
Chapter 9. Post-Treatment Rock and Ground Water Sampling

Post-treatment ground water and rock chip samples were obtained for comparison to pre-treatment samples to fulfill SITE objectives P1 and S1, respectively.

9.1. Rock Chip Sampling Results

Post-treatment rock chip samples were acquired in July 2003. Eight locations adjacent to where pre-treatment rock chips had been acquired were chosen for sampling. Core locations were chosen to give a wide range of treatment extent, and these locations are shown on Plate 4.1.2-1. At the eastern side of the site, where most of the steam was injected, a core was obtained that was centrally located between I-5 and I-6 (BD-I-5-6). Cores were also obtained adjacent to VEA-5 and I-7, which were originally used as extraction wells but were converted to injection wells approximately five weeks after steam injection was initiated. Each of the extraction wells through the center of the treatment area, EX-1 to EX-4, were also chosen for post-treatment sampling, as these cores had some of the highest concentrations in the pre-treatment sampling, and these were some of the locations to which contaminants were being moved in order to be extracted from the subsurface. I-3 was also chosen as a drill back location for the same reasoning. Cores 0.05 meter (0.17 foot) in diameter were obtained for the post-treatment sampling using the triple tube drilling technique, and again rock chip samples were acquired using a hammer and a cold chisel. The extraction protocol outlined in Chapter 4.1.2 was followed, except that the methanol was removed from the sample at the laboratory rather than in the field. Sampling was concentrated in the depths of the boreholes where contamination had been detected during pre-treatment characterization, or where there was visible evidence of contamination.

Post-treatment MERC sampling results for PCE are shown on Plate 4.1.2-1 adjacent to the pre-treatment results, and Table 9.1-1 presents the results for all of the post-treatment MERC samples. The figures on Plate 4.1.2-1 clearly show that PCE concentrations in the rock were lower in the post-treatment samples than in the corresponding location during pre-treatment sampling. The smaller core size used for the drillback meant that less fracture surface was available for sampling, and more of the matrix further from the fracture was, of necessity, included in the sample. It is speculated that this might have had some effect on relative concentrations of pre- and post-treatment samples; however, it cannot be determined at this time if the smaller core size used for the drillback may have caused overall lower concentrations to be measured in these samples.

BD-I-5-6 was approximately 4.6 meters (15 feet) southwest of I-5 and 4.6 meters (15 feet) northwest of I-6. Thus, it was in the center of the area where most of the steam was injected. While steam likely reached this area at depth, the upper portion of the borehole would be expected to experience only modest temperature increases due to heat conduction from the nearby steam injection wells. It was noted that fractures to a depth of approximately 6 meters (20 feet) bgs in this borehole had a sheen and petroleum hydrocarbon odor. The MERC analysis showed the presence of small concentrations of BTEX and isopropylbenzene, compounds had been found in the shallow portion of I-6 prior to treatment, and these compounds persist in the fractures down to a depth of at least 5 meters (16.4 feet) bgs after treatment. PCE was first detected in this borehole at a depth of 22.1 meters (72.6 feet); however, the concentrations were low, ranging from 0.05 to 1.44 mg/kg, with the highest concentration detected in the lowest fracture sampled. These concentrations are generally similar to the concentrations found in I-5, and somewhat less than the concentrations found in I-6, with the exception of the sample from a vertical fracture at 28.9 meters (94.8 feet), which is somewhat higher than might be expected based on pre-treatment sampling results. TCE was also detected in the same fractures with PCE in concentrations ranging from 0.03 to 0.28 mg/kg. Other chlorinated compounds detected are cis- and trans-1,2-DCE and chloroform.

BD-VEA-5 was 1.4 meters (4.5 feet) north of VEA-5, which had been used for steam injection, and thus this location likely saw a small but measurable increase in temperature over its length due to heat conduction from VEA-5. This borehole also had small concentrations of BTEX compounds at approximately the depth of the water table. PCE was detected in this borehole only in fractures deeper than 19.1 meters (62.8 feet) bgs, and concentrations ranged from 0.10 to 3.38 mg/kg. The highest concentration was found in a bedding plane fracture with significant staining, indicating that it had been active in the ground water flow system. This appears to be a significant reduction from concentrations that were as high as 13.1 mg/kg in the pretreatment samples.

BD-I-7 was located approximately 1.8 meters (6 feet) northeast of I-7, and thus also was likely heated somewhat by heat conduction. PCE concentrations in this core ranged from 0.23 to 0.71 mg/kg, which may be a significant reduction from the concentrations that went as high as 5 mg/kg in I-7. Small amounts of TCE were also detected in this core, ranging from 0.09 to 0.22 mg/kg. The

Table 9.1-1. Post-Treatment Rock Chip Sampling Results

Depth in meters	Depth in feet	Fracture Description	1,2,3-trichlorobenzene	1,2,4-trichlorobenzene	1,3-dichlorobenzene	benzene	chlorobenzene	chloroform	cis-1,2-dichloroethylene	ethylbenzene	naphthalene	trans-1,2-dichloroethylene	tetrachloroethylene	trichloroethylene	toluene	total xylenes
BD-VEA-5																
4.4	14.4	V&H, S				0.06				0.11					0.23	0.69
4.4	14.4 Duplicate	V&H, S				0.09				0.16					0.22	0.89
5.6	18.5	V,S														0.17
5.6	18.5 Re-extract															
18.7	61.4	NFCS														
19.1	62.8	H,S				0.04							0.1			
20.4	66.8	BCZ, S														
21.9	72	B,S											3.38	0.16		
25.2	82.7	V, S, C, M											0.18			
BD-EX-1																
6.2	20.5	V, S													0.18	
11.1	36.5	B, C, S														
12.1	39.7	V, S, Sheen	0.12	0.32		0.07			0.04		0.08		0.77	0.06	0.06	0.02
12.1	39.7 Duplicate	V, S, Sheen	0.11	0.29		0.09			0.04		0.08		0.89	0.09	0.07	0.03
14.2	46.7	NFCS														
17.9	58.8	S, not open				0.04					0.11		5.14	0.14	0.04	
25.0	81.9	V, S							0.1				2.58	0.23		
BD-EX-2																
9.7	31.7	NFCS			0.03										0.56	
13.4	44	V, S											2.46	0.1		
14.3	46.8	B, S											0.78			
16.8	55.2	MB														
19.1	62.8	V, S											0.5			
19.1	62.8 Re-extract												0.15			

Table 9.1-1. Continued

Depth in meters	Depth in feet	Fracture Description	1,2,3-trichlorobenzene	1,2,4-trichlorobenzene	1,3-dichlorobenzene	benzene	chlorobenzene	chloroform	cis-1,2-dichloroethylene	ethylbenzene	naphthalene	trans-1,2-dichloroethylene	tetrachloroethylene	trichloroethylene	toluene	total xylenes
BD-EX-3																
6.1	20.1								0.1				1.01	0.9	0.04	
6.1	20.1 Duplicate								0.09				0.96	0.73	0.05	
9.0	29.5	V, C											1.89	0.07		
12.7	41.7	B											1.24	0.1	0.02	
12.7	41.7 Re-extract												0.44	0.05		
14.0	45.9	B, C, S							0.08				3.34	0.47		
14.6	48	NFCS														
16.8	55	B, S, C							0.14				1.32	0.49		
BD-EX-4																
5.5	18	B, S, Sheen													0.08	0.07
7.5	24.7	B, S													0.04	0.06
9.9	32.5	V, S														0.04
9.9	32.5 Duplicate	V, S							0.02						0.03	0.05
14.8	48.7	B, S											0.07			0.04
16.4	53.9	H, S														
18.4	60.4	B, C, S							0.02				0.65	0.32		0.02
20.1	66	NFCS														
20.7	67.9	V, S											0.34	0.32	0.03	
24.5	80.4	B														
BD-I-3																
23.2	76.2	B, S, C											0.4	0.11		
23.2	76.2 Re-extract												0.08			
23.7	77.8	NFCS											0.73	0.11		
26.0	85.4	H, S, B											2.75	0.1		
26.3	86.4	V, C, S				0.05			0.03				1.34	0.33		

Table 9.1-1. Continued

Depth in meters	Depth in feet	Fracture Description	1,2,3-trichlorobenzene	1,2,4-trichlorobenzene	1,3-dichlorobenzene	benzene	chlorobenzene	chloroform	cis-1,2-dichloroethylene	ethylbenzene	naphthalene	trans-1,2-dichloroethylene	tetrachloroethylene	trichloroethylene	toluene	total xylenes
26.3	86.4 Duplicate	V, C, S							0.03				1.82	0.46		0.05
30.1	98.6	B, C, S				0.02	0.05		0.03		0.06	0.03	15.78	0.4		0.05
30.3	99.5	H, S											7.02	0.31		0.05
30.3	99.5 Re-extract												1.74	0.07		
BD-I-5-6																
2.7	8.9	V&B, S, O, Sheen				0.1				0.04					0.08	0.2
2.7	8.9 Re-extract					0.03									0.03	0.03
2.7	8.9 Duplicate					0.15				0.07					0.15	0.39
5.0	16.4	V, S, O				0.25				0.24		0.04			0.29	1.09
5.0	16.4 Re-extract					0.06				0.04					0.08	0.16
15.0	49.3	NFCS														
18.1	59.3	B, C, S														
18.1	59.3 Duplicate															
22.1	72.6	V, S						0.1					0.16	0.08		0.03
23.4	76.9	B, S						0.03	0.22			0.03	0.23	0.28		
23.4	76.9 Re-extract								0.09				0.12	0.16		0.03
25.4	83.3	B														
25.8	84.6	V, S											0.05			
28.9	94.8	V, S											1.44	0.21		
BD-I-7																
15.0	49.1	V, S														
15.5	50.7	V, S											0.71	0.15		
15.5	50.7 Duplicate	V, S											0.37	0.09		
20.5	67.3	NFCS							0.15				0.23	0.21	0.04	
21.3	70	V, S											0.45	0.22		

nonfractured core sample (NFCS) collected from a depth of 20.1 meters (68 feet) bgs in I-7 had shown a small concentration of PCE (0.71 mg/kg). A sample from a broken core zone at a depth of 20.5 meters (67.3 feet) bgs in BD-I-7 showed a small concentration of PCE, as well as small concentrations of TCE, cis-1,2-DCE, and toluene.

BD-EX-4 was located approximately 1.4 meters (4.5 feet) north of EX-4. EX-4 showed a temperature increase along its length due to heat conduction from a nearby injection well, and also showed a small temperature increase at a depth of about 6 to 12 meters (20 to 40 feet) bgs that appears to be steam/hot water flow in a fracture. PCE concentrations found in EX-4 prior to treatment ranged from 4.41 to 7.48 mg/kg. Samples obtained from the same depth range in BD-EX-4 had PCE concentrations ranging from nondetect to 0.65 mg/kg. TCE concentrations ranged from nondetect to 0.32 mg/kg. Very low concentrations of trans-1,2 DCE were also detected in the post-treatment core. A fracture at 5.5 meters (18 feet) bgs in BD-EX-4 contained an oil sheen and significant staining, and the rock chip analysis detected small amounts of toluene and xylene in this fracture. Fractures at this depth in EX-4 had been nondetect during the pre-treatment sampling, thus, the small amount fuel components detected post-treatment may indicate that contaminants were being displaced toward EX-4 for recovery.

BD-EX-1 was located approximately 1.2 meters (3.8 feet) south of EX-1. EX-1 had shown a small temperature increase (to 20°C; 68°F) at a depth of 6.1 meters (20 feet) bgs during the later part of the steam injection. Pre-treatment rock chips in this area had shown PCE concentrations as high as 19 and 21 mg/kg at the bottom of the borehole. PCE concentrations in the bottom of BD-EX-1 were 5.14 and 2.58 mg/kg. The highest concentration was detected in a fracture that was not thought to be open based on visual observation of the core in the field. Detections of TCE were as high as 0.23 mg/kg. Small amounts of BTEX compounds were detected in the central portion of this borehole, as well as 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, and naphthalene.

BD-EX-2 was located approximately 1.1 meters (3.5 feet) east of EX-2. Essentially no temperature increase was recorded at EX-2. During the pre-test characterization, PCE concentrations in EX-2 were as high as 12 and 18 mg/kg. BD-EX-2 showed PCE concentrations ranging from 0.15 to 2.46 mg/kg. There was only one small hit of TCE of 0.10 mg/kg. There were very small concentrations of toluene and 1,3-dichlorobenzene in the NFCS taken from a depth of 9.7 meters (31.7 feet) bgs, which was located approximately 0.5 meters (1.7 feet) from the nearest feature, a bedding plane fracture at 9.1 meters (30 feet) bgs.

BD-EX-3 was located approximately 1.7 meters (5.5 feet) east-southeast from EX-3. EX-3 was the extraction well farthest from the area of steam injection, and no significant temperature increase was recorded in this well. EX-3 had some of the shallowest detections of PCE, starting at a depth of 6.7 meters (22 feet) bgs, and concentrations went as high as 8 and 10 mg/kg. BD-EX-3 had PCE concentrations ranging from 0.44 to 3.34 mg/kg, and TCE concentrations ranging from 0.05 to 0.90 mg/kg. cis-1,2-DCE was detected at several locations, with the highest concentration being 0.14 mg/kg.

BD-I-3 was located approximately 1.6 meters (5.2 feet) south of I-3. During the pre-treatment characterization, the highest detections of PCE were in I-3, where the bottom three fractures sampled had concentrations of 41.8 mg/kg at 26.8 meters (88 feet) bgs, 54.4 mg/kg at 29.3 meters (96 feet) bgs, and 72 mg/kg at 29.6 meters (97 feet) bgs. During the steam injection, no temperature increases would be expected at this well; however, the temperature data show some sporadic increases. Because the pre-treatment characterization had shown that contamination existed only in the bottom of this borehole, starting at approximately 21.3 meters (70 feet) bgs, sampling during the drill back concentrated on the bottom of the borehole. This borehole contained the highest PCE concentrations found during the drill back, with 15.78 mg/kg detected at 30.1 meters (98.6 feet) bgs, and 7.02 mg/kg detected at 30.3 meters (99.5 feet) bgs. Other fractures from 26.0 to 26.3 meters (85.4 to 86.4 feet) bgs also had PCE concentrations ranging from 1.34 to 2.75 mg/kg. A fracture at 23.2 meters (76.2 feet) bgs had a smaller concentration (0.08 mg/kg), and a sample from a broken core zone at 23.7 meters (77.8 feet) bgs showed 0.73 mg/kg of PCE, as well as 0.11 mg/kg of TCE. At most places where PCE was detected, a small amount of TCE was also detected. In the most contaminated fractures, small amounts of cis- and/or trans-1,2-DCE were also detected. The most contaminated fracture at 30.1 meters (98.6 feet) bgs also contained small amounts of benzene, chlorobenzene, and naphthalene, and there was a low concentration of 1,3-dichlorobenzene at 26.3 meters (86.4 feet) bgs. Based on observation of the core in the field, it was thought that these fractures at 30.1 and 30.3 meters (98.6 and 99.5 feet) bgs were not open.

Overall, the post-treatment rock samples showed lower PCE concentrations than had been found in the pre-treatment samples. However, it must be kept in mind that it can be difficult to ensure that post-treatment borings sample the same structures as were sampled in pre-treatment borings. This is particularly true in the case of steeply-dipping fractures containing contaminant, such as those at 29.3 and 29.6 meters (96 and 97 feet) bgs in I-3. Some of the highest rock chip concentrations were found in samples from fractures that were not thought to be open based on visual observation in the field. BTEX contamination remains at approximately the depth of the water table in the eastern portion of the site. This contamination likely comes from an LNAPL plume that is known to exist to the east of the Quarry. Because the steam injection was targeting chlorinated solvent contaminants at depth, little steam was injected into the shallow zones near the water table. The shallow BTEX contamination could be remaining from before the steam injection, or it could have moved back into the area after the steam injection was completed. Despite the fact that no temperature increases were expected or noted at I-3, EX-2, or EX-3, decreases in rock concentrations were also noted at these locations. The cause of these decreases is not known.

QC Summary. The most significant QC problem noted with these samples was contamination in several of the sand blank samples that were prepared in the field. Contaminants found in the sand blanks included n-isopropylbenzene, 1,3,5-trimethylbenzene, 1,2,4-

trimethylbenzene, sec-butylbenzene, and p-isopropyltoluene, which are some of the same contaminants that were found in sand blanks during pre-treatment MERC sampling. It was determined that these contaminants were coming from a waxy coating on the lid of the sample jars. Table 9.1-1 contains only the contaminants that are known to be coming from the rock chips. Duplicate samples from the BD boreholes showed RPDs ranging from 4 to 64 percent, with 20 percent of the results outside of the criteria commonly used for evaluating duplicates of less than 40 percent difference. However, it should be kept in mind that these concentrations are low (most of them less than 1 mg/kg) and this may make the RPDs large.

Several of the samples were re-extracted with methanol for an additional week after the first methanol extraction. In virtually every case, additional contaminants were extracted by the fresh methanol. Concentrations found by re-extraction were generally 15 to 50 percent of the concentration that was found in the initial extraction. Although these data are not definitive on the extraction efficiency of the method used, they do indicate that actual rock chip concentrations are generally at least 30 percent higher than those detected by this method.

PCE concentrations were found to be high in some laboratory control samples and in MS/MSD samples, and it appeared that this was due to a discrepancy between the calibration and spiking standards. Xylenes and ethylbenzene were also high in many of the laboratory control samples; however, these compounds were generally not detected in rock chip samples. Despite these QC problems, the data quality is sufficient for the purposes of this project.

9.2. Ground Water Monitoring

For the post-treatment ground water sampling, the intention had been to sample the same ground water intervals that had been sampled prior to the steam injection in order to compare pre-treatment and post-treatment concentrations, and this was done when possible. However, not all of the intervals used for pre-treatment sampling were accessible after treatment, as several wells had been completed with grout for steam injection or monitoring purposes. Thus, adjustments were made to the sampling program. The intervals that were sampled during the three post-treatment ground water sampling rounds are shown in Tables 4.1.7.1-1 and 4.1.7.2-1. For wells I-4, I-5, I-6, I-7, and I-8, which were used as injection wells, the intervals sampled after steam injection correspond to some of the steam injection intervals, and the samples were obtained through the carbon steel standpipes that had been used to inject the steam. VEA-5 was sampled above the injection interval, which was open for extraction. All of the same intervals in the deep wells were sampled during the post-treatment sampling. Compilations of the ground water data are given in Table 9.2-1. The data are also shown on Plate 9.2-1.

Table 9.2.1-1. Post-Treatment Ground Water Sampling Results

Well I-2						
Interval, meters bgs	<13.7			>13.7		
Compounds/Date	May-03	Oct-03	May-04	May-03	Oct-03	May-04
cis-1,2-Dichloroethylene		0.00075J			0.0007J	
Chloroform		0.0016			0.0017	
Trichloroethylene		0.0042			0.0036	
Toluene		0.0016				
Tetrachloroethylene	0.0008J	0.065	0.0015	0.00096J	0.059	0.0018

Well I-3							
Interval, meters bgs	<15.2			>15.2			
Compounds/Date	May-03	Oct-03	May-04	May-03	May-03 ^d	Oct-03	May-04
Acetone				0.0011J			
cis-1,2-Dichloroethylene		0.00097J				0.00088J	
Chloroform		0.0037	0.0007J			0.0036	0.00067J
Trichloroethylene		0.0068	0.003		0.0044	0.0068	0.0026
Toluene		0.0037	0.004				0.00088J
Tetrachloroethylene	0.0012	0.13	0.044	0.0018	0.0012	0.14	0.034

Table 9.2.1-1. Continued

Well I-4			
Interval, meters bgs	21.3-33.5		
Compounds/Date	May-03	Oct-03	May-04
Acetone	0.0066	0.0048J	0.0076
Dichloromethane		0.0012	0.0026
Methyl Ethyl Ketone	0.001J		
cis-1,2-Dichloroethylene	0.0012	0.0012	0.0036
Chloroform		0.012	0.004
Benzene	0.0028	0.0024	0.0035
Trichloroethylene		0.00037J	0.00067J
Methyl Isobutyl Ketone	0.0038	0.0025	0.0023J
2-Hexanone	0.018	0.0083	0.0041J
Tetrachloroethylene	0.00097J	0.0038	0.0087
Chlorobenzene	0.0022	0.0017	0.0012
1,2,4-Trimethylbenzene			0.0006J
p-Dichlorobenzene	0.0028	0.0018	0.00082J
1,2,4-Trichlorobenzene	0.0014	0.0015	0.0024
Naphthalene	0.00086J	0.00077J	0.0016J
1,2,3-Trichlorobenzene			0.00086J

Well I-5			
Interval, meters bgs	21.3-36.6		
Compound/Date	May-03	Oct-03	May-04
Acetone	0.055	0.038	0.054
Methyl Ethyl Ketone	0.003J	0.0024J	0.0029J
cis-1,2-Dichloroethylene	0.00089J	0.0014	0.0016
Chloroform		0.0019	
Benzene	0.0029	0.003	0.0031
Methyl Isobutyl Ketone	0.00073	0.00065J	
2-Hexanone	0.0058	0.0029	
Tetrachloroethylene	0.002	0.0058	
Chlorobenzene	0.0026	0.0025	0.0022
p-Dichlorobenzene	0.0034	0.0027	0.0023
o-Dichlorobenzene	0.0006J		
1,2,4-Trichlorobenzene	0.0096	0.0095	0.0076
Naphthalene	0.014	0.0091	0.0096
1,2,3-Trichlorobenzene	0.0088	0.0056	0.0045

Well I-6			
Interval, meters bgs	9.1-15.2		
Compound/Date	May-03	Oct-03	May-04
Acetone	0.0078		
Dichloromethane	0.0024	0.0039	
Carbon Disulfide		0.0041	
Methyl Ethyl Ketone	0.00051J		
cis-1,2-Dichloroethylene	0.00059J	0.0007J	0.00075J
Chloroform	0.029	0.22	0.0019
Carbon Tetrachloride		0.074	
Benzene	0.0014	0.00091J	0.00087J
Trichloroethylene	0.006	0.039	0.026
Tetrachloroethylene	0.0011	0.0012	

Table 9.2.1-1. Continued

Well I-7			
Interval, meters bgs	23.5-30.2		
Compounds/Date	May-03	Oct-03	May-04
Vinyl Chloride	0.0012	0.0006J	
Acetone	0.0076		
1,1-Dichloroethylene	0.0035	0.00074J	
Dichloromethane	0.0018	0.0063	
trans-1,2-Dichloroethylene	0.002		
Methyl Ethyl Ketone	0.0015J		
cis-1,2-Dichloroethylene	0.028	0.014	0.0063
Chloroform	0.010	0.015	
Benzene	0.004	0.0054	0.0035
Trichloroethylene	0.031		
Toluene	0.00085J	0.00068	
Tetrachloroethylene	0.080	0.00054J	
Chlorobenzene	0.0011	0.002	0.0012
1,2,4-Trichlorobenzene	0.0013	0.0036	0.0024
Naphthalene	0.0016J	0.0024	0.0024
1,2,3-Trichlorobenzene	0.00077J	0.0019	0.00096J

Well I-8							
Interval, meters bgs	14.0-17.4				23.5-28.3		
Compound/Date	May-03	Oct-03	May-04	May-04 ^d	May-03	Oct-03	May-04
Vinyl Chloride	0.00089J		0.0022	0.0023		0.0057	0.0066
Acetone	0.019	0.28	0.037	0.040	0.71	0.0072	0.25
1,1-Dichloroethylene	0.00065J	0.0013	0.0017	0.0018	0.00059J	0.0056	0.0063
Dichloromethane	0.0017		0.0016	0.0016			
trans-1,2-Dichloroethylene		0.00067J				0.0018	0.0014
Methyl Ethyl Ketone	0.78	0.0062	0.44	0.46	0.013	0.059	0.0045J
cis-1,2-Dichloroethylene	0.018	0.031	0.042	0.042	0.0096	0.13	0.14
Chloroform	0.0063	0.0016	0.00098J	0.001	0.00064J	0.0035	0.0014
Benzene	0.0065	0.015	0.012	0.012	0.0064	0.028	0.027
Trichloroethylene	0.06	0.086	0.062	0.062	0.044	0.73	0.34
Toluene	0.0029	0.0042	0.0031	0.0031	0.0019	0.0043	0.0039
1,1,2-Trichloroethane						0.00072J	
2-Hexanone					0.0038		
Tetrachloroethylene	0.40	1.30	0.40	0.40	0.77	2.20	1.30
Chlorobenzene	0.0017	0.0086	0.0048	0.005	0.004	0.015	0.015
Ethyl Benzene	0.00073J	0.0025	0.0021	0.0021	0.00065J	0.0039	0.0041
Total Xylenes	0.004	0.011	0.0072	0.007	0.005	0.0087	0.01
Isopropylbenzene		0.00055J	0.00057J	0.00056J			0.0014
1,1,2,2-Tetrachloroethane						0.001	
n-Propylbenzene		0.00072	0.0006J	0.00062J		0.00075J	0.0016
1,3,5-Trimethylbenzene	0.00096J	0.0048	0.0029	0.0029	0.0016J	0.0016	0.0021
tert-Butylbenzene		0.00067J				0.00068J	
1,2,4-Trimethylbenzene	0.0019	0.015	0.0092	0.0087	0.0027	0.017	0.019
Sec-ButylBenzene							0.0007J
p-Isopropyltoluene		0.00069J	0.00075J	0.00074J		0.00073J	0.0023
m-Dichlorobenzene		0.00074J				0.00081J	0.0011
p-Dichlorobenzene		0.0019	0.00063J	0.0006J	0.0013	0.002	0.0023
o-Dichlorobenzene		0.0013	0.00099J		0.00059J	0.0018	0.0019
n-Butylbenzene				0.00085J		0.00057J	
1,2,4-Trichlorobenzene	0.0018	0.025	0.0071	0.0063	0.0093	0.022	0.027
Naphthalene	0.031	0.11	0.11	0.11	0.024	0.14	0.19
1,2,3-Trichlorobenzene	0.0011	0.01	0.0035	0.0031	0.004	0.011	0.012

Table 9.2.1-1. Continued

Well EX-1							
Interval, meters bgs	<12.2			>12.2			
Compound/Date	May-03	Oct-03	May-04	May-03	Oct-03	Oct-03 ^d	May-04
Chloromethane		0.0008J					
cis-1,2-Dichloroethylene					0.00058J		
Chloroform	0.00065J	0.014	0.00064J	0.00053J	0.016	0.015	0.00069J
Carbon Tetrachloride	0.00076J			0.00062J			
Trichloroethylene	0.00084J	0.0038	0.0018	0.00072J	0.004	0.0041	0.002
Toluene		0.0054	0.0038				0.00065J
Tetrachloroethylene	0.001	0.057	0.021	0.00097J	0.064	0.08	0.022

Well EX-2							
Interval, meters bgs	4.6-7.6				18.3-21.3		19.8-22.9
Compound/Date	May-03	May-03 ^d	Oct-03	May-04	May-03	Oct-03	May-04
trans-1,2-Dichloroethylene					0.00062J		
Methyl Ethyl Ketone	0.00087J	0.00069J			0.028		
cis-1,2-Dichloroethylene	0.00066J	0.00067J	0.0019		0.011	0.0016	
Chloroform			0.0018		0.005	0.0031	
Carbon Tetrachloride	0.00079J	0.00075J			0.012		
Benzene					0.0022		
Trichloroethylene	0.0063	0.0058	0.0062		0.092	0.0074	
Toluene			0.0031		0.0034		
Tetrachloroethylene	0.22	0.20	0.13	0.0051	2.60	0.20	0.0065
Chlorobenzene					0.003		
Ethyl Benzene					0.002		
Total Xylenes		0.00065J			0.0078		
Isopropylbenzene					0.00083J		
1,1,2,2-Tetrachloroethane					0.0013		
n-Propylbenzene					0.0015		
1,3,5-Trimethylbenzene	0.00092J				0.014		
1,2,4-Trimethylbenzene		0.00052J			0.033		
sec-Butylbenzene					0.00061J		
p-Isopropyltoluene					0.003		
p-Dichlorobenzene					0.0016		
o-Dichlorobenzene					0.0006J		
n-Butylbenzene					0.0032		
1,2,4-Trichlorobenzene					0.011		
Naphthalene	0.0071	0.0088	0.0006J		0.19		
1,2,3-Trichlorobenzene					0.0048		

Table 9.2.1-1. Continued

Well EX-3			
Interval, meters bgs	Upper Half		10.7-13.7
Compound/Date	May-03	Oct-03	May-04
Vinyl Chloride	0.0045	0.02	0.029
Acetone	0.0066		
1,1-Dichloroethylene	0.0024	0.0092	0.012
trans-1,2-Dichloroethylene	0.0014	0.0027	0.0035
Methyl Ethyl Ketone	0.0025J		
cis-1,2-Dichloroethylene	0.11	0.18	0.20
Chloroform	0.005	0.0073	0.0014
Benzene	0.013	0.018	0.029
Trichloroethylene	0.72	1.40	1.80
Toluene	0.0052	0.023	0.0071
Tetrachloroethylene	6.70	28.00	15.00
Chlorobenzene	0.015	0.027	0.03
Ethyl Benzene	0.0024	0.007	0.0037
Total Xylenes	0.016	0.053	0.013
Isopropylbenzene		0.0015	0.001
1,1,2,2-Tetrachloroethane	0.0024	0.0039	
n-Propylbenzene	0.00071J	0.0019	
1,3,5-Trimethylbenzene	0.0087	0.025	0.018
tert-Butylbenzene		0.00083J	
1,2,4-Trimethylbenzene	0.021	0.051	0.015
sec-Butylbenzene		0.00091J	0.00057J
p-Isopropyltoluene	0.0006J	0.0056	0.0073
m-Dichlorobenzene	0.00056J	0.0011	0.0016
p-Dichlorobenzene	0.0033	0.0061	0.0089
o-Dichlorobenzene	0.00057J	0.0012	0.0015
n-Butyl Benzene			0.0028
1,2,4-Trichlorobenzene	0.0063	0.02	0.0097
Naphthalene	0.18	0.18	0.0095
1,2,3-Trichlorobenzene	0.0033	0.0072	0.0043

Well EX-4								
Interval, meters bgs	3.0-6.1				6.1-9.1			
Compound/Date	May-03	Oct-03	Oct-03 ^d	May-04	May-03	Oct-03	May-04	May-04 ^d
Acetone								
Methyl Ethyl Ketone								
Chloroform		0.0044	0.0044	0.0016		0.0041	0.0014	0.0014
Carbon Tetrachloride		0.00079J		0.00099J		0.00068	0.0011	0.0011
Trichloroethylene		0.0044	0.0044	0.0014		0.0037	0.0011	0.001
Toluene		0.0032	0.0029			0.0071		
Tetrachloroethylene	0.00089J	0.0033	0.0029		0.0012	0.0045		

Well EX-4 Continued						
Interval, meters bgs	15.2-18.3			18.3-21.3		
Compound/Date	May-03	Oct-03	May-04	May-03	Oct-03	May-04
Acetone	0.0017J			0.0016J		
Methyl Ethyl Ketone	0.00085J			0.00085J		
Chloroform		0.0046	0.0013		0.0048	0.0014
Carbon Tetrachloride		0.00053J			0.00058J	0.00087J
Trichloroethylene	0.0044	0.0032	0.00095J		0.003	0.00093J
Toluene		0.0051			0.0015	
Tetrachloroethylene	0.0017	0.0042	0.00053J	0.0019	0.0058	0.00066J

Table 9.2.1-1. Continued

Well JBW-7817B			
Interval	Open Bore-Hole		
Compound/Date	May-03	Oct-03	May-04
Chloroform		0.00071J	
Methyl Ethyl Ketone	0.00058J		

Well VEA-5			
Interval, meters bgs	<23.5		
Compound/Date	May-03	Oct-03	May-04
cis-1,2-Dichloroethylene		0.0035	0.00066J
Benzene		0.0097	0.0055
Trichloroethylene		0.0016	0.00074J
Tetrachloroethylene	0.00066J	0.0043	0.00096J
Ethyl Benzene		0.02	0.00074J
Total Xylenes		0.0019J	0.0011J
Isopropylbenzene		0.0038	0.0018
n-Propylbenzene		0.0035	0.00074J
1,2,4-Trimethylbenzene		0.0089	0.0042
sec-Butylbenzene		0.00066J	
p-Isopropyltoluene		0.0011	0.00058J
Naphthalene			0.00065J

Well SM-1					
Interval	Interval 1		Interval 3		
Compound/Date	May-03	Oct-03	May-03	Oct-03	May-04
Acetone			0.017		
Chloroform	0.016	0.014	0.007	0.009	0.0078
Tetrachloroethylene		0.0038	0.0019	0.003	0.0025

Well SM-2						
Interval	Interval 2			Interval 3		
Compound/Date	May-03	Oct-03	May-04	May-03	Oct-03	May-04
Chloromethane		0.00053J				
Vinyl Chloride	0.0081	0.0075	0.01	0.0033	0.0016	0.0033
Acetone	0.0065	0.0054	0.0085	0.0017J		
1,1-Dichloroethylene	0.0051	0.0041	0.0046	0.0026	0.0014	0.0022
trans-1,2-Dichloroethylene	0.0022	0.0022	0.0022	0.0016	0.0012	0.0014
Methyl Ethyl Ketone	0.0013J	0.0015J	0.0019J			
cis-1,2-Dichloroethylene	0.10	0.17	0.44	0.092	0.11	0.30
Chloroform	0.0081	0.0079	0.007	0.0062	0.0057	0.0066
Benzene	0.0021	0.0021	0.0021	0.0017	0.0012	0.0014
Trichloroethylene	0.40	0.33	0.44	0.32	0.25	0.24
Toluene	0.0025	0.0025	0.0031	0.00096J	0.00059J	0.00091J
Tetrachloroethylene	0.15	0.12	0.17	0.26	0.18	0.20
Chlorobenzene	0.00079J	0.00077J	0.00069J			0.00055J
Total Xylenes			0.00089J	0.00063J		0.0007J
1,2,4-Trimethylbenzene						0.00054J
1,2,4-Trichlorobenzene						0.00058J
Naphthalene		0.00089J	0.0013J	0.0012J	0.00059J	0.0022
1,2,3-Trichlorobenzene						0.00081J

Table 9.2.1-1. Continued

Well SM-3						
Interval	Interval 1			Interval 3		
Compound/Date	May-03	Oct-03	May-04	May-03	Oct-03	May-04
Acetone				0.014		
Chloroform	0.0067	0.0052	0.0041	0.0034	0.003	0.00078J

units-mg/l

Empty cell indicates compound was not detected.

d-represents field duplicate

J - estimate

9.2.1. May 2003 Monitoring Round

The first round of post-treatment ground water samples were collected in May 2003, approximately six months after completion of the steam injection. The long period between completion of the steam injection and the first round of sampling was necessary due to problems with accessing the site during the winter. PCE concentrations were in general low during this round of sampling, especially when compared to the high concentrations that were being extracted when the steam injection was discontinued. PCE concentrations in the samples from all intervals of EX-1, EX-4, I-2, I-3, I-4, I-5, I-6, JBW-7817B, and VEA-5 that were sampled were below the MCL. For some of these intervals, that means that the concentrations dropped by as much as four orders of magnitude in the five month period immediately following the end of operations. Other samples, such as those from I-7 and I-8, showed increases in concentration from what had been extracted from these wells early in the steam injection. These concentration increases seem counterintuitive based on the fact that these wells were used for steam injection during the later part of the project. However, PCE-contaminated ground water could have entered these wells from the south or east after operations ceased. Samples from EX-3 and EX-2 remained similar to what they had been during the steam injection. Samples that had significant PCE concentrations also had significant TCE and DCE concentrations, and vinyl chloride was usually detected in these intervals.

During this sampling round, fuel components were found to have a much wider distribution than they had prior to steam injection, when they had largely been restricted to the eastern part of the site. Fuel components now also appeared in I-4, EX-2, I-8, and I-7. It appears that acetone, DCE, and vinyl chloride are now also more widely distributed.

Interval 1 of SM-1 and SM-3, both of which are below the target zone, were both nondetect for PCE during this sampling round. Small concentrations of chloroform were detected. Interval 3 of these same two wells, which are approximately at the same elevation as the treatment area, shows PCE concentrations similar to those found prior to treatment. SM-2, which had contained significant contamination in Intervals 2 and 3 prior to treatment, showed similar levels of PCE and other contaminants in this first round of post-treatment samples. These intervals are at approximately the same elevation as the treatment area.

9.2.2. October 2003 Monitoring Round

Ground water results from this second round of sampling generally show higher contaminant concentrations than were found in the first round of sampling. PCE and TCE concentrations in I-2, I-3, EX-1, and EX-2 were similar to concentrations found prior to treatment. I-8 and EX-3 have the highest concentrations of PCE and TCE in this sampling round, and these wells still show the presence of fuel components and chlorobenzenes, compounds that had not been detected prior to treatment. I-4, I-5, I-6, and I-7 have lower concentrations of PCE and TCE than they had prior to treatment, which is consistent with the fact that these wells were used for steam injection and thus saw significant temperature increases during operations. These wells now contain some of the fuel components and chlorobenzenes that were presumably mobilized during the steam injection. EX-4, which was the closest extraction well to the heated area, does not contain fuel components, and PCE concentrations have decreased since the first sampling round. PCE concentrations in this well remain lower than they had been prior to treatment. Small concentrations of carbon tetrachloride, chloroform, and toluene were detected in this well during this sampling round. VEA-5 shows small concentrations of PCE and its breakdown products. Fuel components (but not chlorobenzenes), which were not detected in the April sampling round, have now moved back into this well, likely due to the LNAPL plume that is in this area. The absence of chlorobenzenes in this sample likely indicates that the fuel components are from a different source than the fuel components found in other wells.

Interval 1 of SM-1, which is below the treatment area, now shows a small amount of PCE; however, the results for all the other intervals of the deep wells that were sampled remain very similar to the results from the first round of post-treatment sampling. Essentially wells SM-1 and SM-3 show very little or no contamination, while SM-2 has contamination in Interval 2 and 3 as it had before treatment.

9.2.3. May 2004 Monitoring Round

Ground water results from this final round of sampling generally show lower levels of contaminants than were found in the October 2003 monitoring round. This likely demonstrates some of the same type of temporal variations in ground water quality that were found prior to treatment. PCE and TCE concentrations remain high in wells I-8 and EX-3, as do fuel components and chlorobenzenes. All of the post-treatment samples from these wells show significant concentrations of TCE, DCE, and vinyl chloride, which had not been detected prior to treatment. I-3 and EX-1 appear to have ground water concentrations that are similar to pre-treatment concentrations. Lower concentrations compared to pre-treatment levels are found in wells EX-2, EX-4, and I-2. In this sample round, wells I-4, I-5, I-6, and I-7 have lower PCE concentrations than were detected prior to treatment; however, they now contain fuel components and chlorobenzenes that were not detected prior to treatment and were presumably mobilized during treatment. Borehole JBW-7817B remains clean, and VEA-5 still contains fuel components but very little chlorinated solvent.

Little change is found in the results for the deep wells. Interval 1 of SM-1 could not be sampled during this round to confirm the result for October 2003, which showed a small concentration of PCE. Although Interval 2 of SM-2 appears to contain somewhat higher contaminant concentrations now than it did prior to treatment, Interval 3 of this well seems to show a decrease in ground water concentrations. SM-3 remains clean in all sampled intervals.

9.2.4. Ground Water QC Summary

Quality control checks on the ground water data from the post treatment sampling show that there were only minor quality control problems with these analysis, and the data are of acceptable quality for the project objectives. Trip blanks indicated there were no problems with sample integrity during shipping. Mostly dedicated sampling equipment was used so that equipment blanks generally were not required; however, one equipment blank from the October 2003 sampling round had a small concentration of chloroform. There were some differences between the results of one sample and its duplicate from the May 2003 sampling round, as the RPD in PCE concentrations was 40 percent, and TCE was not detected in the sample but was detected at a concentration of 0.0044 mg/l in the duplicate. Duplicates from the October 2003 and May 2004 sampling rounds had acceptable RPDs, ranging from zero to 22 percent. MS/MSD results showed only a few analytes that were slightly out of the acceptable range. Laboratory control samples were acceptable with only a few exceptions, as were surrogate recoveries. The May 2004 data were validated, and minor quality control problems lead to the estimation of certain results. Nondetect acetone results were rejected, while positive acetone results were estimated due to low response factors. Positive or nondetect results for several analytes were estimated due to low laboratory control sample recoveries, however, of these analytes, only carbon tetrachloride was ever detected in the samples.

9.2.5. Ground Water Summary

As summarized in Chapter 2.4, Phase I and II ground water sampling, which were done in April and November 1998, seemed to identify two source zones of DNAPL in the northern portion of the upper tier. A source zone for PCE was found in JBW-7816 and JBW-7817A which appeared to extend to the west at least as far as JMW-0201. Smaller concentrations of PCE breakdown products TCE, DCE, and vinyl chloride are also found in this area. A second source that contained more unusual chemical species, including carbon disulfide, chloroform, and carbon tetrachloride, was found in JBW-7821 and JBW-7818. In addition, two LNAPLs were found in this area: what was thought to be an oil lubricant in JBW-7817A, and a mixture of weathered fuel and possibly lubricants in JBW-7820 (HLA, 1999c). Small concentrations of chlorobenzene were found in JBW-7817A and JBW-7816. This research project targeted the PCE source area, but at least one LNAPL plume was also known to exist within the target zone.

Plate 9.2.4-1 shows total VOC concentrations in ground water over the life of the project for wells that were used for extraction. Pre-treatment ground water sampling performed as part of this study in December 2001 and April 2002 showed PCE exceeding MCLs throughout the target area. Lower concentrations of PCE breakdown products were also found. Low concentrations of fuel components were found in wells at the eastern side of the site (I-4, I-5, JBW-7817B, and VEA-5). Low concentrations of BTEX were also found in the 11-14 meters (35-45 feet) depth interval of EX-3 in the December 2001 sampling round. This fuel plume appeared to be highly mobile, as it moved into Interval 3 of SM-3 between April and June of 2002. Trichlorobenzenes were detected in low concentrations in the north-central portion of the site (I-2 and I-3), and carbon tetrachloride was found in deep intervals of EX-4 and I-4.

When the extraction system was turned on prior to the initiation of the steam injection system, PCE concentrations in the extracted water were low across the site. The highest PCE concentrations were found in wells EX-1 (0.15 mg/l) and I-2 (0.12 mg/l). Within one week, PCE concentrations had increased substantially in EX-3 (1.30 mg/l) and VEA-5 (1.4 mg/l). VEA-5 also started showing low concentrations of trichlorobenzenes at that time. On September 23, what is interpreted as a plume of spent solvents, containing high concentrations of PCE, TCE, trichlorobenzenes, and other petroleum hydrocarbons, entered wells EX-2, I-2, EX-3, and EX-1. It is interpreted that the source of these spent solvents must have been in the vicinity of these wells and VEA-5, and that they were mobilized by the steam injection towards the west. Although the September 30 round of sampling once again showed relatively low contaminant concentrations, by October 7, many of these same wells, in addition to I-3 and EX-4, again showed high concentrations of PCE, TCE, chlorobenzenes, and petroleum hydrocarbons. Another large slug of these contaminants reached many of the extraction wells on November 12. By the end of steam injection, contaminant concentrations appeared to be declining in wells EX-2, I-2, I-3, JBW-7817B, and EX-4, whereas concentrations continued to increase in wells EX-1 and EX-3. Overall, the

effluent water samples showed a trend of increasing contaminant extraction rates at the time the system was shut down, including very high concentrations of DRO. The data clearly indicate that additional contaminants had already been mobilized and could have been captured by the extraction system had operations been continued beyond November 26.

Carbon tetrachloride was common in the vapor samples, and was also present in ground water samples from I-7, EX-4, and EX-1. It reached its highest concentrations during the study in well EX-1 from September 16 to November 19. Based on the Phase II characterization, the source area for carbon tetrachloride was thought to be outside of the target area for steam injection, at JBW-7821, which is approximately 7.3 meters (24 feet) to the southeast of the target area. It is possible that some of this contamination was pulled into the treatment area by pumping at EX-1, allowing it to be recovered.

It is difficult to determine any clear trends in the post-treatment ground water data. Higher contaminant concentrations were seen in wells I-8 and EX-3 than were seen in pre-treatment samples. Well EX-1 shows a similar level of contamination pre- and post-treatment. Wells I-2 and I-3 showed concentrations in May 2003 and May 2004 that were significantly lower than the initial concentrations, but the concentrations found in October 2003 were similar to pre-treatment levels. Wells I-4, EX-2, and EX-4 showed possible reductions in ground water concentrations. Wells JBW-7817B and VEA-5 were not sampled prior to steam injection, but after treatment showed essentially no chlorinated solvents. VEA-5 contained a floating NAPL composed of fuel before treatment; however, after treatment, fuel components were not seen in this well until the final sampling round. I-5 and I-7 contained no PCE or TCE in the final sample round; however, both contained low concentrations of fuel components and chlorobenzenes. In I-6, which had been used for steam injection over most of its length, PCE was completely absent in the final post-treatment sample; however, the TCE concentration increased after treatment to approximately the same concentration that PCE had been prior to treatment.

While the main contaminant found during pre-treatment sampling was PCE, ground water samples at the end of the post-treatment sampling showed higher concentrations of fuel components and chlorinated benzenes, apparently indicating that these contaminants were mobilized by the steam injection and remained mobilized a year and a half after steam injection ceased. The highest concentrations of contaminants found in post treatment samples were found in I-8 and EX-3. The high concentrations in EX-3 are likely explained by the fact that this extraction well was furthest from the injection area, and appears to have had contaminants mobilized towards it; however, there was not sufficient treatment time for the bulk of these contaminants to be extracted. In the case of I-8, it appears that water from the mobilized plume flowed into this well after the extraction system was turned off, as this well had been used for steam injection during the later half of the injection period.

Post treatment ground water sampling results were affected by several factors, including re-establishment of natural ground water gradients and flow directions after the extraction system was shut off, and perhaps seasonal changes in recharge and/or gradients. Temperature profiles of wells in the post-operational period (after November 19, see Plate 7.1-2) show a trend towards increasing temperature in wells along the southeast margin of the site (JBW-7817B and I-8 and in TC-1, VEA-7, and VEA-8) which continues until late December, after which time the temperatures decline. At the same time, wells and monitoring arrays immediately to the west of the steam injection wells (EX-4, I-9, VEA-4, and VEA-9) undergo continued heating in the period after steam injection, continuing to the final temperature measurements in February 2003. This association of heating and cooling trends may reflect the initial migration of heated water towards the southeast and northwest, along hydraulic gradients established during steam injection. The temperature decline along the southeastern edge of the site in late December 2002 may reflect the re-establishment of natural ground water flow along strike of bedding planes towards the northwest. The contrast between the relatively large increase in temperature observed in EX-4 and VEA-9 compared to that in EX-1 and I-9 may reflect the existence of somewhat better connections along strike from I-7 compared to poorer connections adjacent to I-8, and also to the poor interconnection between the eastern part of the site and the central part.

The apparent hydrogeological boundary between the eastern and central parts of the site (under normal hydraulic gradients) may have prevented a detectable migration of heat from the central axis of the site to those wells on the northern margin of the site. The interaction of heated water moved against the natural hydraulic gradient during injection conditions, and subsequently by the re-established natural gradient, may also account for the increase in temperature detected in VEA-3 in the post-treatment period. The re-establishment of natural ground water flow along strike of bedding towards the northwest (at least in the eastern, well-connected, part of the site) accounts for the relatively high contaminant concentrations found in wells I-7 and I-8 in the first post-treatment samples, despite the fact that these wells were used for steam injection. The continued migration of displaced, contaminated water along strike of bedding is reflected in the later increase in contaminant concentration in wells in the central part of the site and along its northern boundary (EX-4, VEA-5, I-3, I-2).