

COST AND PERFORMANCE REPORT

Pump and Treat, *In Situ* Chemical Oxidation, and
Soil Vapor Extraction
at the Union Chemical Company Superfund Site,
South Hope, Maine

December 2001

SITE INFORMATION

IDENTIFYING INFORMATION

Site Name: Union Chemical Company Superfund Site

Location: South Hope, Maine

CERCLIS #: MED042143883

ROD Date: December 1990

ESD Date: April 1994

TREATMENT APPLICATION

Type of Action: Remedial

Period of Operation: January 1996 - Ongoing (data available through October 2000)

Quantity of Groundwater Treated: 8,352,867 gallons (January 1996 through December 1999)

Quantity of Soil Treated: 48,000 cubic yards

BACKGROUND

Historical Activity that Generated Contamination at the Site: Chemical manufacturing, solvent recovery, and hazardous waste treatment

Waste Management Practice That Contributed to Contamination: Leaking storage drums, spills, use of a septic tank and a leachfield for disposal of process wastewater

Facility Operations [5,6,7]:

- C The 12.5-acre Union Chemical Company (UCC) Superfund Site is located in a rural area of Maine approximately seven miles west of Rockport and 32 miles east of Augusta. The site is bounded on the east and southeast by Quiggle Brook, on the north by Route 17, and on the southwest and west by woodland. The eastern boundary of the site includes a floodplain and wetland area.
- C UCC operated from 1967 to 1986 as a producer and distributor of solvent for the removal of furniture finishes. Operations were expanded in 1969 to include solvent reclamation and recycling services; these services subsequently developed into UCC's primary business.
- C In 1979, the Maine Department of Environmental Protection (MEDEP) discovered that groundwater at the site was contaminated with volatile organic compounds (VOCs). Waste treatment operations at the site were discontinued in 1984, at which time MEDEP and EPA removed from the site all drums and liquid storage tanks (2,000 drums and 30 liquid storage tanks containing over 10,000 gallons of liquid waste and sludge), as well as some contaminated soil.
- C The UCC site was added to the National Priorities List (NPL) in October 1989.

- C From 1988 through 1990, a Remedial Investigation (RI) and Feasibility Study (FS) were performed to assess the source, nature, and extent of contaminated groundwater and soil. The RI/FS showed that on-site groundwater and soils and off-site surface water (Quiggle Brook) had been contaminated with VOCs, but that contaminants had not migrated across Quiggle Brook.

Regulatory Context [5,6]:

- C A Record of Decision (ROD) was issued for the site in December 1990 and included groundwater remediation, as well as remediation of contaminated on-site soil, debris, sludge, and facilities.
- C An Explanation of Significant Differences (ESD) was issued in April 1994 to change the treatment technology for contaminated soils and to expand the groundwater extraction system into the source area.

Remedy Selection: The selected groundwater remedy is vacuum-enhanced groundwater extraction, on-site groundwater treatment, and on-site discharge of treated groundwater into Quiggle Brook. The original soil remedy was excavation and on-site low temperature aeration of the source area soils. In April 1994, the soil remedy was changed to soil vapor extraction (SVE) for more aggressive cleanup. Because soil excavation is not required with SVE, this remedy also allowed the groundwater extraction system to be expanded into the source area.

SITE LOGISTICS/CONTACTS

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MATRIX DESCRIPTION

MATRIX IDENTIFICATION

Type of Matrix Processed Through the Treatment System: Groundwater

CONTAMINANT CHARACTERIZATION [2,5,7,10]

Primary Contaminant Groups: Halogenated and non-halogenated volatile organic compounds (VOCs)

- C During the remedial investigation (RI), VOCs and N,N-dimethylformamide (DMF), a semi-volatile organic compound, were detected in the shallow and bedrock aquifers at the site. Metals, primarily iron and manganese, have also been detected in the groundwater. Contaminated soil at the site was determined to be a source for groundwater contamination.
- C During the RI, the VOCs most frequently detected in the groundwater included (in decreasing order of frequency) 1,1-DCA, TCE, 1,1-DCE, and 1,1,1-TCA. The maximum initial concentrations of these contaminants (in ug/L) were 12,000 (1,1-DCA); 84,000 (TCE); 2,700 (1,1-DCE); and 73,000 (1,1,1-TCA).
- C A maximum N,N-DMF concentration of 29,000 ug/L was observed in the groundwater in April 1996 (in Well B-12S).
- C Two contaminated groundwater plumes are present in the area between the UCC facility and Quiggle Brook. The more northerly plume resulted from the migration of chemical constituents from an old leach field on the site, while the source of the more southerly plume is believed to be a former drum storage area south of the plant buildings, where a storage tank had reportedly leaked. Information is not available about the initial size of the two plumes.
- C Figures 1 and 2 show TCE concentrations observed during a sampling episode conducted in November 1994 (prior to the beginning of remediation at the site) in the shallow and bedrock aquifers, respectively. As shown in these figures, TCE concentrations were as high as 9,800 ug/L in the shallow aquifer (overburden wells) and 1,300 ug/L in the bedrock aquifer. Isoconcentration contours were not available for the bedrock aquifer.

MATRIX CHARACTERISTICS AFFECTING TREATMENT COSTS OR PERFORMANCE

Hydrogeology [2,5]:

Two aquifer systems have been identified beneath the site - a shallow aquifer and a bedrock aquifer. The shallow aquifer flows easterly and discharges into Quiggle Brook. The shallow aquifer consists of poorly graded sands and silts and extends downward from 5 to 10 ft bgs to a depth of 20 feet bgs in the northwest corner of the site and to a depth of 70 to 80 feet bgs under the main plant buildings and near Quiggle Brook. The bedrock aquifer also flows easterly and likely discharges into Quiggle Brook. The bedrock aquifer consists of highly fractured bedrock and extends downward below the shallow aquifer to a depth of 165 feet bgs or more. Table 1 presents technical aquifer information.

Table 1. Technical Aquifer Information [2,5]

Unit Name	Thickness (ft)	Conductivity (ft/day)	Average Linear Velocity (ft/year)	Flow Direction
Shallow	20 - 80	Not provided	<20	East
Bedrock	85 - 165	Not provided	<20	East

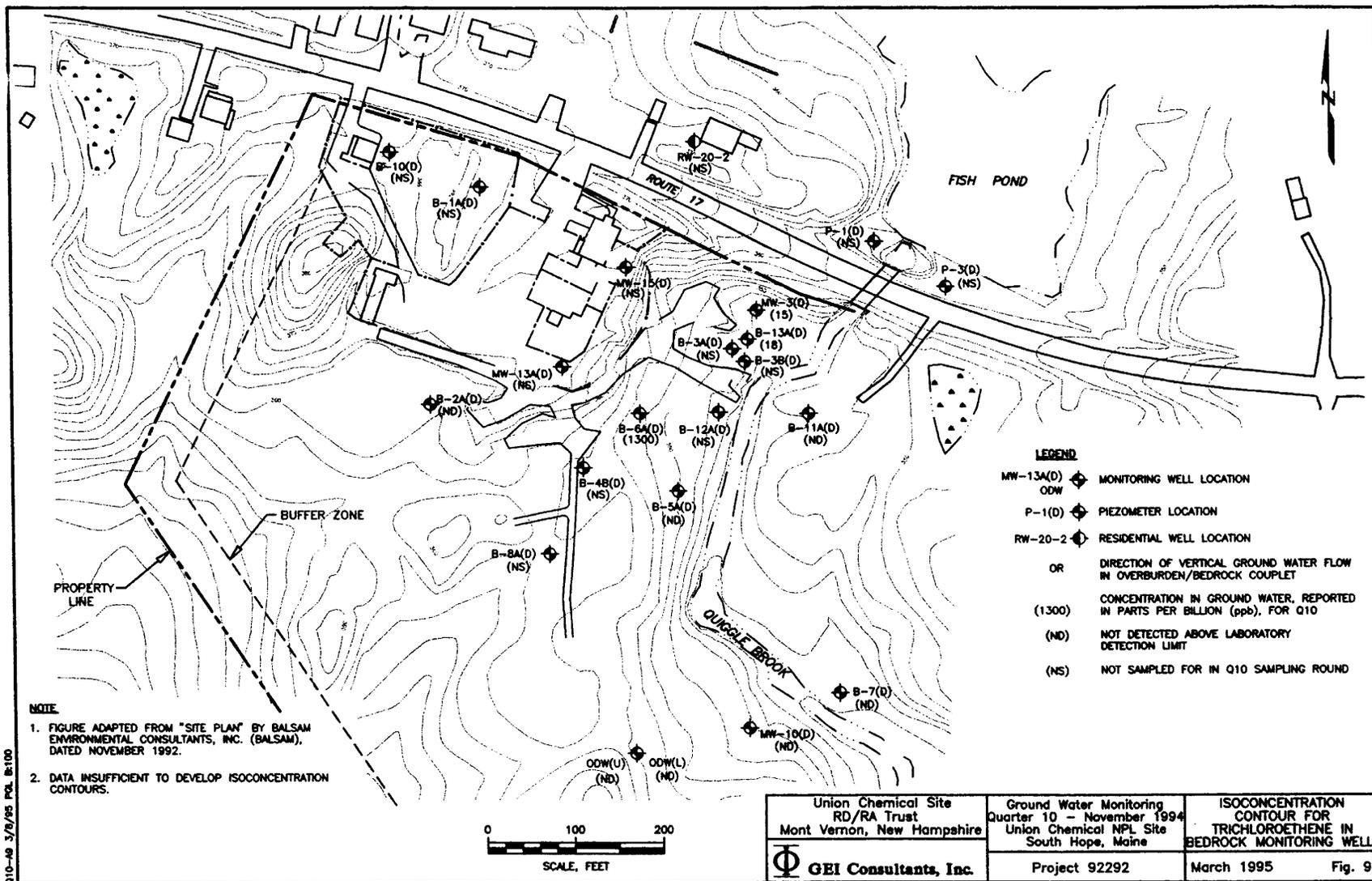


Figure 2. TCE Concentrations in the Bedrock Aquifer - November 1994 [16]

TREATMENT SYSTEM DESCRIPTION

PRIMARY TREATMENT TECHNOLOGY [7]

- Pump and treat (P&T) with metals removal (oxidation, pH adjustment, flocculation, and clarification), filtration, organics removal (air stripping and UV/oxidation), and granular activated carbon (GAC)
- Soil vapor extraction (SVE) enhanced with hot air injection
- *In situ* chemical oxidation (sodium permanganate and potassium permanganate addition)

SUPPLEMENTAL TREATMENT TECHNOLOGY [7]

Thermal oxidation of vapors from the various water treatment units and the SVE unit

SYSTEM DESCRIPTION AND OPERATION

System Description [7,11,12,13]:

The three technologies that are being used to treat soil and groundwater at the Union Chemical Company site (pump and treat, soil vapor extraction, and *in situ* chemical oxidation) are described below. The pump and treat system is being used to remove contaminants and to draw down the water table to increase the size of the vadose zone being treated by SVE.

Pump and Treat System

- C The groundwater extraction system consists of 28 wells, all screened in the shallow aquifer. Table 2 presents technical extraction well data.
- C The above-ground treatment system includes a metals removal system (MRS). The MRS uses oxidation, pH adjustment, flocculation, clarification, and filtration processes to remove mainly iron and manganese from the water. Extracted groundwater is pumped to an equalization tank, where compressed air is injected into the tank to oxidize the inorganic compounds in the water. Potassium permanganate (KMnO₄) and sodium hydroxide (NaOH) convert the soluble metals into insoluble suspended salts. The KMnO₄ is added to enhance the oxidation of the inorganic compounds in the water stream and the NaOH is added to adjust the pH range to optimize the precipitation of the target metals. A polymer solution then groups the particulate inorganics into “flocs”. The flocs settle out of the water stream as the water flows through an inclined plate clarifier. The pH of the water is readjusted back to the neutral range after clarification. A multi-media filter system removes residual inorganic floc. Sludge is periodically pumped from the MRS, dewatered in a filter press, and disposed of as nonhazardous waste.
- C Organics are removed from the water by air stripping, UV/oxidation, and activated carbon adsorption. The metal tray-type air stripper volatilizes VOCs. The VOC-laden air is destroyed by thermal oxidation. The UV/oxidation system reduces large-chain chemicals to carbon dioxide and water by mixing hydrogen peroxide with the water and then subjecting the water to an intense stream of ultraviolet light. Two granulated activated carbon filters remove residual organic compounds from the water through adsorption.
- C The treated water is either discharged via gravity to Quiggle Brook or used for alternate purposes inside the treatment complex, such as wash down.

Table 2. Extraction Well Data [7]

Well Name	Unit Name	Depth (feet bgs)
P-1	Shallow	39.5
P-2	Shallow	44.5
P-3	Shallow	50.5
P-4	Shallow	51.5
P-5	Shallow	49.5
P-6	Shallow	50.5
P-8	Shallow	57.5
P-9	Shallow	52.5
P-10	Shallow	57.5
P-11	Shallow	60.5
P-12	Shallow	61.5
P-13	Shallow	58.5
P-14	Shallow	58.5
P-15	Shallow	63.5
P-16	Shallow	66.5
P-16A	Shallow	69.5
P-17	Shallow	65.5
P-19	Shallow	62.5
P-20	Shallow	64.5
P-21	Shallow	67.5
P-22	Shallow	64.5
P-23	Shallow	64.5
P-24	Shallow	62.5
P-25	Shallow	62.5
P-26	Shallow	66.5
P-27	Shallow	69.5
P-28	Shallow	67.5
P-29	Shallow	65.5

- C The groundwater monitoring network includes 109 wells. For each monitoring event, only approximately 20 wells were sampled and analyzed. From January 1996 through April 1998, the groundwater was monitored quarterly. After April 1998, groundwater monitoring was performed semi-annually.

Soil Vapor Extraction

- C The enhanced SVE system consists of 124 wells (information was not provided about the location and depth of SVE wells). Thirty-three SVE wells remove volatile constituents from the soil above the water table. Ninety-one hot air injection wells heat the soils and increase volatilization. All volatilized compounds removed during SVE are treated in an on-site thermal oxidizer prior to discharge to the atmosphere.
- C The SVE system was a primary means to remove contaminants at the site. In addition to containing the groundwater contamination, the pump and treat system was used to dewater the soil so that it could more easily be treated using the SVE system. This approach doubled the volume of soil that was treated by SVE.
- C The ground surface at the UCC site was graded, capped, and sealed with low-permeability clay to consolidate soils, minimize the discharge of water into the subsurface, and enhance SVE.

In Situ Chemical Oxidation

- C In October 1997 and June 1998, pilot-scale tests of *in situ* chemical oxidation using permanganate addition were performed at the site. Based on the results of those tests, in 1999 and 2000, *in situ* chemical oxidation was used on a full-scale basis to treat groundwater at the site, using the PermOX-ITSM process.
- C *In situ* chemical oxidation at the Union Chemical Company site included injection of potassium permanganate in a two percent solution and sodium permanganate in a 20 to 40 percent solution. The solutions were injected into the subsurface using existing extraction and monitoring wells. Details of each injection are described under system operation.

System Operation [3,7,8,9,11,12,13,14,17,18]:

System operation for the three technologies that are being used to treat soil and groundwater at the UCC site (pump and treat, soil vapor extraction, and *in situ* chemical oxidation) is described below.

Pump and Treat

- C Groundwater is extracted from the aquifer at an average rate of 5.2 gallons per minute (original design was 30 gpm). An average of 2,000,000 gallons of groundwater were extracted each year.

Year	Volume Pumped (gal)
1996	1,664,050
1997	2,739,947
1998	2,611,502
1999	1,337,368

- C The system began operating in January 1996 and continued until it was shut down throughout the site in December 1999. Pumping was resumed on a limited basis from July to October 2000. From January 1996 to December 1999, the treatment system was operational approximately 81 percent of the time, with downtime attributed primarily to problems during startup (January 1996 through February 1997). The treatment system operated intermittently from February through April of 1996 and again during July and August of 1996. Shutdowns were due to common startup items such as interruptions in power, equipment being off line, and computer programming errors. In August and September of 1996, the treatment system was shut down to modify the metals treatment system (e.g., to address iron fouling of an ion exchange column).
- C From 1996 to 1998, the groundwater was analyzed quarterly for VOCs, semi-volatile organic compounds (SVOCs), and metals. Metals and SVOCs besides N,N-DMF have not been detected at the site at elevated concentrations; therefore in April 1998, the monitoring requirements were changed to semi-annual monitoring for VOCs and N,N-DMF only. Analysis for metals with ROD-specified cleanup levels is planned to be performed during closure sampling.
- C Originally, the groundwater treatment system included ion exchange units and a particulate bag filter system to remove metals from the water. Because of excessively high usage rates of the ion exchange media and the tendency for the ion exchange beds to selectively release metals into the water as more amenable metal types entered the units, the ion exchange and bag filter systems were replaced with the metals removal system in 1996.

Soil Vapor Extraction

- C 48,000 cubic yards of soil have been treated by soil vapor extraction at the site.
- C SVE was operated at the site since 1996 without any modifications. The air flow rate and vacuum used by the SVE system were not provided.

In Situ Chemical Oxidation

- C Potassium and sodium permanganate were injected into the subsurface extraction and monitoring wells located in nine areas across the former source area and between the former source area and Quiggle Brook to the east. Additions were made to wells in both the shallow and bedrock aquifers.
- C Table 3 presents information about the permanganate injections performed between May 10 and October 21, 1999, including the dates of each injection and the injection points. A total of 25,874 pounds of potassium permanganate and 3,060 pounds of sodium permanganate were added to the groundwater during this time. An application rate of ten times the minimum amount estimated to oxidize the contaminants at each injection point was used across the site.
- C Additional injections of permanganate were performed through October 2000. Information about the specific dates of the injections and the volumes injected were not available.
- C The majority of the permanganate added was potassium permanganate (2% solution). Sodium permanganate was added using a 20% solution at injection points closest to Quiggle Brook.
- C A pilot study using hydrogen peroxide to treat a hot spot contaminated with DCA was conducted in 2000. The results were inconclusive, and a decision was made to not perform additional injections of hydrogen peroxide.
- C According to the RPM, no additional injections of chemical oxidants (permanganate, peroxide) are planned for the site.

Table 3. May and October 1999 Permanganate Addition [13]

Area	Injection Points Used*	Dates of Permanganate Injection/1999
1	VP-1, VP-2, VP-4, V-36, EW-4	5/10-5/12
		5/20-5/25
2	VP-3, VP-5, VP-6, VP-9	5/27-6/6
		6/18-6/30
3	V-36A, VP-8, VP-10, VP-13, VP-14, VP-15	5/18-7/20
4	VP-11, VP-12, P-16A, V-17, P-17, VP-23, OW-1-S, OW-1-D, B-9A(I), EW-1, MW-13A(D)	6/30-10/6
5	VP-19, VP-20, VP-21, VP-22, P-16, GT-10, MW-14(S), MW-15(D)	6/19-10/21
6	V-7, V-18, VP-24, VP-25, VP-26, B-6A(D), B-6B(I)	8/18-10/6
7	OW-3-2M, OW-3-2S, MS-2-I, MW-3D, OW-3-1S, OW-3-1D, EW-3	7/5-9/11
8	B-3A(D), B-3B(I), B-3B(D), B-13B(I), B-13C(S), B-13A(D), OW-3-3S, GT-15, GT-16	8/16-10/6
9	B-12C(S), B-12-B(I), B-12A(D), GT-17, GT-18	8/16-10/6

* These locations and dates indicate that permanganate additions began at the west part of the site and continued across to the east part of the site.

Operating Parameters Affecting Treatment Cost or Performance

Table 4 presents the groundwater extraction rate, the target groundwater cleanup levels, the water discharge criteria, and the target soil cleanup levels which are the major operating parameters affecting cost and performance for this technology.

Table 4. Performance Parameters [4,5,7,8,9,14]

Parameter	Value	
Average extraction rate	5.1 gpm	
Target groundwater cleanup levels (ug/L)	Arsenic - 5 N,N-Dimethylformamide (DMF) - 390 1,1-Dichloroethane (DCA) - 5 1,2-DCA - 5 1,1-Dichloroethene (DCE) - 7 cis-1,2-DCE - 70 trans-1,2-DCE - 100 Ethylbenzene - 700 Lead - 50	Methyl ethyl ketone (MEK) - 170 Methylene chloride - 5 Tetrachloroethene (PCE) - 5 Toluene - 2,000 Trichloroethene (TCE) - 5 Total xylenes - 10,000 1,1,1-Trichloroethane (TCA) - 200 Vinyl chloride - 2
Water discharge criteria established for the site (ug/L)	Arsenic - 2.0 Lead - 0.9 Chromium VI - 5.0 Copper - 3.7 Nickel - 22 Zinc - 5.0 Aluminum - 20 Antimony - 20 Iron - 90 Manganese - 5.0 Selenium - 5.0 Chloride - 20 Mercury - 0.2 Silver - 10 Cadmium - 5.0 Sulfide - 1,000 Cyanide - 10 1,1,1-TCA - 0.5 1,1,2-TCA - 0.5 1,1-DCA - 0.5 1,1-DCE - 0.5 TCE - 0.5	Bis (2-ethylhexyl) phthalate - 10 1,2-DCA - 0.5 cis-1,2-DCE - 0.5 1,3-Dichlorobenzene - 0.5 Carbon tetrachloride - 0.5 Chlorobenzene - 0.5 Chloroform - 0.5 Ethylbenzene - 0.5 Freon 113 - 1.0 Methylene chloride - 1.0 Toluene - 0.5 trans-1,2-DCE - 0.5 Trichlorofluoromethane - 0.5 Vinyl chloride - 0.5 Xylene - 1.5 2-Methylnaphthalene - 10 PCE - 0.5 Chloroethane - 0.5 DMF - 3 2-Butanone (also MEK) - 1.0 Isophorone - 10
Target soil cleanup levels (mg/kg)	1,1-DCE - 0.1 PCE - 0.1	TCE - 0.1 Total Xylenes - 100.0

Timeline

Table 5 presents a timeline for the major events performed during this remedial project.

Table 5. Project Timeline [3,6,7]

Start Date	End Date	Activity
1979	---	VOCs discovered in groundwater at site
1984	---	Source materials and some contaminated soil removed from the site
1988	1990	RI/FS performed
10/89	---	Union Chemical Company added to the National Priorities List (NPL)
12/90	---	ROD signed
4/94	---	ESD signed

Start Date	End Date	Activity
10/94	9/95	Soil consolidation and site capping
6/95	11/95	Construction and installation of the extraction, groundwater treatment, and SVE/hot air injection systems
1/96	12/99	Pump and treat system operated
1996	Ongoing	SVE/hot air system operated
7/96	10/96	Modifications made to the metals removal system
10/97	8/98	Pilot-scale permanganate addition to groundwater
5/99	10/00	Full-scale permanganate addition to groundwater
7/00	10/00	Pump and treat system operated on a limited basis
Mid-00	---	Pilot study using hydrogen peroxide to treat hot spot
Summer-01	---	Injection of molasses/sodium lactate for anaerobic reductive dechlorination
10/01	4/02	Monitoring planned to be conducted

TREATMENT SYSTEM PERFORMANCE

CLEANUP GOALS/STANDARDS [4,5]

The groundwater cleanup goals specified in the ROD are to treat all portions of the shallow and bedrock aquifers underlying the UCC site and all portions of contaminated groundwater immediately off the site to levels that will protect human health and the environment.

Table 4 lists the specific target groundwater cleanup levels for 17 contaminants. Cleanup levels for 16 of the contaminants were established in the ROD. The cleanup level for N,N-DMF was established by EPA during remedial design. The cleanup levels were based on maximum contaminant levels (MCL) and non-zero maximum contaminant level goals (MCLG), if available. In addition, the standard for N,N-DMF was based on Maine's maximum exposure guideline (MEG).

TREATMENT PERFORMANCE GOALS [7]

Treated groundwater must meet discharge criteria established for the site. Specific criteria are listed in Table 4.

PERFORMANCE DATA ASSESSMENT [8,9,10,11,12,13,14]

System performance for the three technologies that are being used to treat soil and groundwater at the UCC site (pump and treat, soil vapor extraction, and *in situ* chemical oxidation) is described below. Through June 1999, the SVE system had extracted the largest amount of contaminant mass from the surface.

Pump and Treat

- C From January 1996 through June 1999, approximately 9,600 pounds of VOCs were removed from the site by the pump and treat and SVE systems, as shown in Figure 3. This consisted of approximately 600 lbs of chlorinated VOCs removed from groundwater and nearly 9,000 lbs removed by the SVE system. Figure 3 also shows that the mass flux rate for VOCs removed from groundwater declined from a maximum of 142 lbs per month (December 1996) to less than 10 lbs per month as of October 1998. The mass flux rate remained below 10 lbs per month between October 1998 and November 1999.

- C Figure 4 shows a total of approximately 950 lbs of VOCs removed from the groundwater from January 1996 to June 1999, which includes the 600 lbs of chlorinated VOCs shown on Figure 3. The 350 lbs of nonchlorinated VOCs consisted of compounds such as BTEX, ketones, and N,N-DMF.
- C Table 6 presents analytical results from monitoring well locations B-4, B-5, B-8, and B-12. These wells are located downgradient of the source area and have groundwater concentrations above the cleanup goals for one or more selected contaminants (1,1-DCA, cis-1,2-DCE, trans-1,2-DCE, TCE, total xylenes, and N,N-DMF). Data are presented by well through November 1999.
- C Figures 5 through 10 show changes in time of groundwater contaminant concentrations for 1,1-DCA, cis-1,2-DCE, trans-1,2-DCE, TCE, total xylenes, and N,N-DMF, respectively. For each of these six contaminants, data generally are presented for two selected wells: one well in which the contaminant concentration was at or below the established cleanup level in November 1999 and the other well in which the contaminant concentration remained above the cleanup level in November 1999. (See Table 6 for information about an individual well.) Figures 5 through 10 show that, in general, contaminant concentrations in the aquifer are decreasing over time. According to the RPM, concentration variations in the wells were attributed to a variety of factors, including seasonal influences, laboratory variability, and effects from permanganate additions.
- C Cleanup levels for trans-1,2-DCE and total xylenes were not exceeded in any of the wells sampled in November 1999. Therefore, contaminant concentration changes are only presented for one well in Figures 7 and 9 (the figures for trans-1,2-DCE and total xylenes, respectively).
- C According to the RPM, the plume size has been reduced, however the amount of reduction has not been quantified.
- C Groundwater contaminant concentrations in all wells monitored during the November 1999 groundwater monitoring period were lower than the target cleanup levels for the following six contaminants: 1,2-DCA, carbon tetrachloride, chloroform, toluene, total xylenes, and trans-1,2-DCE.
- C Figure 11 shows the concentrations of 1,1-DCA, TCE, and N,N-DMF in the influent to the aboveground treatment system during January 1996 and November 1999. From January 1996 to November 1999, the 1,1-DCA, TCE, and N,N-DMF concentrations in the influent to the treatment system decreased from 3,600 ug/L to 1,900 ug/L (1,1-DCA), from 3,000 ug/L to 85 ug/L (TCE), and from 4,800 ug/L to 970 ug/L (N,N-DMF).
- C According to the RPM, effluent concentrations were not above the treatment system discharge criteria shown in Table 4.
- C According to the RPM, in general, groundwater concentrations of ethenes are decreasing more rapidly than the concentrations of ethanes in the groundwater. This trend can be demonstrated by comparing the decrease in 1,1-DCA concentrations in the influent to the aboveground treatment system with the decrease in TCE concentrations in the influent to the aboveground treatment system, as shown in Figure 11. This trend is observed primarily because the ethenes are responding more rapidly to the permanganate additions than the ethanes.

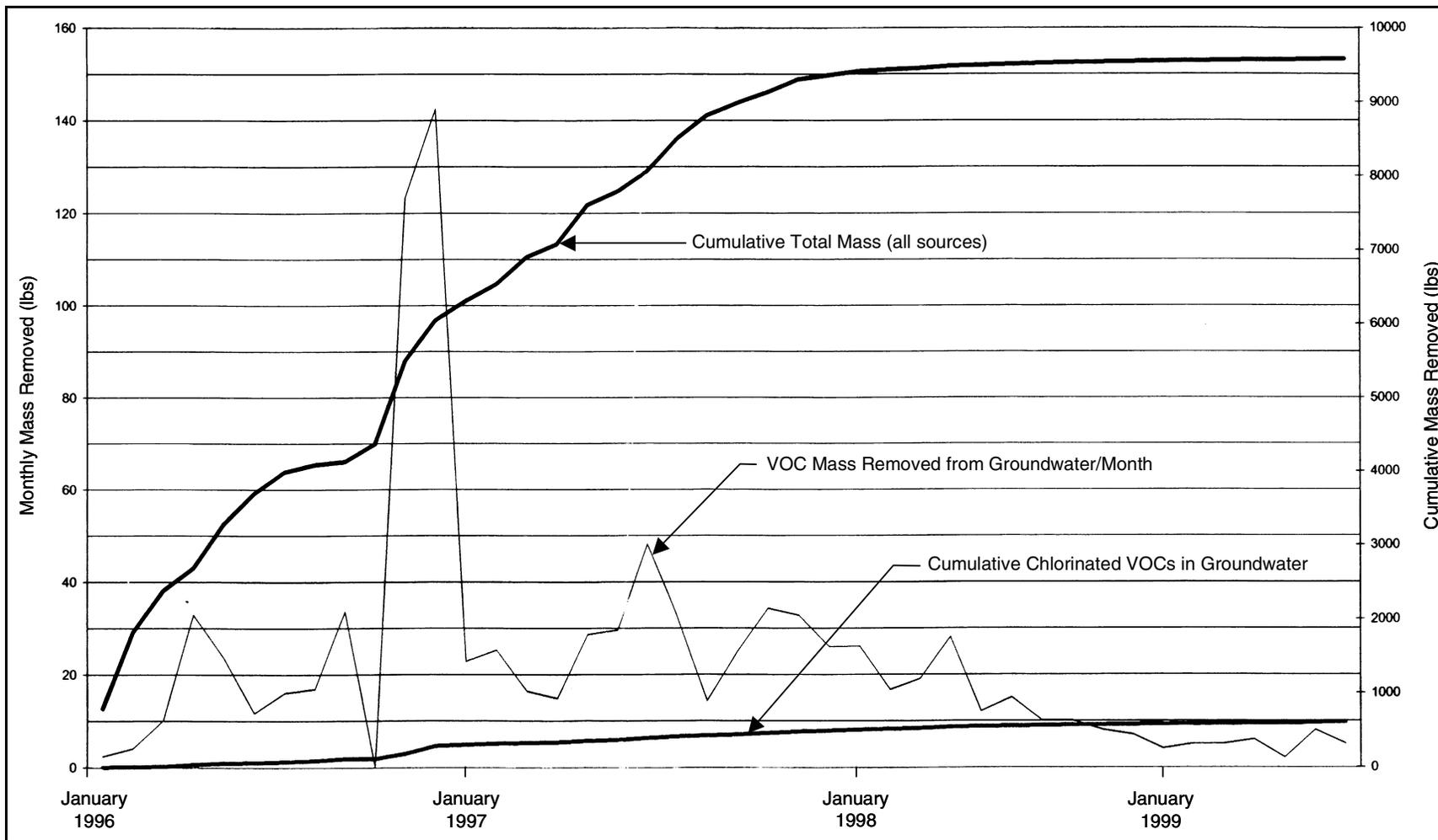


Figure 3. Treatment Plant VOC Removal (all sources) - 1996 to 1999

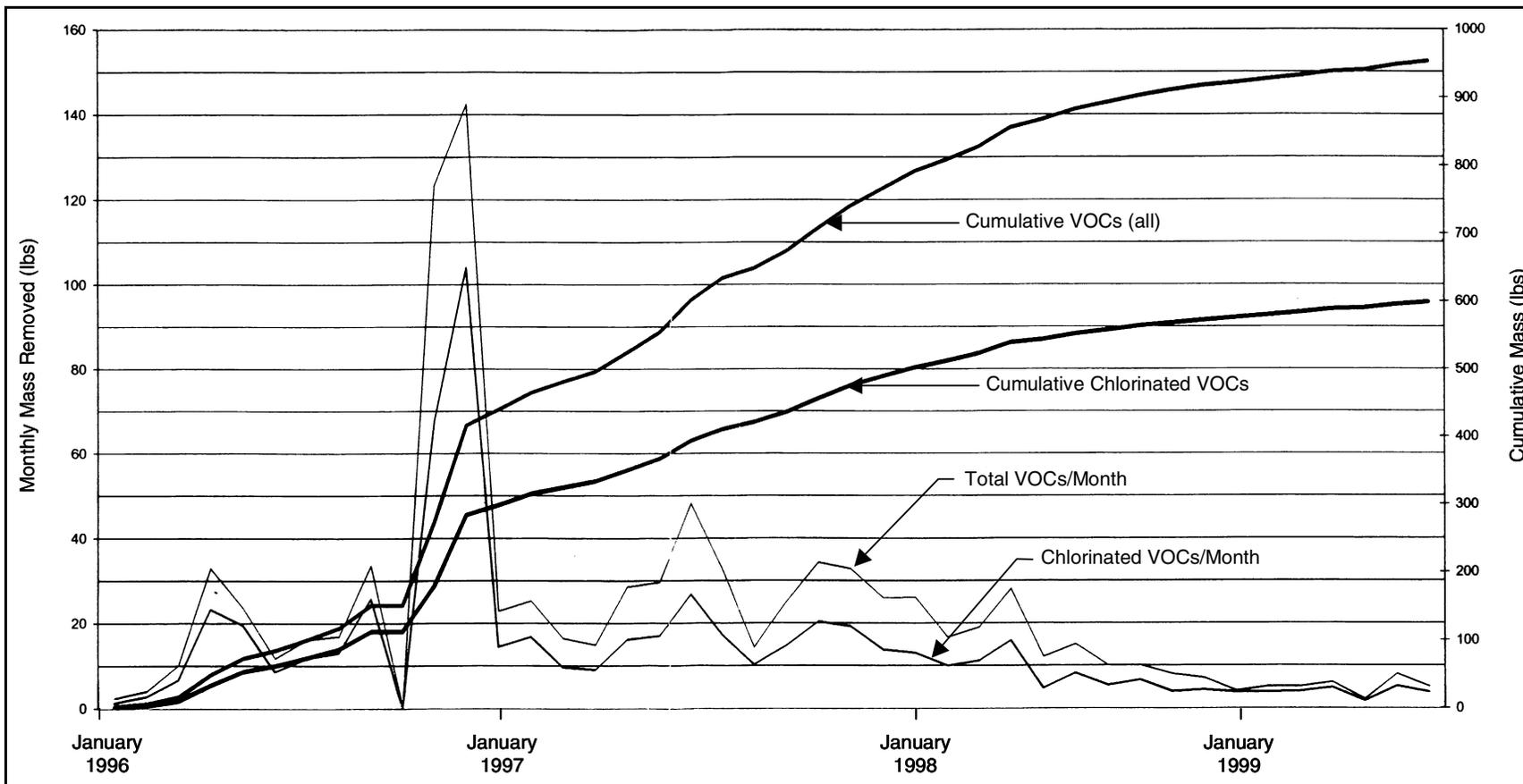


Figure 4. Treatment Plant VOCs Removed From Groundwater - 1996 to 1999

Table 6. Summary of Groundwater Contaminant Concentrations at Union Chemical Company Superfund Site¹[17]

WL	WSZ	MP	Sample Date	1,1-DCA		cis-1,2-DCE		trans-1,2-DCE		TCE		Total Xylenes		N,N-DMF	
				Concentration (ug/L)	DL ²										
Target Cleanup Level =				5 ug/L		70 ug/L		100 ug/L		5 ug/L		10,000 ug/L		390 ug/L	
B-4	D	16	4/3/96	35		24		5	Yes	5	Yes	5	Yes	3	Yes
B-4	D	17	7/10/96	41		42		0.7		5.1		0.5	Yes	3	Yes
B-4	D	18	10/9/96	1300		660		50	Yes	330		50	Yes	1100	
B-4	D	21	7/29/97	380		230		2		110		5		200	
B-4	D	22	10/23/97	280		170		2		88		3	Yes	220	
B-4	D	26	11/11/99	NS		50		0.7		43		1	Yes	NS	
B-4	I	26	11/11/99	5		NDA		NDA		8		1	Yes	NS	
B-5	D	21	7/29/97	100		0.5	Yes	0.5	Yes	0.5	Yes	0.5	Yes	210	
B-5	D	22	10/23/97	81		0.5	Yes	0.5	Yes	0.5	Yes	0.5	Yes	140	
B-5	D	23	4/28/98	70		0.5	Yes	0.5	Yes	0.5		0.5	Yes	41	
B-5	D	24	10/6/98	280		0.5	Yes	0.5	Yes	0.5	Yes	0.5	Yes	180	
B-5	D	25	4/7/99	170		NDA		NDA		0.5	Yes	1	Yes	390	
B-5	I	16	4/3/96	77		5	Yes	5	Yes	5	Yes	5	Yes	310	
B-5	I	18	10/9/96	180		1.4		1	Yes	1.2		1	Yes	250	
B-5	I	20	4/8/97	320		1		0.5	Yes	1		0.5	Yes	1800	
B-5	I	22	10/23/97	600		3		0.5	Yes	1		0.6		1300	
B-5	I	23	4/28/98	690		2		0.5	Yes	0.8	Yes	1	Yes	1200	
B-5	I	24	10/6/98	340		3		0.5	Yes	1		1	Yes	120	
B-5	I	25	4/7/99	580		0.5	Yes	0.5	Yes	0.5	Yes	1	Yes	1300	
B-5	S	16	4/3/96	150		70		25	Yes	25	Yes	25	Yes	4.2	Yes
B-5	S	17	7/10/96	86		60		2.5	Yes	10		2.5	Yes	4.2	
B-5	S	18	10/9/96	48		29		2.5	Yes	7.5		2.5	Yes	17	
B-5	S	19	1/9/97	20		14		0.5	Yes	4		0.5	Yes	3	Yes
B-5	S	20	4/8/97	11		8		0.5	Yes	4		14		3	Yes
B-5	S	21	7/29/97	14		10		0.5	Yes	3		0.5	Yes	3	Yes
B-5	S	22	10/23/97	160		20		0.5	Yes	10		1	Yes	44	
B-5	S	25	4/7/99	17		0.5	Yes	1		0.8		1	Yes	3	Yes
B-8	D	17	7/10/96	950		47		5	Yes	35		30		5800	
B-8	D	21	7/29/97	720		40		0.5	Yes	34		44		6300	
B-8	D	22	10/23/97	800		33		0.5	Yes	26		42		4900	
B-8	D	23	4/28/98	780		32		0.5	Yes	23		28		3700	
B-8	D	24	10/6/98	600		19		0.5	Yes	11		13		5800	
B-8	D	25	4/7/99	660		32		0.5	Yes	20		31		2900	
B-8	D	26	11/11/99	1100		47		5	Yes	31		34		3300	
B-8	I	15	1/4/96	140		10	Yes	10	Yes	10	Yes	10	Yes	16000	

Table 6. Summary of Groundwater Contaminant Concentrations at Union Chemical Company Superfund Site¹ (continued)

WL	WSZ	MP	Sample Date	1,1-DCA		cis-1,2-DCE		trans-1,2-DCE		TCE		Total Xylenes		N,N-DMF	
				Concentration (ug/L)	DL ²										
Target Cleanup Level =				5 ug/L		70 ug/L		100 ug/L		5 ug/L		10,000 ug/L		390 ug/L	
B-8	I	16	4/3/96	20		1.1		1	Yes	1.1		1	Yes	7	Yes
B-8	I	17	7/10/96	15		1.2		0.5	Yes	0.9		0.5	Yes	4.6	
B-8	I	18	10/9/96	130		7.6		1	Yes	7.9		1.9		1500	
B-8	I	19	1/9/97	8		0.7		0.5	Yes	0.6		0.5	Yes	3	
B-8	I	20	4/8/97	9		1		0.5	Yes	1		0.5	Yes	6	
B-8	I	21	7/29/97	12		1		0.5	Yes	0.9		0.5	Yes	4	
B-8	I	22	10/23/97	14		2		0.5	Yes	1		0.6		14	
B-8	I	24	10/6/98	7		0.6		0.5	Yes	0.7		1	Yes	3	Yes
B-12	D	17	7/10/96	8.2		11		5	Yes	15		12		3	Yes
B-12	D	25	4/7/99	7		5		0.5	Yes	6		1	Yes	3	Yes
B-12	I	16	4/3/96	4700		4600		500	Yes	500	Yes	6100		19000	
B-12	I	18	10/9/96	8400		7400		500	Yes	200		11000		17000	
B-12	I	20	4/8/97	6600		4800		8		5400		24400		8200	
B-12	I	22	10/23/97	5300		4200		5		2600		12200		14000	
B-12	I	23	4/28/98	1300		1300		3		560		3600		2700	
B-12	I	24	10/6/98	1900		1600		3		670		5000		1800	
B-12	I	25	4/7/99	790		0.5	Yes	3		430		2140		780	
B-12	I	26	11/11/99	1000		360		5	Yes	300		840		610	
B-12	S	16	4/3/96	9600		13000		2500	Yes	2500	Yes	20000		20000	
B-12	S	17	7/10/96	13000		9300		500	Yes	24000		38000		18000	
B-12	S	18	10/9/96	16000		15000		1000	Yes	9100		25000		19000	
B-12	S	20	4/8/97	4800		4200		25		0.5	Yes	37000		2600	
B-12	S	23	4/28/98	190		270		4		410		249		4.8	
B-12	S	25	4/7/99	290		350		6		470		318		3	Yes
B-12	S	26	11/11/99	150		2	Yes	2	Yes	2	Yes	5	Yes	12	

MP = monitoring period

NS = not sampled

NDA = no data available

WL = well location

WSZ = well stratigraphic zone (D = bedrock, I = intermediate, S = shallow)

DL = detection limit

¹ This table includes selected analytical results from monitoring periods and wells at which groundwater concentrations for one or more selected constituents are higher than the cleanup levels established for those constituents. Highlighted concentrations are higher than cleanup levels. For a given well and stratigraphic zone, the table presents results in chronological order from oldest to newest.

² Yes = Concentration is below the detection limit; the detection limit has been reported.

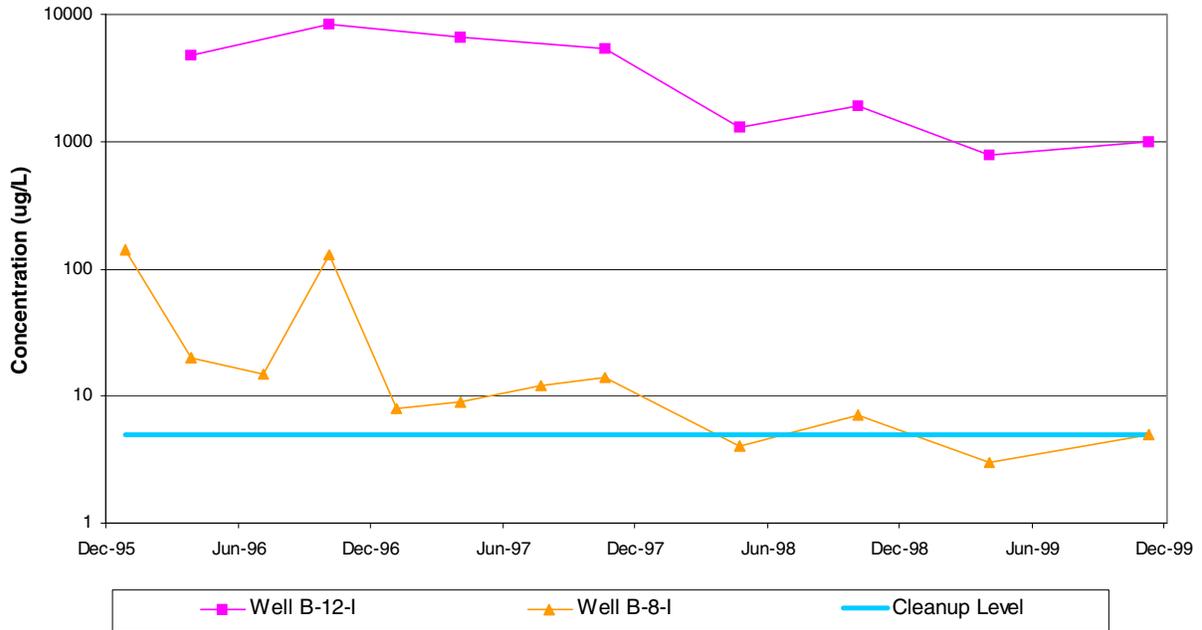


Figure 5. 1,1-DCA Concentrations in Selected Wells [10,11]

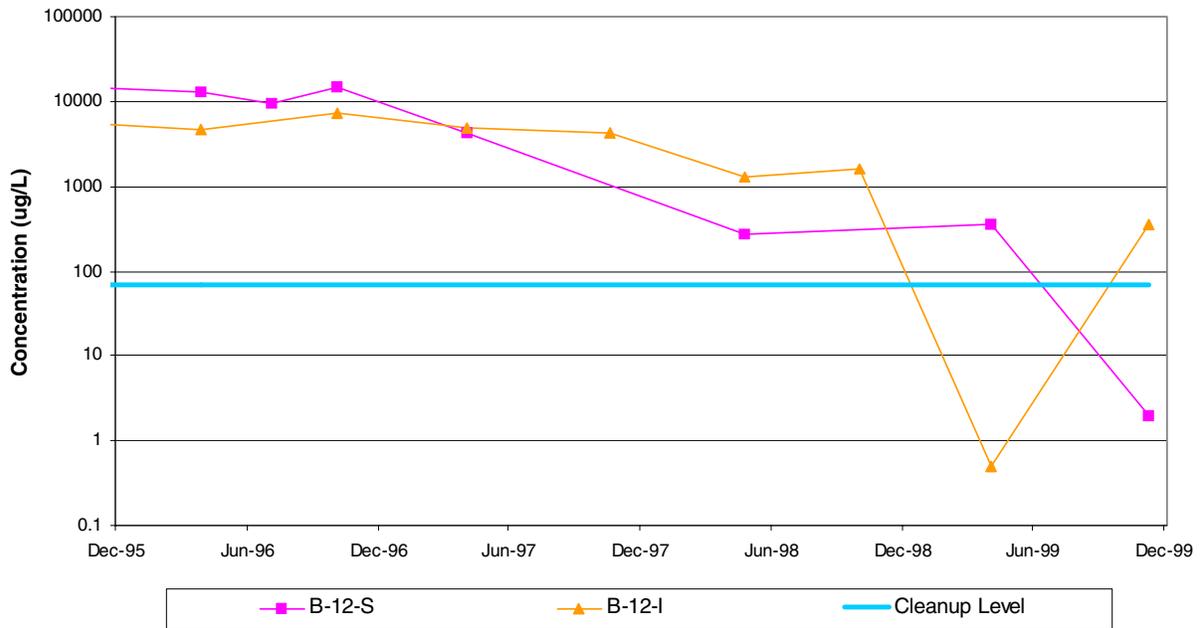


Figure 6. cis-1,2-DCE Concentrations in Selected Wells [10,11]

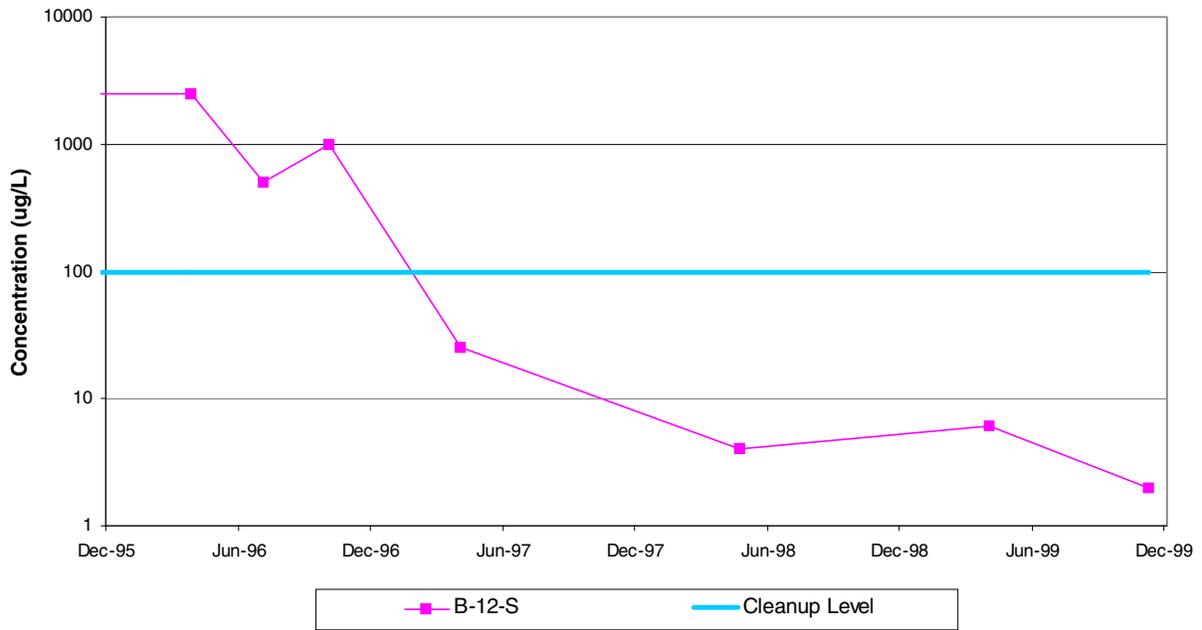


Figure 7. trans-1,2-DCE Concentrations in Well B-12-S [10,11]

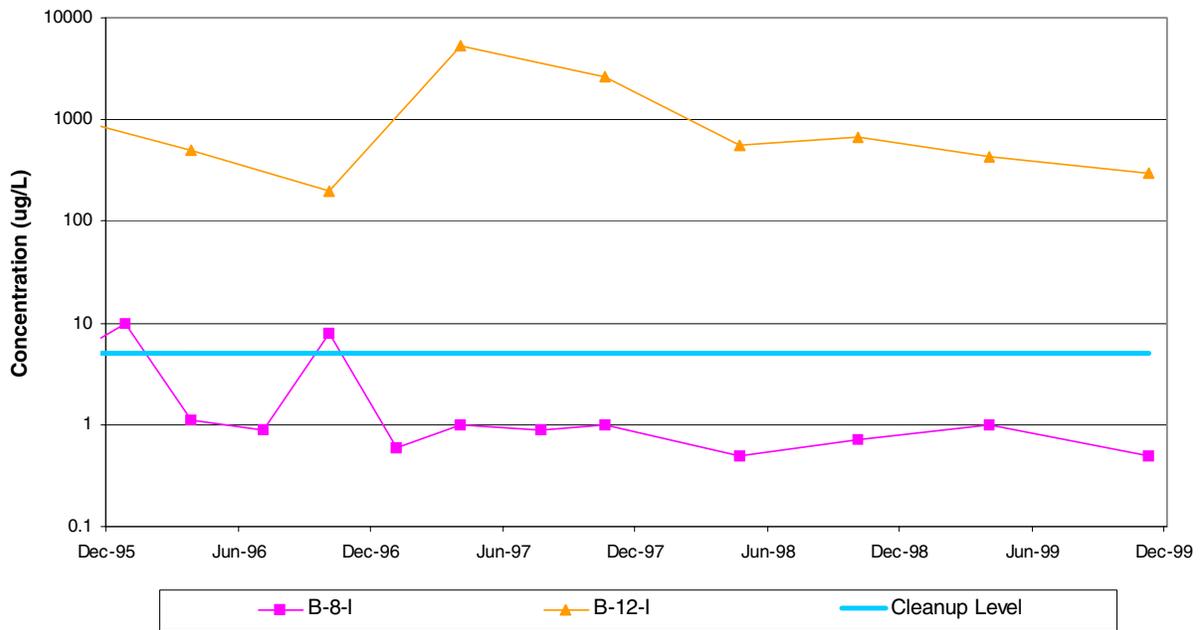


Figure 8. TCE Concentrations in Selected Wells [10,11]

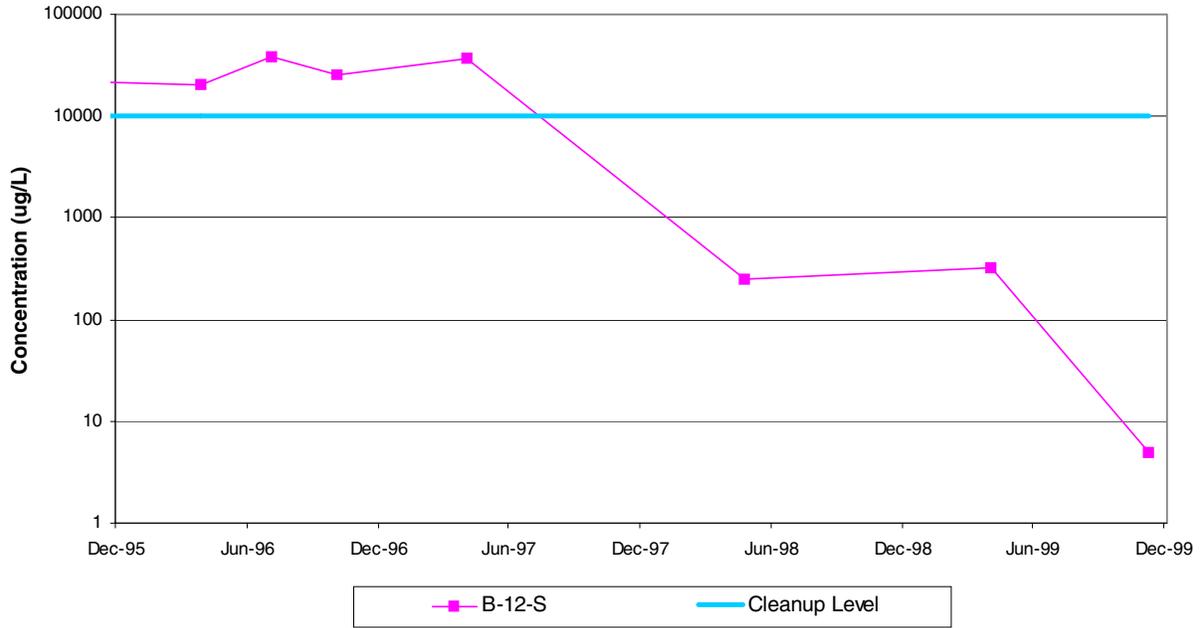


Figure 9. Total Xylene Concentrations in Well B-12-S [10,11]

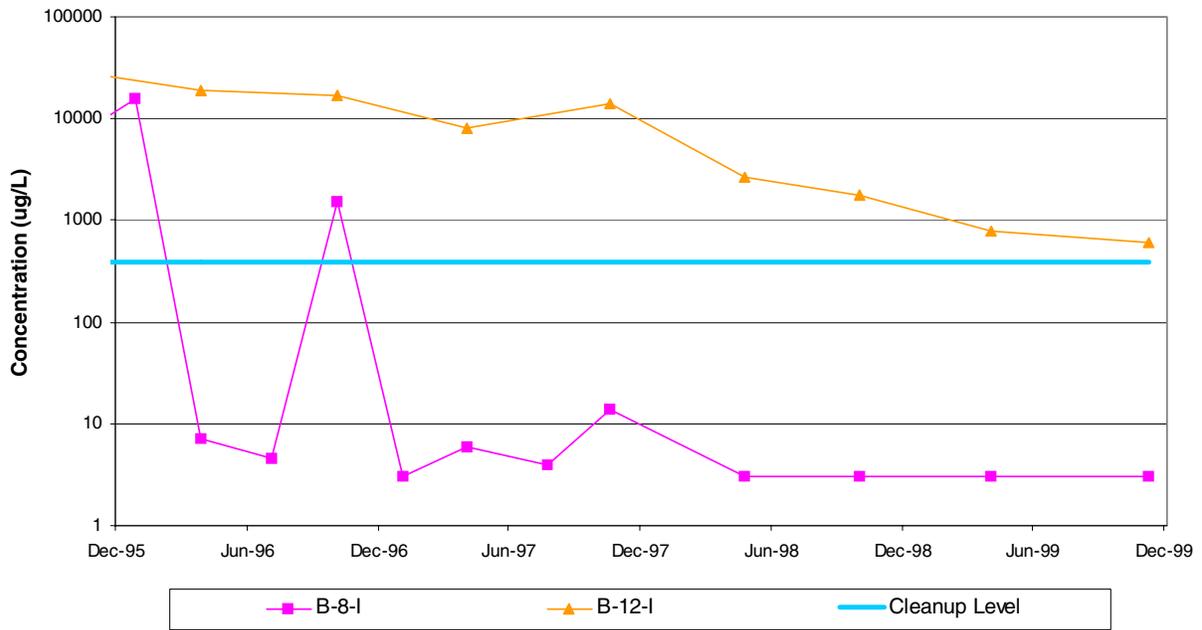


Figure 10. N,N-DMF Concentrations in Selected Wells [10,11]

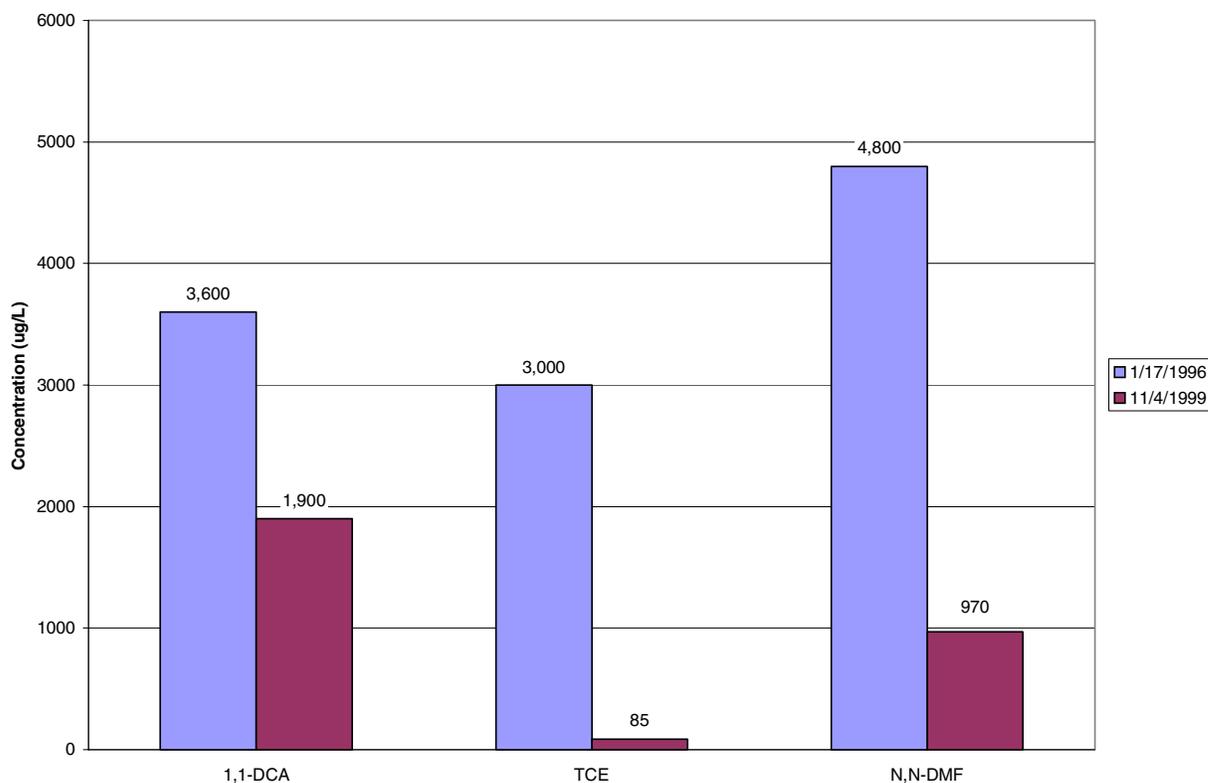


Figure 11. Contaminant concentrations in the Influent to the Aboveground Treatment System [11]

Soil Vapor Extraction

- Nearly 9,000 lbs of VOCs were removed by the SVE system over the period from 1996 to June 1999. The majority of this removal occurred in 1996 and 1997, with 8,700 lbs removed in that two-year period. No additional information was provided about the concentrations of contaminants in soil or soil gas at the site during this time period.
- According to the RPM, the results from a September 1998 sampling event showed that the soil was in compliance with target soil cleanup levels.

In Situ Chemical Oxidation

- C IT Corporation considered three methods for evaluating the performance of *in situ* chemical oxidation at this site: (1) reductions over time in the level of contaminants in the influent to the aboveground treatment system, (2) reductions over time in the level of contaminants in individual wells at the site; or (3) reductions over time in the level of contaminants across the entire area where *in situ* chemical oxidation was performed (area-wide method). Based on the results from a pilot study, IT Corporation selected the area-wide method as being the most comprehensive.
- C The area-wide method involved measuring the contaminant concentrations in the groundwater in April 1999, November 1999, and April 2000 in the areas where *in situ* chemical oxidation was being performed.
- C Table 7 presents the estimated mass of TCE, 1,2-DCE, and 1,1-DCA removed from the groundwater as a result of the *in situ* chemical oxidation technology and the percent reduction through April 2000. In addition, data are provided for the first six months and the second six months following injection of permanganate.

Table 7. Summary of Contaminant Reductions from Full-Scale Chemical Oxidation

	TCE	1,2-DCE	1,1-DCA
Pre-Injection Mass (4/99) (lbs)	37.58	34.79	48.05
Chemical Injection (May 10, 1999 through October 21,1999)			
Mass Reduction First 6 Months After Injection (4/99-11/99) (lbs)	29.57	23.00	8.53
Mass Reduction Second 6 Months After Injection (11/99-4/00)** (lbs)	3.87	-6.79	-24.82
Mass Reduction (Cumulative Through April 2000)** (lbs) (% reduction from pre-injection mass)	33.44 (89%)	16.21 (47%)	-16.29 (-79%)

* Multiple injections

** Negative values show increases in mass

- C As shown in Table 7, the permanganate addition performed in 1999 reduced the TCE and 1,2-DCE levels in the groundwater but was not effective in reducing levels of 1,1-DCA. The mass of TCE in groundwater was reduced by 89 percent between April 1999 and April 2000, and no rebound was observed. During this time, the mass of 1,2-DCE was reduced by 47 percent, with rebound observed following the second six-month injection period. For 1,1-DCA, an initial reduction in mass was observed following the first six months of injection. However, the mass of 1,1-DCA increased following the second six month injection period, and no overall mass reduction in 1,1-DCA was observed.
- C The mass of contaminant removed by *in situ* chemical oxidation was estimated by IT Corporation, taking into account the mass removed by the pump and treat system and rebound from *in situ* chemical oxidation. The specific calculations and data used by IT Corporation for estimating mass removed by *in situ* chemical oxidation was not provided in the available references.
- C According to the RPM, addition of permanganate to the groundwater has increased the rate of groundwater cleanup at the site, particularly with respect to the decreases of TCE and DCE.

PERFORMANCE DATA COMPLETENESS [8,9,10,11]

- C The VOC mass flux rate and the cumulative VOC removal data included in Figures 3 and 4 were available on a monthly basis.
- C In general, the treatment system influent concentrations included in Figure 11 were available on a monthly basis. The data were available more frequently during system startup.
- C The groundwater concentrations included in Figures 5 through 10 were available, in general, on a quarterly basis.

PERFORMANCE DATA QUALITY

The QA/QC program used throughout the remedial action met EPA and the State of Maine requirements. All monitoring was performed using EPA-approved methods, and the site contacts did not note any exceptions to the QA/QC protocols.

TREATMENT SYSTEM COST

PROCUREMENT PROCESS [7]

Union Chemical Trust contracted with American Environmental Consultants to construct and operate the remedial system, under the oversight of EPA. American Environmental Consultants contracted with IT Corporation (formerly Fluor Daniel GTI, Inc.) to construct and operate the remedial system.

COST ANALYSIS [1,18]

Actual remediation costs are presented in Table 8, as provided by the PRP for this application. These costs include the capital and annual operating costs for the pump and treat, SVE, and *in situ* chemical oxidation systems. The capital cost (\$9,500,000) was primarily attributed to the cost for the SVE system (approximately 80%), including the blower and thermal processes. The annual operating costs for the pump and treat and SVE systems (\$600,000) are the average for the most recent 2.5 years of operation; operating costs during startup were higher. The average annual operating costs for the chemical oxidation (\$150,000) were expended in the summers of 1999 and 2000, during full-scale oxidation operations.

In addition to the costs shown in Table 8, more than \$2,000,000 have been spent in studies and design for this site.

Now that active remediation has been completed, the PRP estimated that a longer-term monitoring phase would likely have costs of \$50,000 to \$60,000 per year, given semiannual monitoring requirements.

Table 8. Remediation Costs [1,18]

Capital Costs (\$1995)	
Overhead, engineering, supervision, and procurement (includes design cost)	\$2,900,000
Mobilization and setup	\$200,000
Extraction wells	\$300,000
Monitoring wells	\$1,125,000
Injection wells	\$300,000
Conveyance/piping system	\$400,000
Treatment plant	\$3,200,000
System startup	\$675,000
Closeout activities	\$400,000
Total capital costs	\$9,500,000
Annual Operating Costs	
Average annual operating costs - pump and treat and SVE systems	\$600,000
Average annual operating costs - <i>in situ</i> chemical oxidation system	\$150,000

OBSERVATIONS AND LESSONS LEARNED

- According to the RPM, the remediation efforts at the site were very aggressive, with the site being cleaned up in less than half the time originally anticipated. Use of a combination of pump and treat, SVE, and *in situ* chemical oxidation reduced the concentrations of contaminants at the site, and removed nearly 10,000 lbs of contaminants from start of remediation in 1996 through mid-1999.
- According to the RPM, molasses and sodium lactate were injected into the groundwater during summer 2001. These compounds were added to increase the rate of anaerobic reductive dechlorination of selected contaminants. The RPM indicated that EPA plans to reevaluate the possible need for additional active remediation after review of results from planned sampling episodes for October 2001 and May 2002.
- The SVE system was the primary means to remove contaminants at the site. The pump and treat system was used to dewater the soil so that it could more easily be treated using the SVE system. This approach doubled the volume of soil that was treated by SVE. The SVE system removed nearly 9,000 lbs of contaminants and the pump and treat system approximately 1,000 lbs. The chemical oxidation system targeted areas with elevated contaminant concentrations, but reduced the mass of contaminants by less than 100 lbs within the first year after injection.
- A pilot study using hydrogen peroxide to treat a DCA hot spot was conducted in 2000. The results were inconclusive, and a decision was made to not perform additional injections of hydrogen peroxide.
- Originally, the groundwater treatment system included ion exchange units and a particulate bag filter system to remove metals from the water. Because of excessively high usage rates of the ion exchange media and the tendency for the ion exchange beds to selectively release metals into the water as more amenable metal types entered the units, the ion exchange and bag filter systems were replaced with the metals removal system in 1996. [7]
- The effectiveness of chemical oxidation is partly dependent on the permeability of the soil surrounding the chemical injection locations. At Union, the permeability of the soil surrounding some of the permanganate injection locations was so low that the permanganate remained in the well and did not mix with the surrounding contaminated soil. In these wells, chemical oxidation was not effective in remediating the contaminated soil surrounding the wells. [13]
- A total of \$9,500,000 was expended to construct and install the pump and treat, SVE, and *in situ* chemical oxidation systems at this site, and, since startup was completed, the average operating costs for pump and treat and SVE (combined) has been \$600,000/year and for chemical oxidation \$150,000/year. A unit cost was not calculated for this project because the costs and quantities treated represent a combination of technologies, and the cost and performance of the individual technologies were not precisely quantified.

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ANALYSIS PREPARATION

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Tetra Tech EM Inc. under Contract No. 68-W-99-003.