Soil Vapor Extraction and Groundwater Extraction
Used at Eight Service Stations in Maryland

Site Names: Multiple Retail Service Stations (site names confidential)

Site Locations: Maryland (specific locations not provided)

Contaminants: MTBE, BTEX

Media: Soil and Groundwater

Technology: Soil Vapor Extraction and Groundwater Extraction (VE/GE)

Technology Scale: Full

Cleanup Type: Not identified

Period of Operation: 1990 – 1997; specific period of operation varies by site, as shown in Appendix B

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Site Histories [3]:

At eight retail service stations in Maryland, Chevron Research and Technology Company conducted an evaluation of soil vapor extraction and groundwater extraction (VE/GE) to treat soil and groundwater contaminated with both MTBE and BTEX. A gasoline release had occurred at each site and had migrated to the water table and formed a smear zone (a volume of soil in the saturated aquifer that contains residual NAPL).

Information is provided in Table 1 about the hydrogeology at each site. Sites are identified as A through H; the specific name and location of the sites was not provided. Four of the sites are located in the Coastal Plain Province and are characterized by alluvial sands, silts, and clay. The other four sites are located in the Piedmont Province and are characterized by saprolites (weathered bedrock) of schist and gneiss. Hydraulic conductivities ranged from 3.4 10^{-3} cm/sec to 7.1 10^{-5} cm/sec. Pre-remediation depth to groundwater was <10 ft at site B, between 5-15 ft at site E, and greater than 20 ft for the other 6 sites.

Data on water table fluctuations for five sites shows variations ranging from 2 to 13 ft. For most of the year, the smear zone is submerged (located within or below the capillary fringe) and the smear zone NAPL is immobile. However, falling water table conditions (late summer and early fall) may increase NAPL saturation at the capillary fringe as a result of drainage from the newly formed vadose zone (lateral migration of NAPL).

Table 1. Summary of Hydrogeologic Information for 8 Sites [3]

Site	Date of Gasoline Release	Physiographic Province	Hydraulic Conductivity K (cm/s)*	Pre-remediation Depth to Water Table (ft)	Pre-remediation Water Table Fluctuation (ft)
A	1989	Coastal Plain	NR	31-37	2.5
B	Pre-2/93	Coastal Plain	$1.9\ 10^{-3}$	2-7	5
C	Pre-4/88	Piedmont	$1.32\ 10^{-4}$	NR	NR
D	Pre-2/91	Coastal Plain	$2.67\ 10^{-3}$	21-23	NR
E	Pre-9/89	Coastal Plain	$3.5\ 10^{-4}$	8-12	13
F	5/90	Piedmont	$7.05\ 10^{-5}$	25-28	2
G	Pre-12/92	Piedmont	$7.4\ 10^{-4}$	21-25	4
H	Pre-1/93	Piedmont	$8.96\ 10^{-4}$	28-40	NR

* K determined through pump testing at sites C, D, E, and G; found using slug testing at sites B, F, and H

NR - not reported

Technology Description [3]:

The remediation systems combined vapor extraction and groundwater extraction to treat smear-zone soils through dewatering and volatilization of contaminants. Table 2 provides technical information about the remediation systems used at each of the eight sites, including the number of VE and GE wells, system vacuum and air flow rate, and water yield per well. The vacuum extraction systems at each site included vacuum extraction wells (ranging from 4 to 17 wells per site), one to two regenerative vacuum blowers used to generate an average air flow rate ranging from 4.6 to 18.5 scfm and a mean system vacuum ranging from 22 to 41 inches of water.

The groundwater extraction system at each site included extraction wells (ranging from 2 to 8 wells per site) equipped with pneumatic total fluids pumps. The average pumping rate (water yield) ranged from 0.11 gpm to 0.38 gpm.

The volume of smear zone soils exposed to air varied significantly from site to site. Seasonal water table fluctuations generally ranged from 2 to 5 ft, but a water table fluctuation of more than 10 ft contributed to cleanup efficiency at Site E. Figure 1 shows the water table elevation and VOC removal rate at one of the sites from August 1990 through March 1995. The figure illustrates the fluctuation in water elevation that was found at most sites. According to the technology provider, while the groundwater extraction systems were intended to dewater the smear zone, they were generally undersized and relied on seasonal waster table fluctuation to access NAPL in the lower portion of the smear zone in late summer to early fall.

Figure 1. VOC Removal Rate versus Water Table Elevation [5]

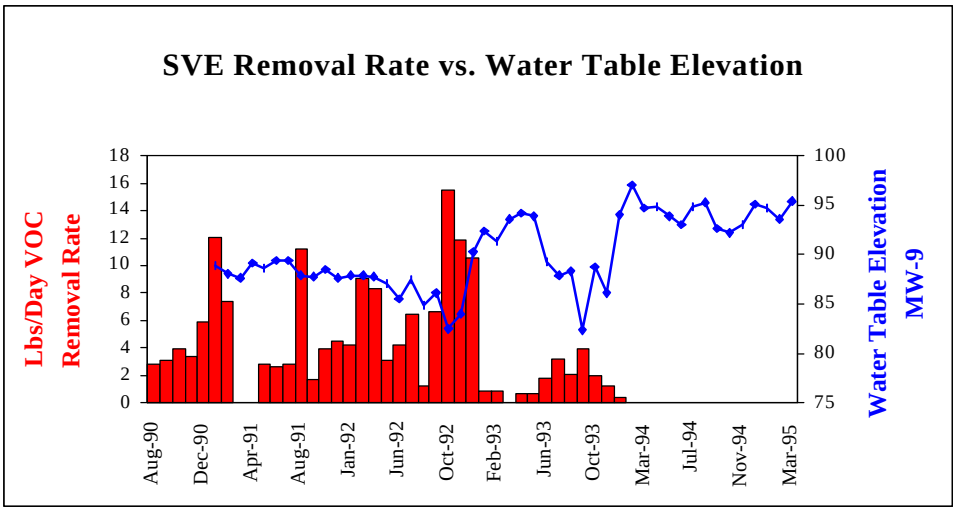


Table 2. Summary of Remediation System Information for Eight Sites [3]

	Vacuum Extraction System				Groundwater System		
Sites	**VE Wells**	**Mean System Vacuum (inches H_2O)**	**Average Air Flow/Well (SCFM)**	**Vapor Mass Removed (kg)**	**GE Wells**	**Mean Water Yield/Well (GPM)**	**Dissolved Mass Removed (kg)**
A	10	36	9.8	6,901	6	0.24	120
B	8	39	4.6	1,367	8	0.33	12
C	5	NR	NR	1,936	5	NR	NR
D	4	37	18.5	3,524	3	0.67	91
E	7	NR	15.2	2,399	2	NR	NR
F	6	40	13.2	3,714	6	0.11	91
G	17	41	6.9	95,648	8	0.38	524
H	5	22	17.4	13,723	5	0.49	3,256

VE – vapor extraction
GE – groundwater extraction
NR - not reported

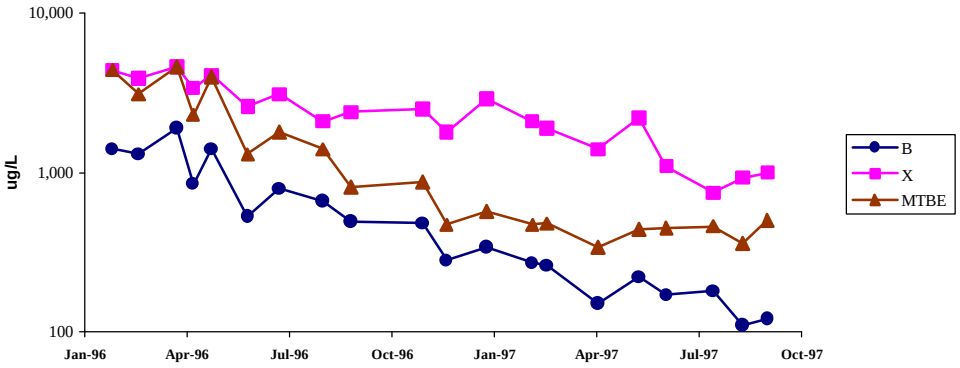
Technology Performance [3,5]:

According to Chevron, the objective of the VE/GE systems was smear-zone dewatering and remediation through volatilization. No specific cleanup goals were established for any of the sites.

Pre-remediation concentrations of MTBE and BTEX in groundwater were relatively stable for a period of up to three years. Figure 2 is an example of remediation time series data provided for Site B, which shows declining groundwater concentrations for MTBE, benzene, and xylene during system operation from January 1996 to October 1997. Table 2 provides a summary of the results from the remediation efforts, in terms of dissolved mass removed and vapor mass removed. The vapor extraction system removed approximately 1,300 kg to 95,000 kg of contaminants per site, and the groundwater system

removed approximately 12 kg to 3,200 kg of contaminants per site. For the 8 sites, the VE/GE systems removed approximately 30 times as much mass in the soil vapor as was removed from the dissolved plume.

Figure 2. Concentrations of MTBE, Benzene, and Xylene in Groundwater - Site B [3]



The sites had an average remediation period of 3.2 years and an average monitoring period of 4.7 years.

In addition, performance was evaluated in terms of the concentration reduction factor and post-remediation rebound factor. The reduction factor was calculated for each well where post-remediation analytical data was available based on initial concentration (Co) divided by ending concentration (Cend), and an average calculated for all wells. Both Co and Cend were derived from time series regression, with initial concentration = Co in the first order decay equation C=Co e(-kt), and Cend being C at t = total days of operation.

Post remediation rebound was calculated for each well (Cpost-Cend)/(Co-Cend) where Cpost is a groundwater concentration value collected within the first 3 sampling events (3-9 months) following system shut-down. According to the researchers, the intent was to select Cpost at sufficient time to allow groundwater concentration rebound to occur, but not so long as to allow natural attenuation to significantly alter post remediation groundwater quality (i.e., years later).

Table 3 summarizes the average data on initial and final concentrations and on concentration reduction factor and post-remediation rebound data for the sites by contaminant. Appendix A presents detailed data by well for each of the eight sites for MTBE, benzene, and xylene.

Table 3. Summary of Performance for the 8 VE/GE Sites [5]

Contaminant	Initial Concentration (ug/L) (Co)	Days of Operation (M time)	End Concentration (ug/L) (C end)	Concentration Reduction Factor	Post-remediation Rebound Factor
MTBE	6,139	923	791	23	-2.87%
BTEX	5,511	839	1,088	69	-9.12%
Xylene	8,539	910	2,859	27	22.63%

Average MTBE concentrations were reduced from 6,139 ug/L to 791 ug/L; BTEX from 5,511 ug/L to 1,088 ug/L; and xylene from 8,539 ug/L to 2,859 ug/L. The average concentration reduction factor for the eight sites was 23 for MTBE, 69 for benzene, and 27 for xylene. For those sites where system shutdown had occurred, the average post-reduction rebound was –2.87% for MTBE, -9.12% for benzene, and 22.63% for xylene. While there was variation in rebound by individual wells at each site and among sites (see Appendix A), the data in Table 3 indicate that on average, MTBE and BTEX concentrations did not generally rebound at sites after shutdown, while on average, there was rebound in xylene concentrations.

Technology Cost [5]:

No cost data were provided for these sites.

Observations and Lessons Learned:

The researcher provided the following observations [3]:

1. MTBE removal rates were found to be similar to those for BTEX, which is not consistent with the assumptions of local chemical equilibrium for NAPL-liquid and NAPL-vapor partitioning. Predicted removal rates for MTBE, based on several assumptions about local chemical equilibrium, were 4 times faster than benzene and 60 times faster than xylene. The reasons for this discrepancy are not known. It is likely that conventional groundwater remediation technologies will encounter similar mass removal limitations for MTBE and BTEX in all but ideal hydrogeologic settings.
2. The VE/GE remediation systems included in this evaluation were successful in targeting smear zone soils for removal of NAPL through volatilization, which in turn removed the source of dissolved-phase contaminants.
3. Reasonably constant source concentrations suggested that without active remediation, neither MTBE nor BTEX would have been rapidly removed from NAPL through natural processes.
4. Remediation of MTBE-contaminated sites does not need to be initiated immediately after a release to be effective. The data from the eight sites in this study showed that remediation of older, weathered NAPL through air-based technologies should experience a similar degree of success for MTBE as for BTEX.

References:

1. Tom Peargin, Chevron Research and Technology Company, and Cristin Bruce and Paul C. Johnson, Department of Civil and Environmental Engineering, Arizona State University. “Application of Aeration-Based Technologies to MTBE-Impacted Sites”. Presentation at In Situ Remediation Alternatives for MTBE Impacted Aquifers, Oxnard, California. August 10, 1999.

2. Tom R. Peargin, Chevron Research and Technology Company. “An Empirical Study of MTBE, Benzene, and Xylene Groundwater Remediation Rates”. In In Situ Bioremediation of Petroleum Hydrocarbon and Other Organic Compounds, Editors Bruce C. Alleman and Andrea Leeson. The Fifth International In Situ and On-Site Bioremediation Symposium, San Diego, California, April 19-22, 1999.

3. Tom R. Peargin, Chevron Research and Technology Company. “An Empirical Study of MTBE, Benzene, and Xylene Groundwater Remediation Rates”. Unabridged Paper from NGWA Conference. Not Dated.

4. Record of Telephone Conversation, Steve Michener, Tetra Tech EM Inc., and Tom Peargin, Chevron. Obtain Information on 8 Small Groundwater Sites. September 9, 1999.

5. Tom R. Peargin, Chevron Research and Technology Company. E-mail to Linda Fiedler, EPA/TIO. Comments on Draft Case Study of Eight Service Stations in Maryland. May 8, 2000.

Appendix A – Detailed Performance Data for Eight Sites

Table A-1. MTBE Data For Eight Sites [5]

Site	Well	MTBE Intial Concentration (ug/L) (Co)	Days of Operation (M time)	MTBE End Concentration (ug/L) (Cend)	Concentration Reduction Factor	Post-Remediation Rebound
A	MW-10	3,083	1091	32	96.0	
A	MW-15	6,162	1003	750	8.2	
A	MW-16	8,849	638	922	9.6	
A	MW-5	27,027	1197	3,031	8.9	
A	VP-3	4,039	914	608	6.6	
B	INF	3,258	576	262	12.4	
B	RW-1	1,027	294	141	7.3	-1%
B	RW-4	804	451	309	2.6	-16%
B	RW—5	1,572	451	121	13.0	50%
B	RW-6	6,519	451	84	77.6	25%
B	RW-7	12,542	451	380	33.0	5%
B	RW-8	1,849	451	484	3.8	22%
C	MW-10	3,714	1256	675	5.5	-18%
C	MW-2	5,127	1256	1,455	3.5	-39%
C	MW-5	3,406	359	1,323	2.6	-62%
C	MW-6	868	1256	182	4.8	-15%
C	MW-7	1,223	1256	148	8.2	-7%
C	MW-8	2,185	812	673	3.2	-29%
C	RW-5	2,670	1256	68	39.1	-2%
C	RW-9	4,510	1256	154	29.3	-3%
D	MW-8	3,925	1294	126	31.2	21%
D	MW-9	5,940	1014	60	99.6	2%
D	RW-1	6,704	1294	134	50.1	-2%
D	RW-2	3,953	1294	158	25.0	10%
E	MW-8	2,550	821	103	24.7	-2%
G	MW-13	7,020	1020	365	19.2	
G	MW-14	1,537	1020	17	91.1	-1%
G	MW-18	1,758	643	173	10.2	4%
G	MW-5	29,932	1020	420	71.2	
G	MW-6	1,450	1020	108	13.4	-8%
H	MW-1	3,987	930	947	4.2	
H	MW-12	7,698	1435	659	11.7	
H	MW-2	11,510	1616	1,316	8.7	
H	MW-3	2,233	461	1,539	1.5	
H	MW-6	8,105	1122	2,178	3.7	
H	MW-7	19,563	1023	3,854	5.1	
H	MW-8	8,856	461	5,309	1.7	
	Ave.	**6,139**	**923**	**791**	**23**	**-2.87%**

Table A-2. Benzene Data for Eight Sites [5]

Site	Well	B Co	B time	B Cend	Reduction Factor	Post-Remediation Rebound
A	MW-13	985	1197	149	6.6	
A	MW-14	4,424	1197	1,764	2.5	
A	MW-15	2,174	1003	36	6.0	
A	MW-16	5,941	638	634	9.4	
A	MW-6	2,516	1197	315	8.0	
A	MW-7	10,958	194	3,121	3.5	
A	VP-3	3,157	914	205	15.4	
B	INF	1,453	576	110	13.2	
B	RW-1	337	294	120	2.8	-5%
B	RW-4	139	451	109	1.3	-191%
B	RW—5	1,612	451	3	495.6	2%
B	RW-6	2,274	451	22	103.8	3%
B	RW-7	4,430	451	213	20.8	-2%
B	RW-8	1,662	451	244	6.8	4%
C	MW-10	4,991	1256	997	5.0	-16%
C	MW-5	2,234	709	58	38.2	-2%
C	MW-6	9,131	1191	433	21.1	1%
D	MW-8	2,543	1294	128	19.9	-4%
D	MW-9	550	1014	14	38.3	2%
D	RW-1	2,802	1294	229	12.3	-8%
E	MW-13	7,279	933	1,898	3.8	74%
F	MW-4	792	1281	9	85.2	
G	MW-13	10,411	1020	1,355	7.7	-15%
G	MW-18	2,541	643	2	1300.0	2%
G	MW-3	7,841	909	863	9.1	-6%
G	MW-5	30,531	1020	3,257	9.4	-1%
G	MW-7	17,989	1020	2,353	7.6	-3%
G	MW-9	5,425	747	274	19.8	
H	MW-1	6,407	930	1,268	5.1	
H	MW-12	2,990	1435	60	49.9	
H	MW-3	3,960	461	1,788	2.2	
H	MW-6	8,864	1122	2,702	3.3	
H	MW-8	13,167	461	8,696	1.5	
H	SP-1	4,866	312	3,239	1.5	
	Ave.	**5,511**	**839**	**1,088**	**69**	**-9.12%**

Table A-3. Xylene Data For Eight Sites [5]

Site	Well	X Co	X time	X Cend	Reduction Factor	Post-Reduction Rebound
A	MW-12	14,725	1103	1,884	7.8	
A	MW-15	8,185	1003	6,052	1.4	
A	MW-16	7,900	638	516	15.3	
A	MW-5	16,759	1197	485	34.6	
A	MW-6	8,005	1197	2,782	2.9	
A	MW-7	8,790	194	2,592	3.4	
B	Influent	4,469	576	1,008	4.4	
B	RW-6	6,067	451	991	6.1	6%
B	RW-7	8,427	451	2,549	3.3	28%
B	RW-8	6,753	451	1,071	6.3	32%
C	MW-10	6,486	1197	3,151	2.1	-14%
C	MW-5	8,010	709	1,877	4.3	-30%
C	MW-7	14,687	1256	1,856	7.9	40%
C	OW-2	12,647	1256	10,905	1.2	235%
D	MW-10	4,420	1281	1,198	3.7	-37%
D	RW-1	1,441	1294	139	10.3	-8%
E	MW-8	9,303	821	678	13.7	13%
F	MW-2	10,032	1364	1,218	8.2	
G	MW-3	13,612	909	5,381	2.5	15%
G	MW-5	12,173	1020	575	21.2	-4%
G	MW-7	9,738	1020	3,075	3.2	17%
G	MW-9	9,891	747	8,461	1.2	
H	MW-1	5,540	930	2,252	2.5	
H	MW-11	1,533	1542	644	2.4	
H	MW-2	3,254	1427	5	601.0	
H	MW-3	6,330	461	3,763	1.7	
H	MW-6	5,893	1122	2,343	2.5	
H	MW-8	14,481	461	11,145	1.3	
H	**SP-1**	8,084	312	4,302	1.9	
	Ave.	**8,539**	**910**	**2,859**	**27**	**22.63%**

Appendix B – Period of Operation By Site [5]

Site	Period of operation
A	Main system started up 1/94. Pumping wells MW-7, MW-8, MW-11, MW-12, MW-14, MW-15. SVE from these plus VP-1 through VP-4. MTBE release ~9/96 affects some wells. Turned off 7/97 but turned back on 9/97 after LPH showed up in some wells.
B	VE/GE began 1/96 from RW-1 through RW-8, shut down 9/17/97
C	VE/GE began 4/91. GE 4" wells MW-2, MW-10, RW-5, RW-8, RW-9. SVE 2" wells MW-5, MW-7, MW-8, MW-9, MW-11. System turned off 3/16/95 and dismantled.
D	Began VE/GE 8/9/93, turned off 6/4/97. GE from RW-1, RW-2, RW-3 (MW-8). VE from above wells plus MW-9.
E	GE system MW-16A and MW-8A. SVE MW-1, MW-6, MW-7, MW-8, MW-9, MW-12, MW-13. Startup was 8/90, shut down 6/95
F	System begin 5/27/93. SVE from RW-1, RW-2, RW-3, & MW-5. GE system upgrade 4/10/95. VE/GE system MW-2 and MW-6.
G	SVE & GE begin 5/94. Current GE MW-6, MW-7, MW-8, MW-10, MW 13, MW-14, MW-15, MW-17, MW-18 (MW-11 from 5/94 - 5/95). SVE all wells to MW-19. VE turned off 10/96, GE turned off 5/97
H	GW & LPH recov. begin 6/93 MW-1, MW-7, MW-8. MW-3 & MW-6 added 5/94. SVE on above wells 7/94.