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## Cost and Performance Summary Report

### In Situ Bioremediation Using HRC<sup>®</sup> at Former Industrial Property San Jose, Santa Clara County, California

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#### Summary Information [1, 2, 4, 7, 8]

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The Former Industrial Property Site (site name confidential) is a 4.1 acre property, located in San Jose, California, that is occupied by a 76,000 square foot building that is currently being used for light industrial retail. From 1960 to 1983, the site was used for various manufacturing operations, including aluminum extrusion and casting (1960 to 1966), and the manufacture of military ordnance and logging equipment, and parts packaging. Manufacturing operations ceased in 1983 and the facility was used for storage until 1988. Releases of chemicals during manufacturing operations resulted in contamination of soil and groundwater at the site. Site investigations, conducted in the late 1980s, showed the presence of volatile organic compounds (VOCs) in the subsurface. Trichloroethene (TCE) concentrations were detected as high as 5,000 µg/L in groundwater and 10,000 µg/kg in soil. In response to orders issued by the State of California Regional Water Quality Control Board (Board), San Francisco Bay Region, additional site characterization and monitoring was performed, and a feasibility study was conducted. As an interim remedial measure, 1,200 cubic yards of VOC-contaminated soil was removed from areas within the building.

Initially, the recommended remedy for the site was a combination of capping, a slurry wall, sleeving of the storm sewer and continued groundwater monitoring. In late March 1997, the site was proposed for a pilot under a state research and development project to develop methods for setting site cleanup objectives. In March 1999, the Board approved the "In-Situ Remedial Alternatives Evaluation Report" for the site, where the proposed remedy was to stimulate anaerobic degradation activities, and proposed the use of Hydrogen Release Compound (HRC<sup>®</sup>) or a benzoate-lactate mixture, subject to the results of bench and pilot scale testing.

Testing performed at the site in 1998 indicated that while biodegradation of VOCs had occurred in the past (based on the presence of biodegradation daughter products, such as cis-1,2-dichloroethene (cis-1,2-DCE), degradation had decreased over time and reached a dormant stage. This was based on the absence of daughter products, such as vinyl chloride and ethene, and the comparatively stable relative composition of VOC impacts based on quarterly monitoring data. Results of bench-scale testing during the Spring of 1999 showed that the use of an electron donor could stimulate microbial activity and biodegradation. HRC<sup>®</sup> and a benzoate-lactate mixture were considered. HRC<sup>®</sup> was selected because it offered a one-time application process with no ongoing operations and maintenance (O&M) activities, while the benzoate-lactate application used a continuous feed system that would require daily O&M activities. Therefore, it was concluded that HRC<sup>®</sup> could stimulate the microbial community and the biodegradation process without disrupting the business activities being conducted at the site. Full-scale HRC<sup>®</sup> application included an application in May 2000, with a second application in November 2001 to promote the completion of the biodegradation process of vinyl chloride to ethene. Cleanup activities at the site are being conducted under Order No. 00-092, Final Site Cleanup Requirements and Rescission of Order Nos. 90-032 and 92-053, issued by the Board. Currently, groundwater monitoring and natural attenuation monitoring are being performed on a semiannual basis at the site.

Lead	Private
Oversight	California Regional Water Quality Control Board

### Timeline [1, 6, 7]

Date	Activity
Spring 1999	Bench- and pilot-scale tests performed
May 2000	First application of HRC <sup>®</sup> performed
November 2001	Second application of HRC <sup>®</sup> performed
May 2000 – July 2003	Groundwater monitoring and natural attenuation monitoring ongoing

### Factors That Affected Technology Cost or Performance [1, 2]

The site consists of homogeneous silty clays from 0 to 50 ft below ground surface (bgs). The depth to groundwater is approximately 7-10 ft bgs with a relatively flat gradient and general groundwater flow towards the northwest. The primary VOCs detected in shallow groundwater at the site are TCE, cis-1,2-DCE, and vinyl chloride. The nature and extent of impacts are limited to depths of approximately 30 ft bgs. Historical data indicate that the groundwater flow velocity is approximately 10 feet per year. Listed below are the key matrix characteristics for this site and the values measured for each during site characterization.

### Matrix Characteristics [1, 2, 6]

Matrix Characteristic	Value
Soil Type	Silty clay
Hydraulic Conductivity	Low
pH	6 - 7
Total Organic Carbon	2 - 3 mg/L
Total Petroleum Hydrocarbons	Not available
Presence of NAPLs	None observed
Depth to Groundwater	7-10 ft bgs
Groundwater Flow Velocity	10 ft per year (approximate)

## Treatment Technology Description [1, 3, 5, 6]

Enhanced in situ bioremediation using HRC<sup>®</sup> was performed at the site. HRC<sup>®</sup> is a proprietary, food quality, polylactate ester that slowly degrades to lactic acid upon hydration. The lactic acid is metabolized to a series of organic acids and hydrogen, which serve as electron donors for reductive dechlorination of chlorinated VOCs.

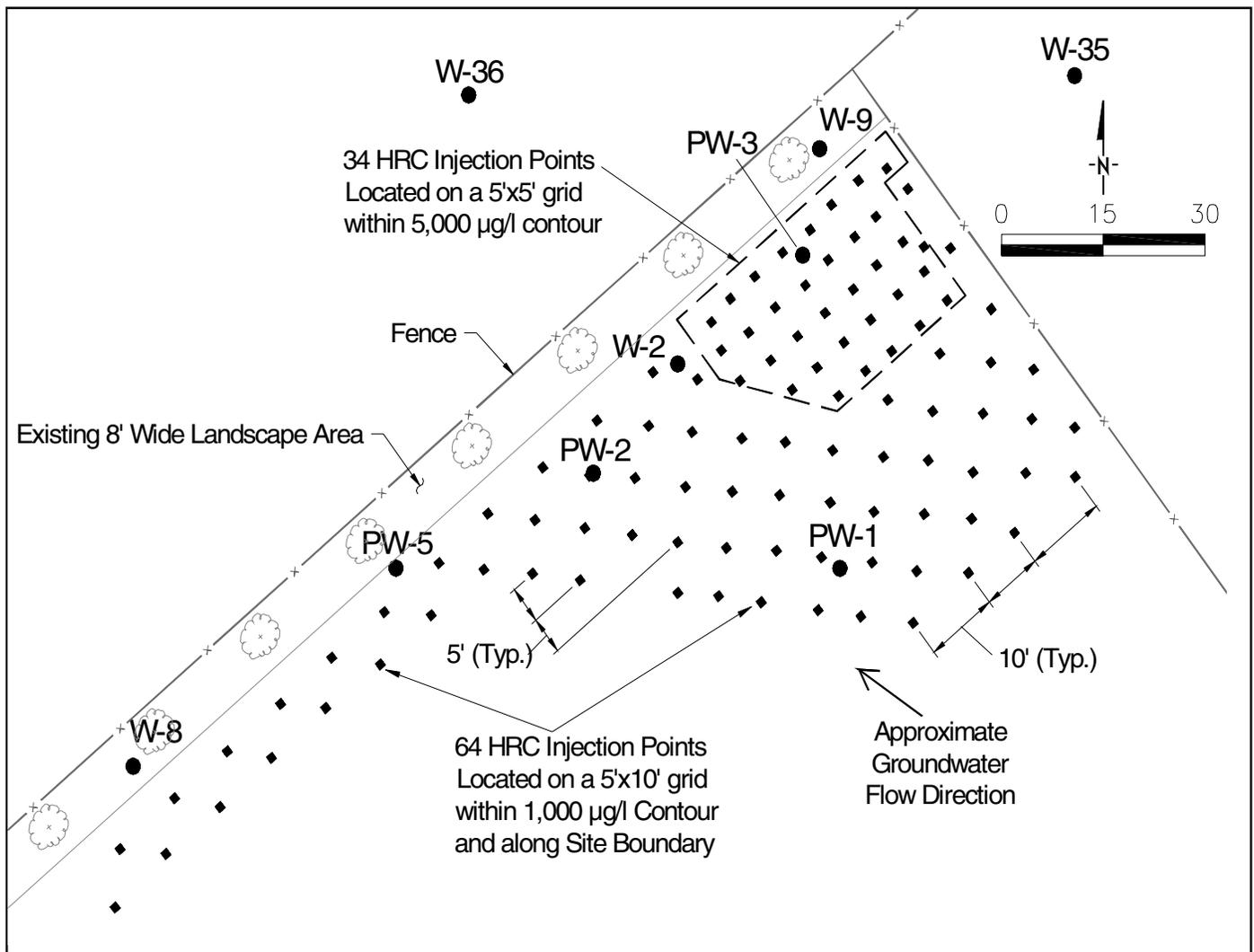
Figure 1 shows a layout of the full-scale HRC<sup>®</sup> injection system. The system included 103 direct-push injection points in the northeast corner of the property and along the northern property boundary. HRC<sup>®</sup> was applied on a 5 ft by 10 ft grid within the 1,000 µg/L TCE in groundwater contour (about two-thirds of the injection points), and on a 5 ft by 5 ft grid within the 5,000 µg/L TCE contour (about one third of the injection points). During the first full-scale application (May 2000), HRC<sup>®</sup> was injected from 8 to 28 ft bgs using a bottom-up injection method. Injection volumes varied depending on the TCE concentration of the area: the 5-ft by 10-ft spaced points received 12 gallons per injection point, while the 5-ft by 5-ft spaced points received 16 gallons per injection point. The 103 HRC<sup>®</sup> injection points received a total of 1,329 gallons (13,290 lbs) of HRC<sup>®</sup> injected over a 10-day period. During the second application (November 2001), HRC<sup>®</sup> was applied using a similar grid system as in the first application, through a total of 105 injection points. Five gallons of HRC<sup>®</sup> were applied per injection point (2.5 lbs per foot), for a total of approximately 575 gallons (5,750 lbs) of HRC<sup>®</sup> across the site. During the second application, HRC<sup>®</sup> was injected from 10 to 30 ft bgs using a top-down injection method.

## Operating Parameters [1, 3, 6]

Listed below are the key operating parameters for this technology and the values measured for each.

Operating Parameter	Value
Number of Injection Points	May 2000 application – 103 injection points November 2001 – 105 injection points
Microbial Activity	Increased after application
Quantity Injected	May 2000 application – 1,329 gal (13,290 lbs) November 2001 application – 575 gal (5,750 lbs)
Injection Pressure	Up to 2000 psi
Application Rate	May 2000 application – 120 to 160 lbs per injection point November 2001 application – 50 lbs per injection point

**Figure 1. Layout of Full-Scale HRC<sup>®</sup> Injection System (concentrations indicated are for TCE)**



Key: W – Monitoring well      PW – Pilot monitoring well

### Performance Information [1, 2, 3, 4, 6, 7, 8]

The objectives for this cleanup were to degrade the TCE source area and to reduce downgradient TCE migration. The groundwater cleanup goals were California EPA and U.S EPA Maximum Contaminant Levels (MCLs). The specified cleanup goals were 5 µg/L for TCE, 6 µg/L for cis-1,2-DCE, 10 µg/L for trans-1,2-DCE, 0.5 µg/L for vinyl chloride, 5 µg/L for PCE, 200 µg/L for 1,1,1-TCA, and 5 µg/L for 1,1-DCA. Soil cleanup goals were not established for the site because the initial concentrations of TCE and PCE were below their respective USEPA Region 9 Preliminary Remediation Goals (PRGs) for residential soils.

Groundwater monitoring was performed using nine monitoring wells, as shown on Figure 1. Groundwater samples were analyzed for TCE and TCE degradation products, as well as selected biodegradation parameters including field measurements of pH and oxidation reduction potential (ORP). Data are provided for four wells from May 2000 through July 2003: well PW-1 located upgradient of the center of the plume, wells W-2 and W-9 located near the center of the plume, and well W-8 located along the perimeter of the plume. Table 1 summarizes the analytical data for these four wells for TCE, cis-1,2-DCE, vinyl chloride, and ethane and ORP. Figures 2 and 3 present the VOC data from wells PW-1 and W-9, respectively.

As shown in Table 1, following the first injection in May 2000, TCE concentrations decreased in all four wells, with concentrations of degradation products cis-1,2-DCE and vinyl chloride increasing. One year following the first injection, concentrations of TCE had decreased from levels as high as 4,600 µg/L (well W-2) to levels ranging from 12 to 600 µg/L. Levels of cis-1,2-DCE ranged from 25 to 2,800 µg/L and vinyl chloride ranged from 35 to 1,000 µg/L. A second injection was performed in November 2001 to promote the completion of the biodegradation process. Following the second injection, concentrations of cis-1,2-DCE and vinyl chloride decreased with a corresponding increase in ethene concentrations. As of July 2003, TCE concentrations were below the cleanup goal in 3 of the 4 wells, with a concentration of 110 µg/L in well W-9. While concentrations of cis-1,2-DCE and vinyl chloride continued to decrease, they remained above the cleanup goals in most of the selected wells.

**Table 1. Summary of Groundwater Monitoring Data for Selected Wells from May 2000 to July 2003 [3]**

Parameter	Units	May -00	July -00	Sept -00	Feb -01	May -01	Aug -01	Feb -02	May -02	Aug -02	Nov -02	Feb -03	July -03
<b>Well PW-1</b>													
TCE	: g/L	1,400	320	46	6	12	2	<20	5	2	3	9	4
cis-1,2 DCE	: g/L	40	950	130	49	84	27	75	51	17	22	33	30
Vinyl Chloride	: g/L	<20	760	2,200	1,900	1,600	1,500	650	410	99	110	82	39
Ethene	: g/L	<20	2.15	27.4	12	10	14	48	32	16	15	12	2.1
ORP	mV	-89	-253	-30	-165	-258	-239	-147	-147	-176	-104	-107	-148
<b>Well W-2</b>													
TCE	: g/L	4,600	540	330	14	13	4	6	4	2	<2	0.6	<0.5
cis-1,2 DCE	: g/L	1,650	1,500	660	24	25	10	15	<2	7	2	3	2
Vinyl Chloride	: g/L	1,660	4,400	5,500	3,200	2,100	100	35	7	10	4	6	4
Ethene	: g/L	2	60	199	460	420	87	50	10	15	22	21	18
ORP	mV	68	131	69	-85	-221	-190	-137	-159	-166	-157	-202	-231

Parameter	Units	May -00	July -00	Sept -00	Feb -01	May -01	Aug -01	Feb -02	May -02	Aug -02	Nov -02	Feb -03	July -03
<b>Well W-8</b>													
TCE	: g/L	224	570	51	13	23	21	9	5	4	8	9	4
cis-1,2 DCE	: g/L	6	960	120	87	77	89	56	32	39	39	46	43
Vinyl Chloride	: g/L	<2	<25	27	90	62	55	61	35	38	42	56	66
Ethene	: g/L	<20	0.05	0.19	0.21	0.12	0.12	0.66	2.5	2.2	2.2	3.2	3.5
ORP	mV	-40	-121	3	-81	-169	-185	-98	-101	-152	-82	-130	-159
<b>Well W-9</b>													
TCE	: g/L	3,620	4,400	4,500	410	600	1,500	<20	40	74	120	67	110
cis-1,2 DCE	: g/L	81	230	280	1,300	2,800	2,900	540	1,100	1,600	2,000	1,700	1,300
Vinyl Chloride	: g/L	17	81	100	1,100	2,000	1,000	1,200	410	680	580	880	380
Ethene	: g/L	<20	0.21	1.4	16	60	52	410	400	310	320	290	300
ORP	mV	145	-28	50	-88	-242	-56	-7	-159	-189	-158	-182	-236

Figures 2 and 3 show the changes in concentration of TCE, cis-1,2-DCE, vinyl chloride, and ethene in wells PW-1 and PW-9, respectively from May 1999 to July 2003. As shown in Figure 2, the largest decrease in TCE concentrations occurred within four months after the first injection in May 2000. During this time, TCE concentrations were reduced from 1,400  $\mu\text{g/L}$  to 46  $\mu\text{g/L}$  in well PW-1, followed by an increase in degradation products cis-1,2-DCE, vinyl chloride. Following the second application in November 2001, vinyl chloride concentrations decreased, from levels above 1500  $\mu\text{g/L}$  to below 100  $\mu\text{g/L}$  by August 2002, and to less than 40  $\mu\text{g/L}$  by July 2003. As of July 2003, cis-1,2-DCE concentrations were 30  $\mu\text{g/L}$ , ethene concentrations were about 2  $\mu\text{g/L}$ , and TCE concentrations had been reduced to 4  $\mu\text{g/L}$ , below the cleanup goal.

As shown in Figure 3, concentrations of TCE initially fluctuated following the first injection in May 2000, until about November 2000. From this time to February 2001, TCE levels decreased from above 4,000  $\mu\text{g/L}$  to about 400  $\mu\text{g/L}$ , with corresponding increases in concentrations of cis-1,2-DCE and vinyl chloride. Following the second application in November 2001, vinyl chloride concentrations decreased, from levels of about 1,000  $\mu\text{g/L}$  to below 400  $\mu\text{g/L}$  by July 2003. As of July 2003, cis-1,2-DCE concentrations were 1,300  $\mu\text{g/L}$ , ethene concentrations were 300  $\mu\text{g/L}$ , and TCE concentrations were 110  $\mu\text{g/L}$ .

Figure 2. Changes in Concentration in Well PW-1 [3]

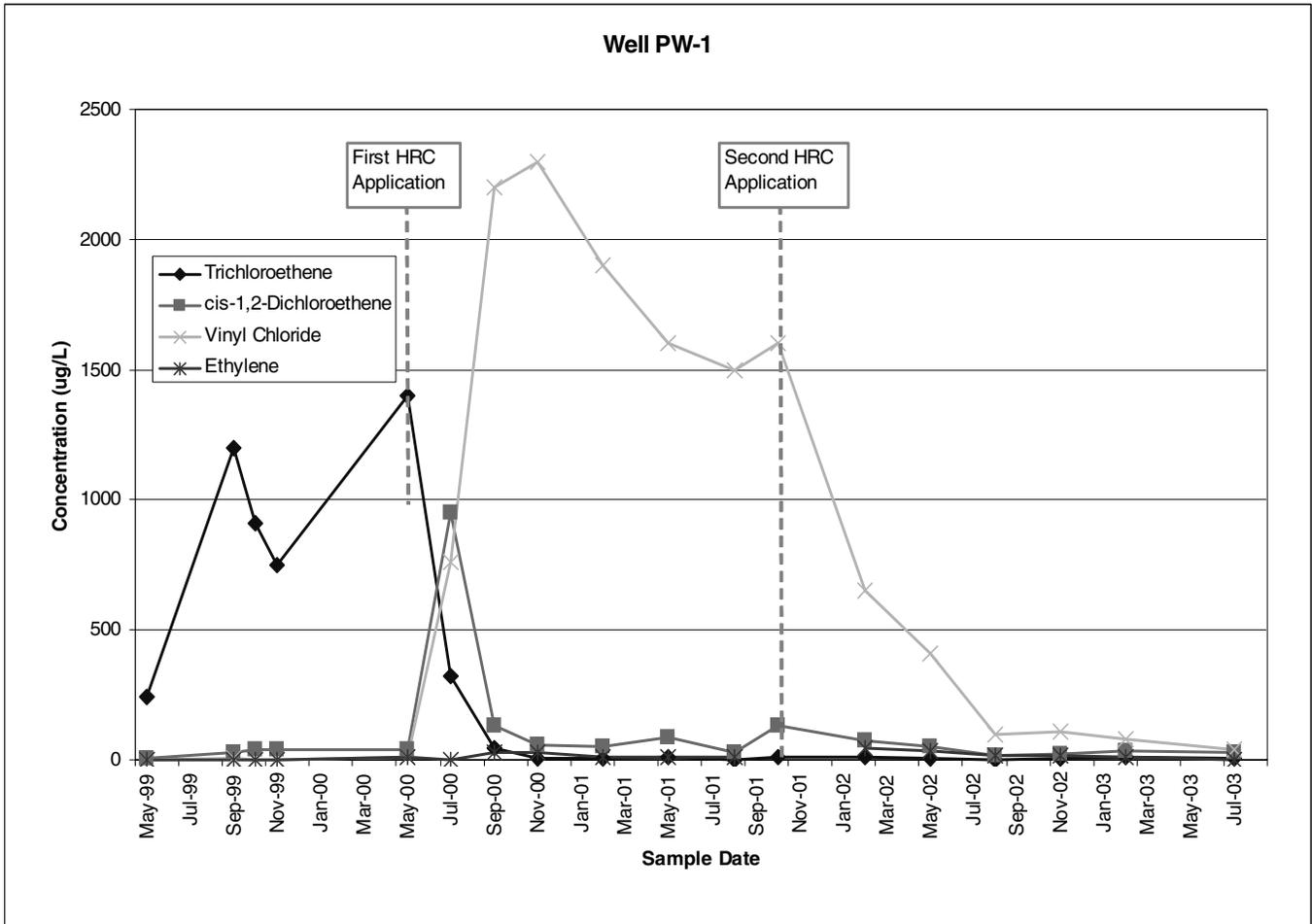
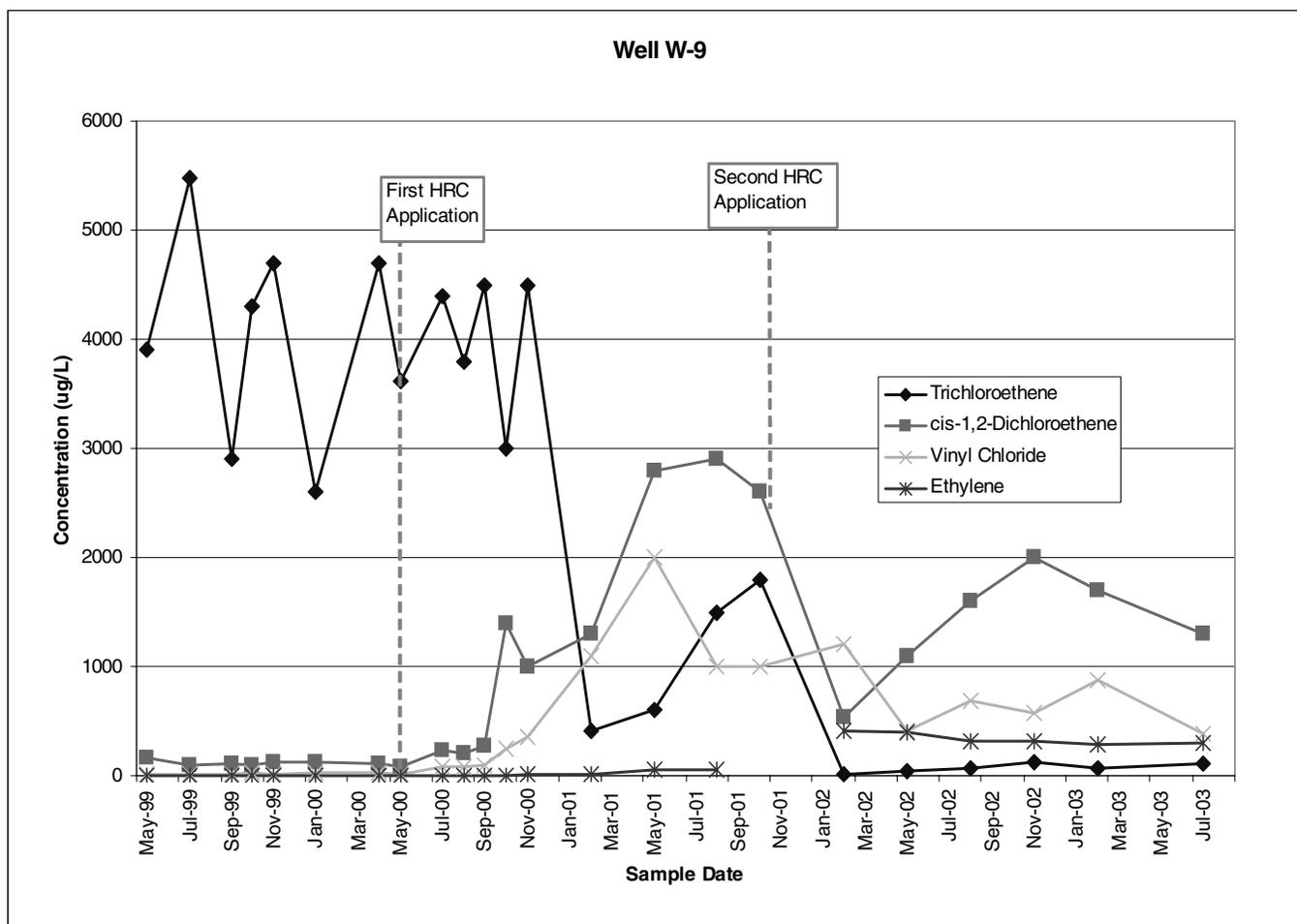


Figure 3. Changes in Concentration in Well W-9 [3]



According to the technology provider, the increase in concentrations of TCE and cis-1,2-DCE from February 2002 through July 2003 at well W-9 is attributed to the proximity of well W-9 to untreated, VOC-impacted groundwater from off-site. The off-site source is a high concentration area located immediately across the property line from well W-9. A monitoring well installed in the source area indicated high concentrations of VOCs, and HRC<sup>®</sup>-treated groundwater is likely mixing with the untreated groundwater migrating from the off-site source, effectively increasing the concentration of TCE and cis-1,2-DCE at well W-9.

In addition to the geochemical evaluations supporting the occurrence of enhanced in-situ bioremediation, several microbial analyses were performed in March 2002 to evaluate the health and diversity of microbial populations at the site. Specific Primer, Phospholipid Fatty Acid (PLFA), and Terminal Restriction Fragment Length Polymorphism (T-RFLP) analyses were completed on groundwater from wells W-2, PW-5, W-35, and W-29. The rationale for selecting the wells was that wells W-2 and PW-5 were both impacted by VOCs and have been treated with HRC<sup>®</sup>; well W-35 was impacted by VOCs but has not been treated with HRC<sup>®</sup>; and well W-29 was not impacted by VOCs and has not been treated with HRC<sup>®</sup> (a background well not shown in Figure 1). The results of the analyses indicated an increased biomass (quantity of DNA

fragments) in the subsurface in the center of the area where HRC<sup>®</sup> was applied (W-2), and less biomass in areas with less HRC<sup>®</sup> (well PW-5) or without HRC<sup>®</sup> (well W-35 and W-29). The specific primer analysis performed to compare the DNA fragments with primers for dehalogenating bacteria indicated that Dehalococcoides were present in the wells with VOC impacts (W-2, PW-5, and W-35), however, Dehalobacter and PCE-dechlorinating Desulfuromonas bacteria were present only in wells treated with HRC<sup>®</sup> (W-2 and PW-5).

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### **Pilot- and Bench-Scale Tests**

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Bench-scale testing performed in May/June 1999 involved combining HRC<sup>®</sup> with site soil and groundwater, and monitoring the concentrations of TCE, cis-1,2-DCE, vinyl chloride, organic acids, and microbial populations. Results indicated that TCE concentrations decreased, TCE degradation product concentrations increased, and anaerobic microbial counts were elevated. A six-month field pilot-scale test demonstrated that the HRC<sup>®</sup> created a reductive environment and enhanced the dechlorination of TCE without the addition of microbial populations (bioaugmentation).

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### **Cost Information [1, 6]**

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The technology provider indicated that the cost for HRC<sup>®</sup> at this site was \$107,900 for 2 applications. Direct push injection costs totaled approximately \$30,000 including two HRC<sup>®</sup> application events and soil sampling. Groundwater monitoring costs averaged approximately \$8,000 per monitoring round for nine wells. This includes field costs (low-flow purging) and laboratory costs for the full suite of in-situ bioremediation monitoring parameters. The estimated budget for the in-situ monitoring and analyses conducted from May 2000 through July 2003 totaled approximately \$130,000.

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### **Observations and Lessons Learned [1, 2, 3, 6, 7]**

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The injection of HRC<sup>®</sup>, using two applications, reduced concentrations of VOCs in the subsurface and accelerated the process of reductive dechlorination and the formation of biomass. TCE concentrations were significantly reduced after the first application, with a corresponding increase in degradation products cis-1,2-DCE and vinyl chloride. Following the second application to complete the degradation process, TCE concentrations were reduced to below cleanup goals in selected wells. Concentrations of cis-1,2-DCE and vinyl chloride decreased, with corresponding increases in ethene concentrations, though the levels remain above cleanup goals in selected wells. Currently, groundwater monitoring and natural attenuation monitoring are being performed on a semiannual basis at the site.

The data indicate that one well (well W-9) showed an increase in concentrations of TCE and cis-1,2-DCE for a period following the second application of HRC<sup>®</sup>. The technology provider suggested that this may be attributed to the proximity of well W-9 to untreated, VOC-impacted groundwater from off-site, likely resulting in mixing.

HRC<sup>®</sup> was selected rather than benzoate lactate to stimulate anaerobic degradation because it offered a one-time application process with no ongoing O&M activities; the benzoate-lactate application used a continuous feed system that would require daily O&M activities. Therefore, it was concluded that HRC<sup>®</sup> could stimulate the microbial community and the biodegradation process without disrupting the business activities being conducted at the site.

### Contact Information

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### **Acknowledgments**

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This report was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Office of Superfund Remediation and Technology Innovation. Assistance was provided by Tetra Tech EM Inc. under EPA Contract No. 68-W-02-034.