-scale air sparging system, used from May 1998 to February 1999, are shown in Figure 9. The startup of the air sparging system appeared to lead to a spike in VOC mass removal by the SVE system, but this spike was not sustained and the VOC mass removal returned to a relatively low level shortly after startup. The air sparging did not have a substantial effect on the VOC mass removal by the groundwater extraction system, as shown in Figure 8. The site contractor concluded that the air sparging system did not have a significant effect on increasing mass removal and recommended that its use be discontinued at the site.

Treatment Cost [4]

Prowell Environmental, Inc. (Prowell) provided detailed information about the actual costs for the air sparging and SVE operations at the TGA remediation. Table 2 provides a summary of the capital and operation and maintenance (O&M) costs for the combined air sparging/SVE system for the years 1997-2002. As shown in Table 2, the total cost for treatment (without disposal of residues) was approximately $406,000.

Prowell also provided detailed information about the actual costs for the groundwater extraction operations at the TGA remediation, as shown in Table 3 for the years 1997-2003. As shown in Table 3, the total cost for groundwater extraction (without disposal of residues) was approximately $2,000,000.

For the 958 pounds of VOC removed by the system during this time, the cost corresponds to a calculated unit cost of $2,540 per pound of VOC removed.

Figure 9. SVE System Results - April to November 1998 [3]

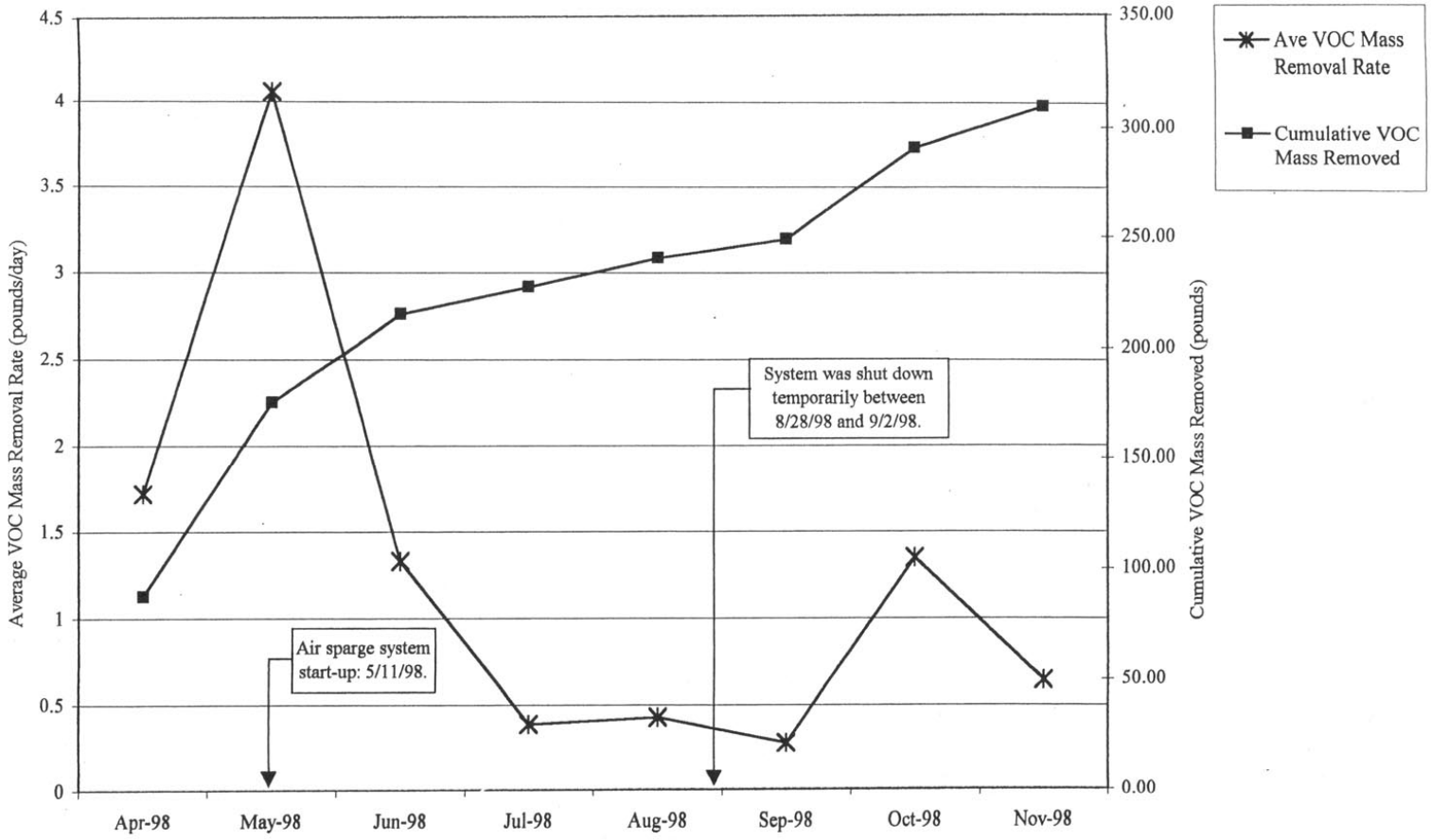


Table 2. Summary of Capital and O&M Costs for Combined Air Sparging/SVE System for TGA Remedy, 1997-2002 [4]

Cost Category/Element	Cost ($ Year Basis)						Description
	1997	1998	1999	2000	2001	2002	
Capital Cost Elements							
Technology mobilization, setup, and demobilization	0	0	0	0	0	0	Included in construction cost
Planning and preparation	2,000	10,504	0	0	0	0	SVE bid, PM, DEQ coord., and admin
Site work	0	0	0	0	0	0	-
Equipment and appurtenances							
Structures	12,896	14,550	0	0	0	0	SVE pipe and treatment equipment
Construction	29,349	59,311	0	0	0	0	Sparge/SVE wells, pipe and equipment installation
Other	0	11,328	0	0	0	0	Construction/O&M reports and construction oversight
TOTAL CAPITAL	44,245	95,693	0	0	0	0	-
O&M Cost Elements							
Labor and materials (O&M)	0	53,228	6,257	2,723	2,350	0	-
Labor and materials (Monitoring)	0	27,071	6,392	2,458	2,700	1,800	-
Utilities and fuel	-	-	-	-	-	-	SVE electricity in Cascade facility bill
Equipment ownership, rental, or lease	0	0	0	0	0	0	-
Performance testing and analysis	0	13,820	29,472	11,954	12,506	4,350	All vapor samples
Other (supplies, health and safety)	0	0	14,579	6,621	3,000	0	Annual O&M plans, meetings, PM

Table 3. Summary of Capital and O&M Costs for Combined Air Sparging/SVE System for TGA Remedy, 1997-2002 [4] (Continued)

Cost Category/Element	Cost ($ Year Basis)						Description
	1997	1998	1999	2000	2001	2002	
Data management, validation, and quarterly reporting	0	6,936	4,772	2,232	1,720	860	-
Annual and monthly reporting	0	12,958	16,933	8,500	6,500	4,000	DEQ meetings and annual reports (SVE portion)
TOTAL O&M	0	114,013	78,405	33,588	28,776	11,010	
Other Technology-Specific Costs							
Compliance testing and analysis	0	0	0	0	0	0	Included under performance testing
Soil, sludge, and debris excavation, collection, and control	0	0	0	0	0	0	-
Disposal of residues	4,000	0	0	0	0	0	IDW for 2 sparge and 3 piezo wells
TOTAL Other Technology-Specific Costs	4,000	0	0	0	0	0	-
TOTAL COST (by year)	**44,245**	**209,706**	**78,405**	**33,588**	**28,776**	**11,010**	
TOTAL COST (all years, without residue disposal)	**$405,629**						

Table 3. Summary of Capital and O&M Costs for Groundwater Extraction System for TGA Remedy, 1997-2003 [6]

Cost Category/Element	Cost ($ Year Basis)						
	1997	1998	1999	2000	2001	2002	2003
Capital Cost Elements							
Technology mobilization, setup, and demobilization	0	0	0	0	0	0	0
Planning and preparation	42,155	45,913	0	0	3,231	0	0

Table 3. Summary of Capital and O&M Costs for Groundwater Extraction System for TGA Remedy, 1997-2003 [6] (Continued)

Cost Category/Element	Cost ($ Year Basis)						
	1997	1998	1999	2000	2001	2002	2003
Site work	0	0	0	0	0	0	0
Equipment and appurtenances							
Structures	19,614	43,448	0	0	0	0	0
Construction	84,344	341,088	0	0	28,375	4,403	0
Other	0	16,746	0	0	0	0	0
TOTAL CAPITAL	146,113	447,196	0	0	31,606	4,403	0
O&M Cost Elements							
Labor and materials (O&M)	31,936	142,489	109,838	42,332	55,132	36,615	22,745
Labor and materials (Monitoring)	103,798	39,647	71,889	36,218	41,559	22,895	21,752
Utilities and fuel	1,600	1,600	1,700	1,700	1,800	1,890	2,513
Equipment ownership, rental, or lease	0	0	0	0	0	0	0
Performance testing and analysis	840	24,204	27,106	20,934	25,334	25,974	25,989
Other (supplies, health and safety)	4,100	33	0	0	0	0	0
Data management, validation, and quarterly reporting	58,623	46,507	39,234	36,887	38,760	56,707	56,475
TOTAL O&M	200,897	254,480	249,767	138,071	162,505	144,081	129,474
Other Technology-Specific Costs							
Compliance testing and analysis	0	0	0	0	0	0	0
Soil, sludge, and debris excavation, collection, and control	0	0	0	0	0	0	0
Disposal of residues	25,712	89,301	0	0	868	0	0
TOTAL Other Technology-Specific Costs	25,712	89,301	0	0	868	0	0
TOTAL COST (by year)	**372,722**	**790,977**	**249,768**	**138,071**	**195,059**	**148,484**	**129,474**
TOTAL COST (all years, without residue disposal) $2,024,554							

Observations and Lessons Learned [6]

Performance data from 1991 through 2003 show that a total of 958 pounds of VOCs were removed from the site using groundwater pump and treat, air sparging, SVE, DPE, and TFE. The total mass removed consisted of 561 pounds removed from groundwater, 377 pounds removed from soil, and 20 pounds removed as LNAPL.

While the extent of the TCE plume in TGA groundwater showed significant on-site plume size and concentration reductions from 1996 to 2003, concentrations remained above cleanup levels.

The total cost for use of groundwater pump and treat, air sparging, SVE, DPE, and TFE, was approximately $2,430,000, corresponding to a calculated unit cost of $2,540 per pound of VOC removed, based on a cumulative total of 958 pounds removed. Approximately 90% of the total cost was attributed to the groundwater extraction system.

The following observations and lessons learned were provided by the site contractor:

- Early on-site groundwater extraction provided the greatest annual rate of pounds of mass removed, reinforcing the value of early near source IRAM actions.

- The off-site control trench has been an effective interceptor of plume movement, to the extent that it transects the off-site TGA plume. Additional plume characterization before control trench IRAM design would have helped delineate the full length of interceptor trench line needed. However, as an IRAM, the time delay and costs for further characterization were not consistent with the higher value of taking plume interception actions as soon as possible.

- Soil vapor extraction was most effective in removing source area mass during the first year of operation. SVE was specifically well suited for Source Area 1, where LNAPL was present above TGA groundwater and thus available for vapor extraction with concurrent groundwater extraction drawdown.

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Sources:

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