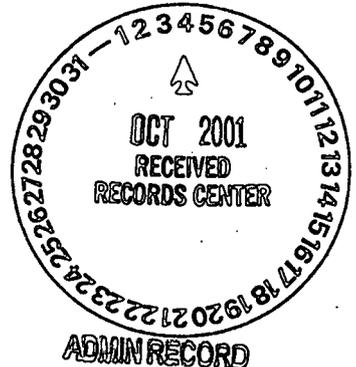


FINAL PU&D YARD PLUME
ENHANCED NATURAL ATTENUATION
TREATABILITY STUDY REPORT

September 2001



DOCUMENT CLASSIFICATION
REVIEW WAIVER PER
CLASSIFICATION OFFICE

Y 26

EXECUTIVE SUMMARY

This report documents the results of in Situ treatability testing performed on the Property Utilization and Disposal (PU&D) Yard Plume on the north side of the Rocky Flats Environmental Technology Site (RFETS) near Golden, Colorado. The purpose of this treatability study was to evaluate the effectiveness of the Hydrogen Release Compound[®] (HRC[®]) for degradation of volatile organic compounds (VOCs) in low groundwater flow regimes. HRC[®] is a proprietary, environmentally safe, food quality, polylactate ester formulated for slow release of lactic acid. The lactic acid releases dissolved hydrogen that facilitates the microbial dechlorination of chlorinated solvents. This project is a cooperative effort between RFETS and the Department of Energy (DOE) Subsurface Contaminant Focus Area (SCFA), and funding was provided by DOE SCFA.

In February 2001, sixteen material insertion points (MIPs) were installed in an area with elevated concentrations of tetrachloroethene (PCE). The method of insertion used is a new innovative approach that allows a more focused placement of the HRC[®] in a cost-effective manner.

Two monitoring wells were also installed, one in the area of highest known PCE concentrations and one approximately ten feet downgradient. Eight hundred pounds of HRC[®] was inserted into the MIPs. Monthly monitoring was initiated two months later to determine the effect on contaminant concentrations.

Initially, concentrations of PCE and other contaminants increased with time, which is consistent with other successful applications of HRC[®]. Concentrations have since decreased. Based on the data collected to date, these decreases in concentration appear to be from microbial degradation as opposed to dispersion or other processes. Monitoring of the site will continue through the end of the calendar year in order to determine more definitively the effectiveness of the technology.

**FINAL PU&D YARD PLUME
ENHANCED NATURAL ATTENUATION
TREATABILITY STUDY REPORT**

TABLE OF CONTENTS

EXECUTIVE SUMMARY.....	ES-1
1.0 INTRODUCTION.....	1
1.1 Objective.....	1
1.2 Background.....	1
1.2.1 History.....	1
1.2.2 Hydrogeology.....	1
1.2.3 PU&D Yard Subsurface Contamination Summary.....	3
1.2.4 Baseline Treatability Study Conditions.....	3
1.2.5 Biodegradation Processes.....	4
2.0 TREATABILITY STUDY DESCRIPTION.....	8
2.1 Approach.....	8
2.2 Startup.....	8
2.3 Monitoring.....	10
2.4 Deviations from Work Plan.....	10
3.0 TREATABILITY TEST RESULTS.....	10
3.1 Volatile Organic Compounds.....	10
3.2 Inorganic Indicators.....	14
4.0 CONCLUSIONS.....	20
5.0 RECOMMENDATIONS.....	21
6.0 REFERENCES.....	21

FIGURES

1-1 PU&D Yard Groundwater VOC Plume Project Area 2
1-2 Borehole Lithology and PCE Concentration 5
1-3 Degradation of Tetrachloroethene 6
1-4 Degradation of 1,1,1- Trichloroethane 7
2-1 PU&D Yard Groundwater VOC Plume Material Insertion Point Configuration..... 9
3-1 Concentration of PCE and its Degradation Products Versus Time in Well 30900 12
3-2 Concentration of PCE and its Degradation Products Versus Time in Well 31001 12
3-3 Concentration of 1,1,1-TCA and 1,1-DCA Versus Time in Well 30900 15
3-4 Concentration of 1,1,1-TCA and 1,1-DCA Versus Time in Well 31001 15
3-5 Concentration of 1,1,2-Trichlorotrifluoroethane in ug/L Versus Time..... 16
3-6 Alkalinity (in CaCO₃, mg/L) Versus Time 17
3-7 Sulfate (mg/L) Versus Time 17
3-8 Sulfide (mg/L) Versus Time 17
3-9 Chloride (mg/L) Versus Time 17
3-10 Nitrate (mg/L) Versus Time 17
3-11 pH Versus Time 19
3-12 Conductivity (microsiemens per centimeter) Versus Time..... 19
3-13 Oxidation potential (millivolts) Versus Time 20

TABLES

Table 1-1. 1997 Sampling Results From Wells Near Study Area 3
Table 1-2. Summary of VOC Concentrations in Subsurface Soils in IHSS 174A 4
Table 1-3. Baseline Groundwater Concentrations 4
Table 3-1. Concentration of PCE and its Degradation Products in Groundwater 11
Table 3-2. Concentration of 1,1,1-TCA; 1,1-DCA; and 1,1,2-Trichlorotrifluoroethane in
Groundwater 11
Table 3-3. Inorganic Analytical Results 16
Table 3-4. Inorganic Field Parameters..... 18

ACRONYMS

µg/kg	micrograms per kilogram
µg/L	micrograms per liter
DCA	dichloroethane
DCE	dichloroethene
DOE	Department of Energy
HRC [®]	Hydrogen Release Compound [®]
MIP	Material Insertion Point
PCE	tetrachloroethene
PU&D	Property Utilization and Disposal
RFCA	Rocky Flats Cleanup Agreement
RFETS	Rocky Flats Environmental Technology Site
RMRS	Rocky Mountain Remediation Services, L.L.C.
SCFA	Subsurface Contaminant Focus Area
TCA	trichloroethane
TCE	trichloroethene
UHSU	Upper Hydrostratigraphic Unit
VOC	volatile organic compound

1.0 INTRODUCTION

A plume of volatile organic compound (VOC) contaminated groundwater is derived from a contaminant source located in the Property Utilization and Disposal (PU&D) Yard at RFETS (see Figure 1-1). Past investigation results indicate that subsurface VOC contamination is present in the soil at only a few locations. The primary contaminant is tetrachloroethene, although other chlorinated and fluorinated organic compounds are also present (Kaiser-Hill 2001). The initial spills likely occurred many years ago and have had sufficient time to disperse and create a mature plume. Sites such as these present a long-term problem of the dispersed contaminants in the saturated zone. Remedial actions frequently considered for these types of sites includes excavation of the source area or pump and treat methods that have proven costly and ineffective in addressing these older plumes. Enhanced natural attenuation offers a means of addressing contamination in saturated soils at the source and the more dispersed contamination that has developed over time.

The purpose of this treatability study is to evaluate the effectiveness of the commercially available Hydrogen Release Compound[®] (HRC[®]) for enhancing natural attenuation of VOCs in low groundwater flow regimes. HRC[®] is a proprietary, environmentally safe, food quality, polylactate ester formulated for slow release of lactic acid. The lactic acid released by HRC[®] stimulates the degradation of chlorinated VOCs by making low concentrations of dissolved hydrogen available for natural microbial dechlorination. This project is a cooperative effort between RFETS and the Department of Energy (DOE) Subsurface Contaminant Focus Area (SCFA), and funding was provided by DOE SCFA.

1.1 Objective

The objective of this treatability study is to determine if the appropriate subsurface conditions and microbes are present at RFETS for application of HRC[®] to be a successful remediation technique for VOC contaminated soil and/or groundwater.

1.2 Background

1.2.1 History

The PU&D Yard, also known as Individual Hazardous Substance Site (IHSS) 170, was used to store empty drums, dumpsters, cargo boxes and excess materials from 1974 until 1997. Previous investigations found VOC contamination in the soil in the IHSS 174a area in the northeast corner of the PU&D Yard (Figure 1-1). The contamination is likely derived from storage of drums that contained residual VOCs. In addition, small amounts of VOCs could have come from excess equipment and other materials stored at the facility. Sampling of precipitation that collected in tanks at IHSS 170 detected the presence of acetone, methyl ethyl ketone, 1,2-dichloroethane (1,2-DCA), Freon 113 (trichlorotrifluoroethane), ethyl acetate, trichloroethane (TCA), tetrachloroethene (PCE), and toluene (DOE 1992).

1.2.2 Hydrogeology

The PU&D Yard is located on an east-sloping pediment comprised of 30 to 40 feet of Rocky Flats Alluvium that unconformably overlies weathered claystone bedrock. The Rocky Flats Alluvium is comprised chiefly of poorly sorted, clayey gravel and sand with abundant cobble and boulder-sized material and discontinuous lenses of clay, silt, and sand (Kaiser Hill 2001). During the treatability study, it was determined that a gravel lens is present at a depth of approximately 10 feet below ground surface

immediately underlying the study area. The gravel probably acted as a preferential pathway to allow spilled material to immediately migrate into the subsurface. The gravel probably also facilitated the spread of HRC[®] into the contaminated soil.

The PU&D Yard VOC plume is confined to the Upper Hydrostratigraphic Unit (UHSU) which is comprised primarily of the Rocky Flats Alluvium and the underlying weathered bedrock. Depth to groundwater is approximately 5 to 20 feet across the entire PU &D Yard with a hydraulic gradient of approximately 0.02 ft/ft towards the east. In the study area the depth of ground water ranges between about 8 feet in the summer to approximately 16 feet in the winter. The estimated rate of groundwater flow at the PU&D Yard is 100 feet per year (RMRS 1999). Groundwater discharges at isolated small seeps into the valley fill alluvium associated with North Walnut Creek and No Name Gulch and into the groundwater intercept system at the landfill perimeter. Groundwater also discharges as surface water into No Name Gulch (RMRS 2000).

1.2.3 PU&D Yard Subsurface Contamination Summary

Initial soil characterization in 1988 indicated the presence of acetone, benzene, 4-chloro-3-methylphenol, PCE, 1,1,1-TCA, bis (2-ethylhexyl) phthalate in the PU&D Yard area. A soil vapor survey was conducted in 1994 and found elevated levels of methane, benzene, acetone, trichloroethene (TCE), PCE, and 1,1,1-TCA. Based on the soil gas survey results, additional investigations were conducted in 1997 to characterize the extent of subsurface VOCs present. While PCE, TCE, methylene chloride, and naphthalene were detected in the soil, the investigation results indicate that subsurface VOC contamination is limited and the primary soil contaminant is PCE (RMRS 1997).

Groundwater in the area was also sampled in 1997 and the results are shown on Table 1-1. In this general area, PCE, 1,1,1-TCA, 1,1-dichloroethene (DCE), TCE, acetone, and Freon-113 were all found in the groundwater. The sample from Borehole 017497 represents a grab sample from the area of highest soil concentrations. Well 01397 nearest the study area was found to have low concentrations of chlorinated solvents. Well 01497, located further downgradient of the study area, had higher concentrations of some of the same solvents.

Table 1-1. 1997 Sampling Results From Wells Near Study Area

Well	PCE	TCE	1,1,1-TCA	1,1-DCA	1,1-DCE	Carbon Tetrachloride	Naphthalene
017497*	1,700	ND	ND		ND	ND	
01397	5	0.2 J	5	ND	1	0.2 J	0.4 JB
01497	4	30	170	3 J	80	5 J	ND

* One time grab sample from a borehole
B - Detected in Blank
J - Estimated Value
ND - Not Detected

In 1999, an evaluation was completed that determined that natural attenuation might be occurring but that it is not a major factor in controlling the VOC plume. The evaluation also concluded that there was no evidence that plume was having an impact on surface water (RMRS 1999).

1.2.4 Baseline Treatability Study Conditions

The treatability study area is located in the northeast corner of the PU&D yard within IHSS 174a, the PU&D Drum Storage Area. This area was selected because it had the highest concentration of PCE in

8

the groundwater and in the soil in IHSS 174a. At one location, the PCE concentration in the soil was 5,700 micrograms per kilogram (ug/kg) which exceeds the Rocky Flats Cleanup Agreement (RFCA) Tier I Action Levels of 3,150 ug/kg. Table 1-2 shows the concentration in the soil with depth for PCE and TCE within the study area.

Table 1-2. Summary of VOC Concentrations in Subsurface Soils in IHSS 174A

Borehole	Sample Depth (in feet below ground)	Tetrachloroethene (ug/kg)	Trichloroethene (ug/kg)
17497	4.3-4.9	750	ND
	8.5-9.0	830	ND
	11.0-11.5	5,700	ND
18997	5.0-5.5	ND	360J
	9.5-10.0	ND	ND
RFCA Tier I Subsurface Soil Action Levels		3,150	3,280

J estimated concentration of analyte detected below detection limit
 ND analyte not detected

Figure 1-2 graphs the PCE concentration versus depth relative to the borehole lithology and the groundwater table. As can be seen from the figure, most of the PCE is below the water table and is accessible to biodegradative processes within the saturated zone. In addition, there is a potential for impacts to contaminants in the vadose zone due to mounding when the HRC was originally added or caused by smearing due to fluctuations in the water table.

Baseline groundwater samples were collected from the two monitoring wells, 30900 and 31001, prior to the start of the treatability study. The results of analysis of these samples are presented in Table 1-3: Well 30900 is within the source area, 31001 is located 10 feet downgradient of Well 30900. Also included in this table is a grab groundwater sample from material insertion point (MIP)-3 that was collected to verify baseline conditions.

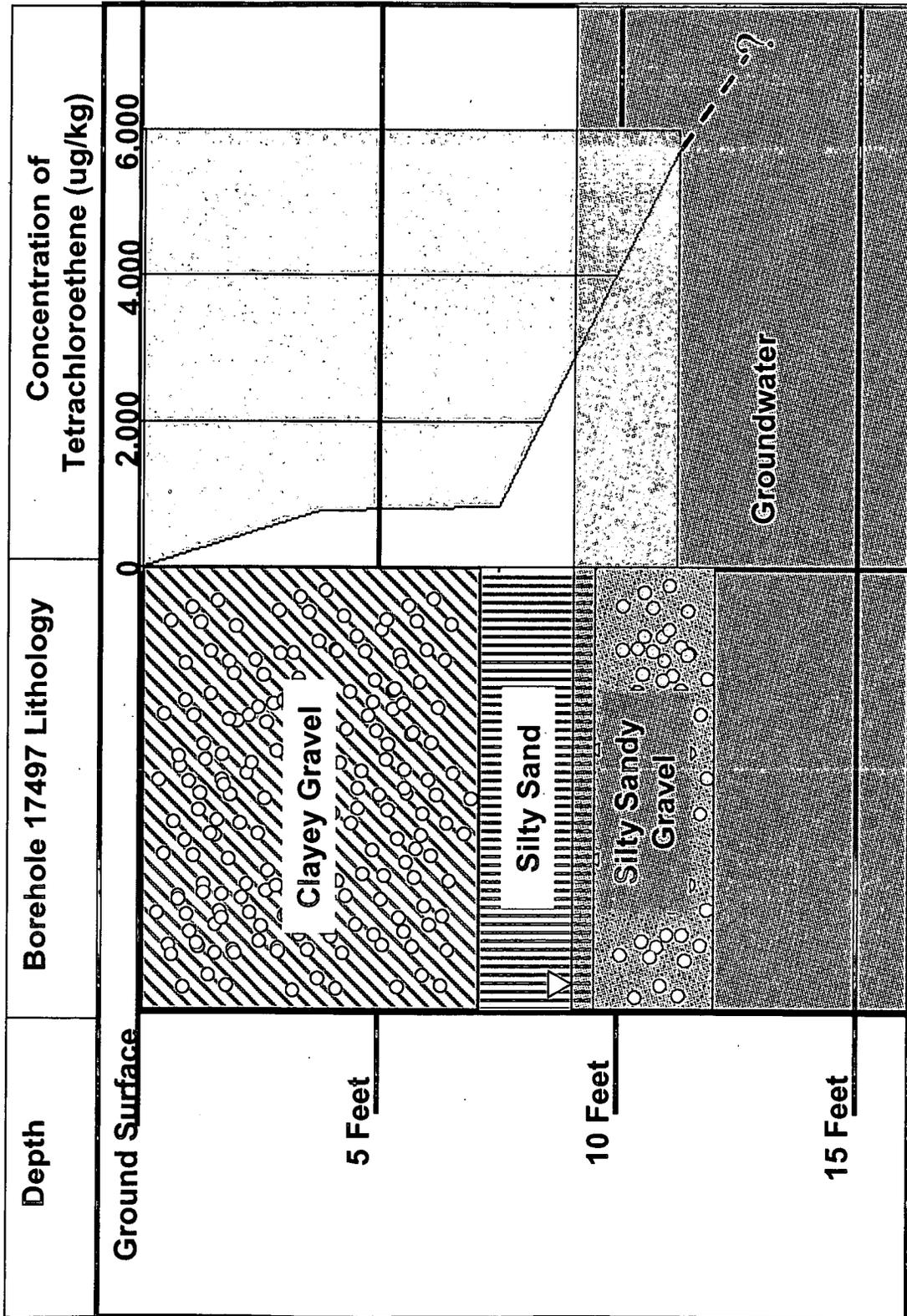
Table 1-3. Baseline Groundwater Concentrations

Well	Tetrachloroethene (ug/l)	Trichloroethene (ug/l)
30900	9	120
31001	18	5.5
MIP-3	4.9	0
RFCA Tier I Groundwater Action Levels	500	500
RFCA Tier II Groundwater Action Levels	5	5

1.2.5 Biodegradation Processes

The primary process expected to occur during this treatability study is biodegradation and more specifically biological reductive dehalogenation. The key to this process is the replacement of the chlorine atoms in the VOC molecule with hydrogen. Figures 1-3 and 1-4 show the degradation steps and intermediate compounds for the dehalogenation of PCE and 1,1,1-TCA, respectively. Degradation products are good indicators of enhanced natural attenuation as long as these are not present from other

Figure 1-2 Borehole lithology and PCE Concentration



10

Figure 1-3 Degradation of Tetrachloroethene

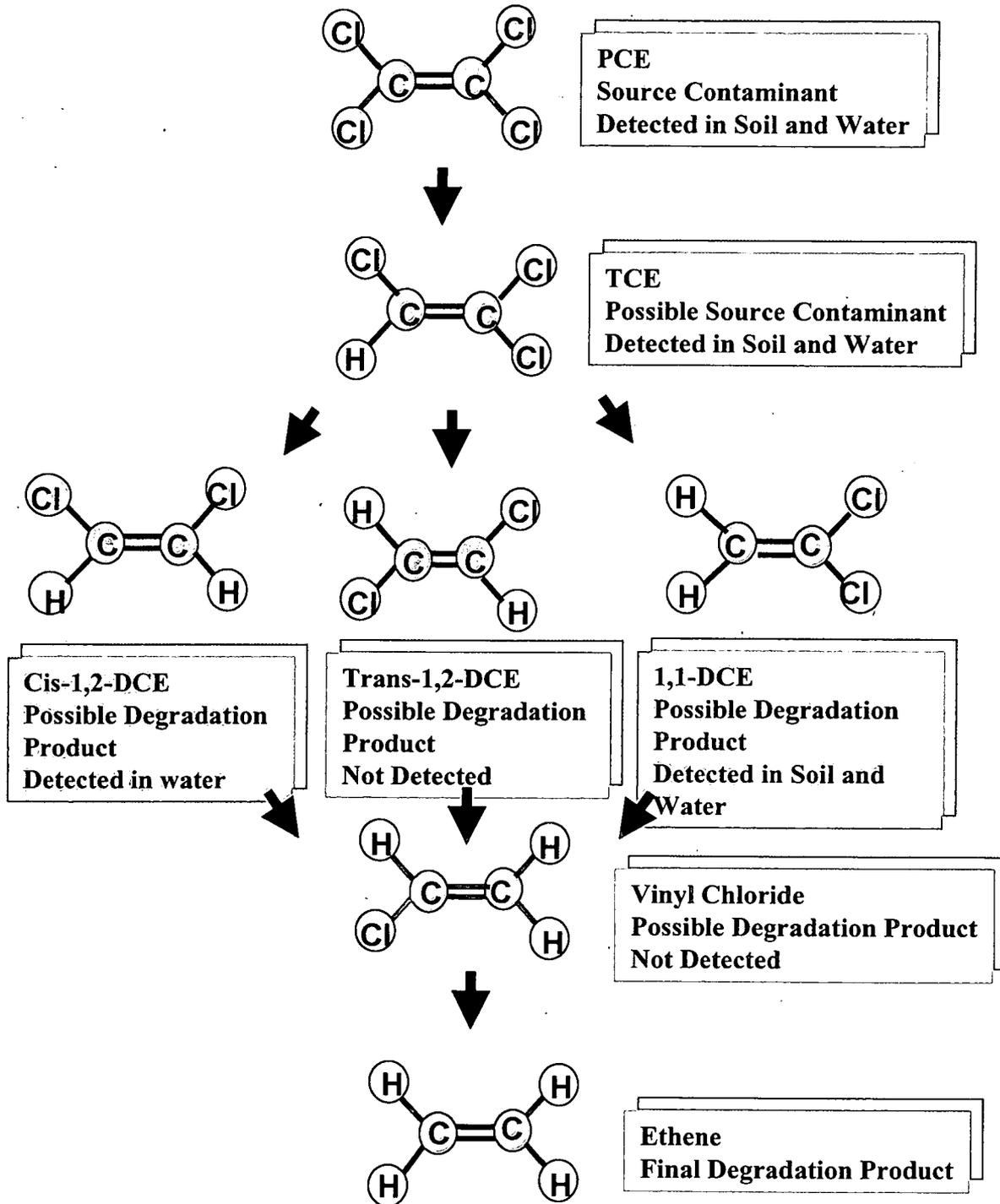
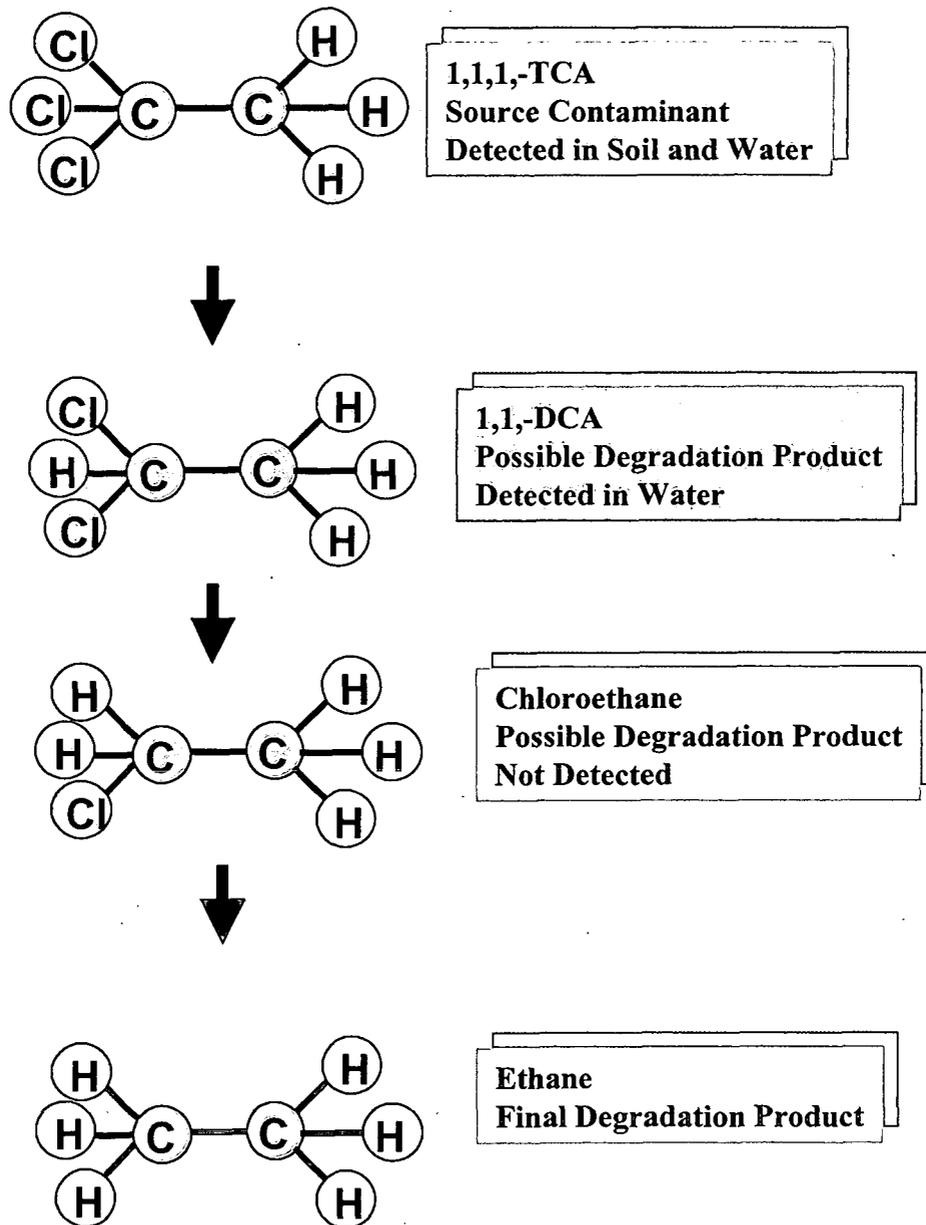


Figure 1-4 Degradation of 1,1,1-Trichloroethane



sources. The end product for PCE degradation is ethene and the end product of 1,1,1-TCA is ethane. These gases will likely coalesce and be quickly released to the atmosphere without being detected.

Although degradation products are good indicators, the key indicator of biodegradation for the PU&D Yard treatability study is a decrease in the primary contaminant concentrations. In addition, other indicators can be used to prove or disprove that degradation is occurring or that the conditions present will promote biological degradation. These factors include dissolved hydrogen, oxidation potential, dissolved oxygen, various anions, and alkalinity.

2.0 TREATABILITY STUDY DESCRIPTION

2.1 Approach

The approach for this treatability study was to place HRC[®] in MIPs into the subsurface in the source area, allow the resident microbes to develop for two months and then monitor the groundwater for a decrease in PCE and for significant changes in known degradation products. Groundwater well 30900 was installed in September 2000 immediately adjacent to borehole 17497, the area of highest VOC contamination. This well and a second well (31001) placed about ten feet downgradient were used to obtain data for the treatability study

2.2 Startup

On January 18, 2001, Monitoring Well 31001 was installed approximately ten feet downgradient from Well 30900 (Figure 2-1). Both wells are screened into the Rocky Flats Alluvium. Well 31001 was screened from the surface into bedrock about 22 feet below ground surface. At the time of completion the well was dry but recovered later in January. Well 30900 is screened deeper (to 31 feet below ground surface) and had a water level of 26 feet below the surface, which is likely below bedrock at this location. Both 30900 and 31001 were sampled to establish baseline concentrations of VOCs (see Section 1.1.5).

In February 2001, nine MIPs were installed on a 5 foot by 3 foot grid spacing around well 30900 (see Figure 2-1). Based on the total volume of the HRC[®], additional MIPs were required to insert all 800 pounds of HRC[®]. These additional MIPs were placed at half of the original grid spacing on the upgradient side of well 30900. A total of sixteen MIPs were required to place all of the HRC. Each MIP was installed using the following steps:

1. A hole was created with Geoprobe[®] push-type sampler 2 1/8" in diameter to a depth between 22 to 25 feet. The MIPs were pushed with a solid point. The formation smearing typically associated with pushing does not appear to have decreased borehole wall permeability.
2. A 3/4 inch tremie pipe was inserted into each MIP, and HRC[®], heated to 100 to 130 degrees Fahrenheit to reduce viscosity, was poured into the pipe using a funnel. As the hole was filled, the tremie pipe was slowly withdrawn.
3. After each hole was filled with HRC[®] to the surface, it was capped with bentonite.
4. Each location was marked with a flag with the MIP number.

Prior to adding the HRC[®], groundwater grab samples were attempted from two of the insertion points as part of establishing the baseline conditions. Sufficient water was present in MIP-3 for a VOC sample (see Section 1.2.4); however, MIP-1 had insufficient water to collect a sample. A total of 800 pounds of HRC[®] was distributed among the 16 MIPs (approximately 50 pounds at each point). Insertion of the HRC[®] was completed on March 1, 2001.

2.3 Monitoring

All sampling and analysis was conducted in accordance with the Final PU&D Yard Plume Enhanced Natural Attenuation Treatability Study Work Plan (Kaiser-Hill 2001). Performance monitoring was not initiated for two months after insertion of the HRC[®] to allow time for subsurface conditions to stabilize and a microbial community to develop. The initial samples after startup were taken in April 2001 and monthly samples were taken thereafter.

2.4 Deviations from Work Plan

There were no significant deviations from the workplan; however, after the MIPs were installed and capped with bentonite, the HRC[®] dissolved into the aquifer causing the bentonite to slump into the hole. Additional bentonite was then added after a few weeks to fill the holes again.

3.0 TREATABILITY TEST RESULTS

Monthly samples were taken from wells 30900 and 31001 to determine:

- If the concentrations of contaminants were decreasing,
- The presence degradation byproducts,
- Whether signs of biodegradation could be detected, and
- If subsurface chemistry would facilitate chemical and/or biological degradation of the contaminants.

Samples were taken for metals, VOCs, anions, and other inorganic parameters. Field measurements were also made to determine the oxidation potential, pH, and conductivity of the sampled groundwater.

3.1 Volatile Organic Compounds

The test data presented in this report was collected between October 2000 and July 2001. Additional samples were collected in August and are anticipated to be collected monthly thereafter until the end of the calendar year or until a determination is made that there is sufficient data to establish whether HRC[®] was effective. As discussed in Section 1.2.5, two common byproducts of PCE degradation are TCE and cis 1,2-DCE. Results for PCE and these degradation byproducts are shown in Table 3-1. Results for additional VOCs are given Table 3-2. The change in concentration of PCE and its byproducts are also shown graphically for Wells 30900 and 31001 in Figures 3-1 and 3-2, respectively. The behavior shown in Well 30900 is similar to what the manufacturer of HRC[®], Regenis, has observed at other sites. Initially, the concentrations go up followed by decrease in

Table 3-1. Concentration of PCE and its Degradation Products in Groundwater

Date	Days from HRC® Insertion	PCE (ug/L)	TCE (ug/L)	CIS 1,2-DCE (ug/L)	Trans 1,2-DCE (ug/L)	1,1,DCE (ug/L)	Vinyl Chloride (ug/L)
Well 30900							
10/21/00	-131	96	7.4	53.1	ND	ND	ND
2/07/01	-22	120	7	78	0.5	0.5	ND
4/30/01	60	180	11	110	0.1	0.4	ND
5/30/01	90	350	23	210	ND	ND	ND
6/27/01	121	240	15	140	0.2	0.5	ND
7/31/01	152	93.6	10.6	91.4	0.19	0.31	0.21
Well 31001							
2/07/01	-22	18	5.5	1.2	ND	2.6	ND
4/30/01	60	130	20	52	0.1	4	ND
5/30/01	90	41	18	4	ND	ND	ND
6/27/01	118	120	25	38	ND	1	ND
7/31/01	152	105	16.3	189	0.13	1.49	0.12

ND =not detected
 ug/L= micrograms per liter

Table 3-2. Concentration of 1,1,1-TCA; 1,1-DCA; and 1,1,2-Trichlorotrifluoroethane in Groundwater

Date	Days from HRC® Insertion	1,1,1-TCA (ug/L)	1,1-DCA (ug/L)	1,1,2-Trichlorotrifluoroethane(ug/L)
Well 30900				
10/21/00	-131	0.5	0.3	Not analyzed for
2/07/01	-22	1	0.6	Not analyzed for
4/30/01	60	2	0.7	10
5/30/01	90	2	2	10
6/30/01	121	1	0.9	8
7/31/01	152	0.96	0.63	4.92
Well 31001				
2/7/01	-22	2	ND	Not analyzed for
4/30/01	60	4	0.4	23
5/30/01	90	1	ND	6
6/27/01	118	2	0.4	14
7/31/01	152	2.07	0.59	11.3

ND =not detected
 ug/L= micrograms per liter

16

Figure 3-1. Concentration of PCE and its Degradation Products versus Time in Well 30900

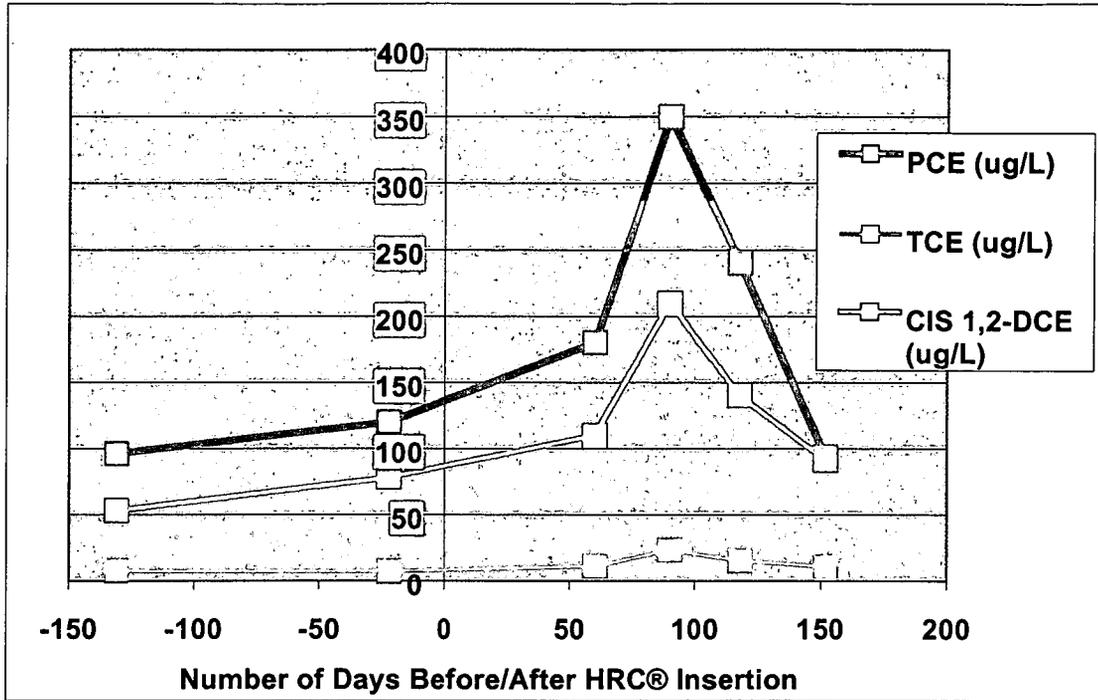
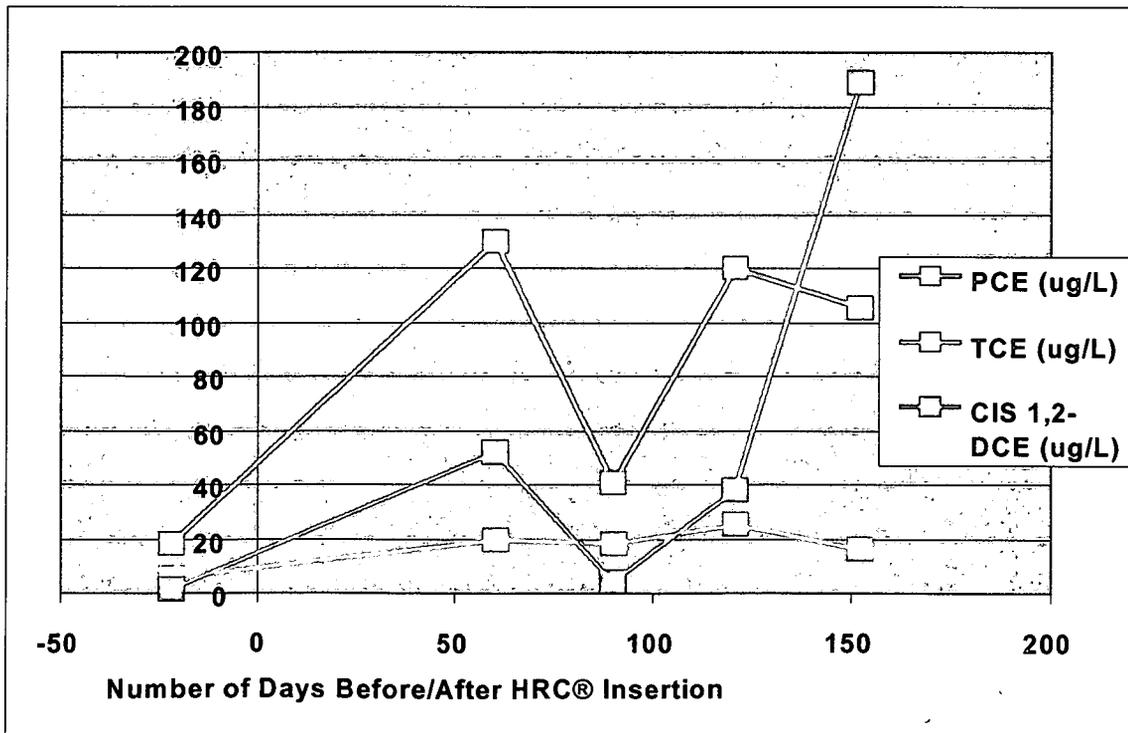


Figure 3-2. Concentration of PCE and its Degradation Products versus Time in Well 31001



concentration. If the data continues to follow this pattern, it should decrease to below the original concentration levels. The data from Well 31001 shows a similar pattern.

The specific cause of the increase in PCE groundwater concentrations is most likely due to one of or a combination of the following conditions:

- A change in the surface tension of free-phase solvents in the pores that would cause more solvent to spread or be released from micropores. This could be from the lactic acid dissolving into the VOCs trapped in the pore space or other changes in the organic phase.
- An increase in the liquid-liquid surface area caused by the effect above and possibly the formation of an emulsion that would allow more mass transfer of the organic phase.
- A change in the relative solubility of the individual VOCs due to the presence of the lactic acid in the aqueous phase that would allow more PCE and/or other VOCs to go into the solution in concentrations differing from baseline or expected percentages.
- Other changes in liquid and organic phases caused by changes in pH, temperature, oxidation-reduction potential, etc. caused by the presence of the lactic acid or by biological activity associated with the lactic acid that result in an increase in relative solubility of the VOCs.

The positive side of increased concentration is that if the organic material is transferred from a separate non-aqueous phase liquid trapped in the soil to an aqueous phase, then the both soil and water remediation can be greatly accelerated. Typically, the non-aqueous phase liquids trapped in soil below the saturated zone have been the most difficult phase to remediate. Presence of this separate phase hampers pump and treat strategies because it acts as a reservoir for contaminants. However, if as this study implies, this phase is being mobilized and then biologically degraded along with the dissolved phase, this could be a much more robust treatment methodology than simply digesting the dissolved fraction. In addition, there could also be some degradation occurring in the vadose zone. There could be a negative side if the chemical effects that cause an increase in concentration outpace the biological effects that reduce the contaminants and/or cause a temporary increase in concentration at downgradient locations. Ideally, the biological effects should degrade the additional PCE before it moves downgradient; however, there is not enough data to confirm these other possible effects at this time.

Although cis 1,2-DCE and TCE could be either from past spills or degradation products, the concentrations do appear to be mirroring the dissolved PCE concentration, and it appears likely that these are predominantly degradation products. The increase in cis 1,2-DCE concentration coincides with the decrease in PCE concentration. This behavior can be attributed to an initial increase in PCE due to chemical effects and followed by a decrease in PCE combined with an increase in all three forms of DCE as the PCE is biodegraded. It is believed that only DCE shows this behavior because it has higher bond energies than TCE and so the kinetics and thermodynamics favor higher concentrations. As the process proceeds, the DCE should eventually decrease as it too degrades.

Another promising trend shown in Table 3-1 is the presence of other degradation products such as trans 1,2-DCE; 1,1,DCE; and vinyl chloride since based on process knowledge, these contaminants are not associated with releases at the PU&D yard. As illustrated in Figure 1-2, vinyl chloride is the last degradation product produced before it goes to the final degradation step and produces ethene. Because the ethene will off gas, it might not be detected. Vinyl chloride has not been detected in this area before. This also indicates that biodegradation is occurring as opposed to just fluctuations in concentration.

Although the concentrations are much lower, 1,1,1-TCA also provides evidence of biodegradation. Figures 3-3 and 3-4 show the change in 1,1,1-TCA and its byproduct, 1,1-DCA with time. These analytes increased in concentration after the introduction of the HRC® and then decreased as the biodegradation process catches up. Well 31001 also shows an unexplained decrease in concentration on May 30, 2001 as was previously discussed. Like the PCE, it is anticipated that future results will show a continued decrease in concentration.

1,1,2-Trichlorotrifluoroethane is a Freon found in groundwater at the PU&D yard in Wells 30900 and 31001. As shown in Figure 3-5, it demonstrates the same behavior as the VOCs. None of its degradation products have appeared, but since it is at such a low concentration, it is unlikely that these will ever be detectable.

3.2 Inorganic Indicators

The decrease in PCE and appearance of its byproducts provide direct evidence that enhanced bioremediation is occurring; inorganic parameters give indirect evidence that degradation is occurring or that the conditions are right for degradation. Table 3-3 shows the results of some of the inorganic analyses performed on Well 30900 and Well 31001. Figures 3-6 through 3-10 show the analytical parameters in Table 3-3. Alkalinity is an indicator of conditions that favors degradation. The higher the alkalinity, the more favorable the conditions are for degradation and, as shown in Figure 3-6, there is steadily increasing alkalinity.

Figures 3-7 and 3-8 show changes in the sulfate and sulfide concentrations. This illustrates that as a reducing environment is created, sulfate concentrations decrease and sulfide concentrations increase. The sulfate concentrations also appear to reflect the VOC concentrations.

Chloride concentrations should increase as VOCs are degraded; However, the existing chloride concentration is so large relative to the VOCs that any effects of this type are probably not going to appear, and there is probably not any kind of correlation that can be drawn from Figure 3-9. The nitrate concentration drop as shown in Figure 3-10 might be from increased biological activity or reducing conditions. One promising aspect of this is that the HRC® could be useful in treating nitrate contamination. It is possible that any reduction in nitrates might be temporary if the nitrates are converted to nitrites and then rebound once all of the HRC® has been consumed and the nitrites are oxidized back to nitrates.

It is clear that extreme changes in the aquifer chemistry are occurring and that these changes are likely driven by factors that favor degradation of contaminants such as reducing conditions and lower pH. These chemical effects provide further evidence that there is a favorable change in the subsurface chemistry due to the increase in biological activity caused by the introduction of HRC®.

Figure 3-3. Concentration of 1,1,1-TCA and 1,1-DCA Versus Time in Well 30900

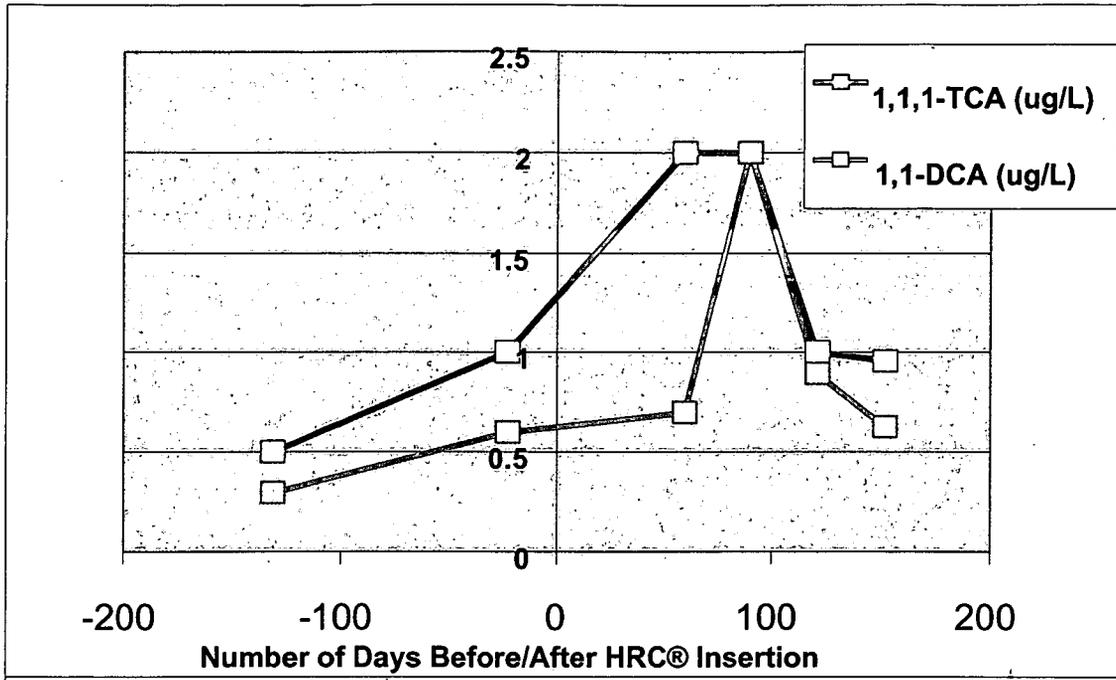


Figure 3-4. Concentration of 1,1,1-TCA and 1,1-DCA Versus Time in Well 31001

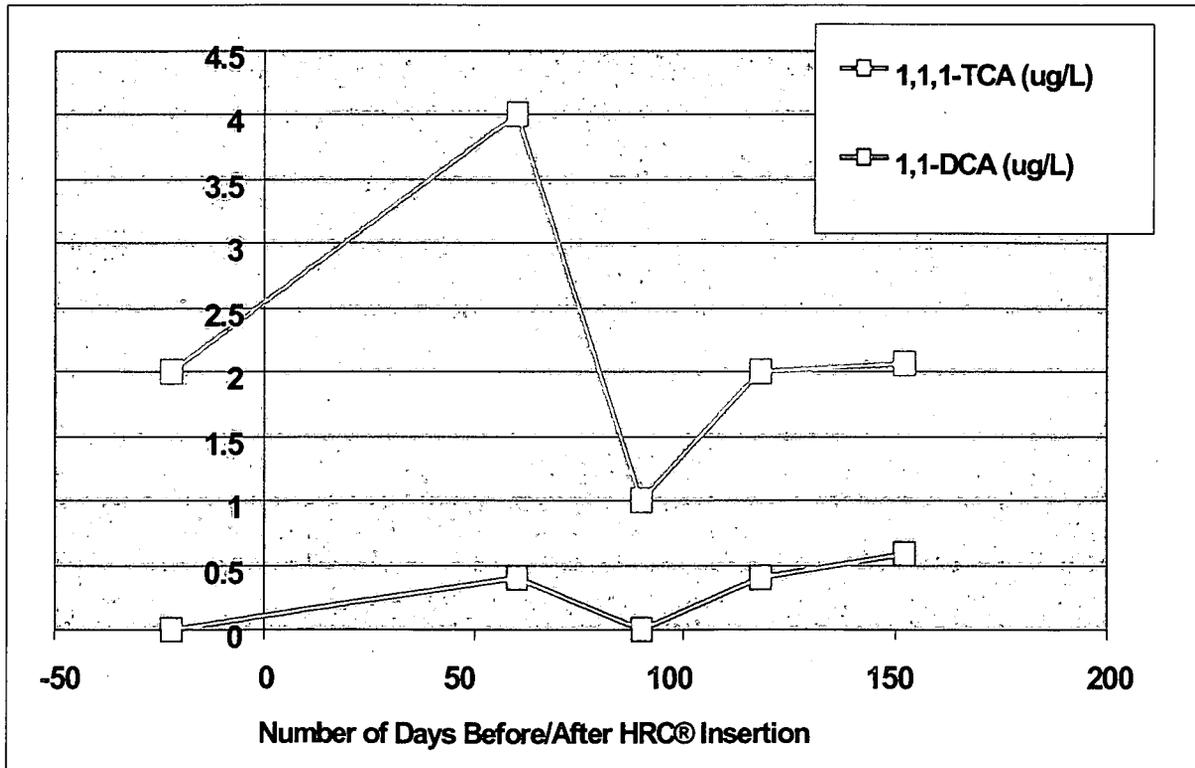


Figure 3-5. Concentration of 1,1,2-Trichlorotrifluoroethane in ug/L Versus Time

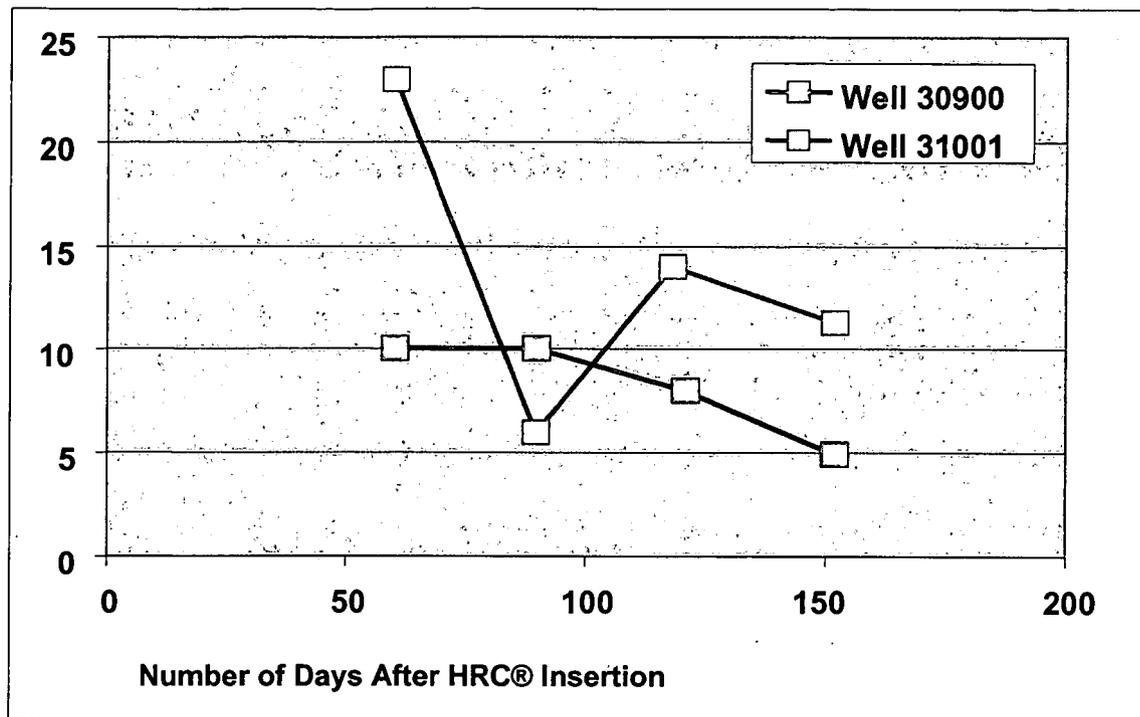


Table 3-3. Inorganic Analytical Results

Date	Days after HRC® Injection	Alkalinity (as CaCO ₃ , mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Chloride (mg/L)	Nitrate (mg/L)
Well 30900						
1/17/01	-43	34	15	0.056	6.4	ND
4/30/01	60	82	160	0.004	25	0.76
5/30/01	90	80	150	ND	25	0.31
6/27/01	118	88	110	0.1	22	0.08
Well 31001						
4/30/01	60	44	22	0.006	12	6.6
5/30/01	90	50	20	ND	10	2.8
6/27/01	118	90	14	0.04	14	1.1

ND=Not Detected

Figure 3-6. Alkalinity (in CaCO₃, mg/L) Versus Time

Figure 3-7. Sulfate (mg/L) Versus Time

21

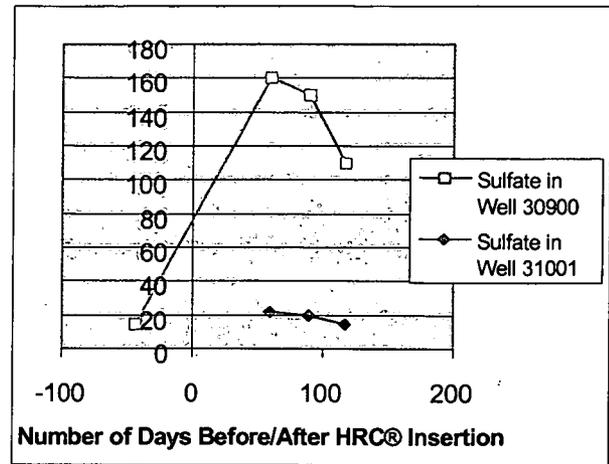
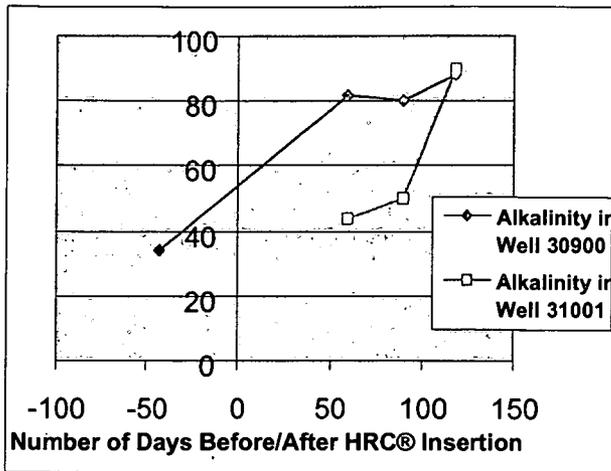


Figure 3-8 Sulfide (mg/L) Versus Time

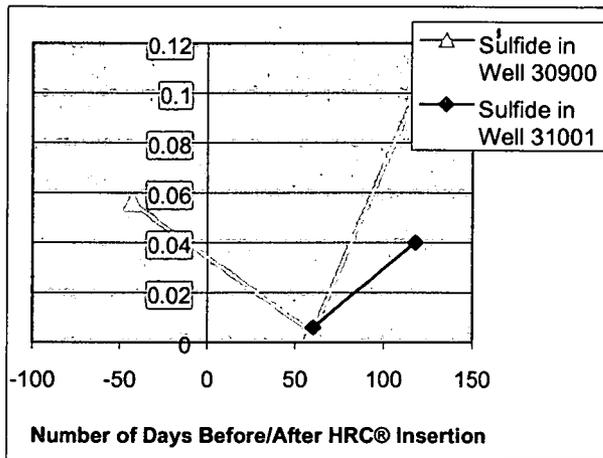


Figure 3-9. Chloride (mg/L) Versus Time

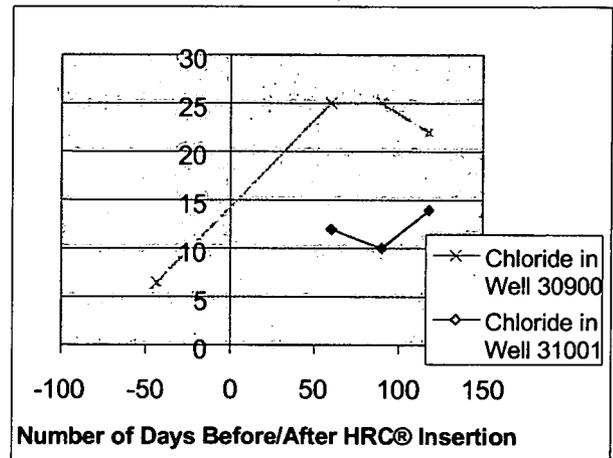
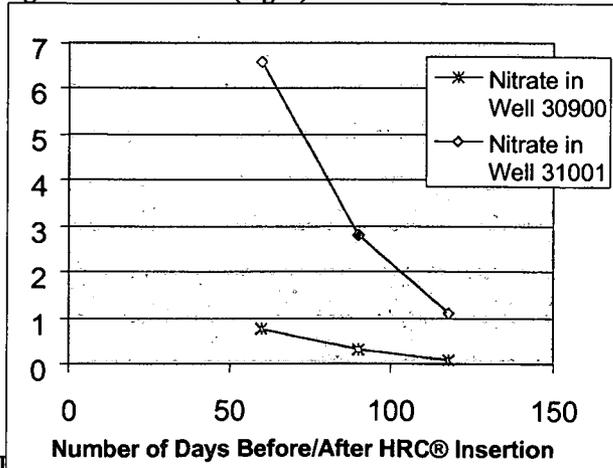


Figure 3-10. Nitrate (mg/L) Versus Time



field measurements also provide further proof of attenuating conditions. Table 3-4 shows the results of key field parameters that were measured at the same time that analytical samples were collected. These same results are shown graphically in Figures 3-

11 to 3-13. Although pH is not considered an indicator for attenuation, it is an indicator of changes in water chemistry and the subsurface environment. If protons supplied by the lactic acid alone caused the pH change, then the slight rebound in pH might be an indication that the lactic acid concentration was dropping.

Table 3-4. Inorganic Field Parameters

Date	Days after HRC [®] Injection	pH	Conductivity (uS/cm)	Eh (mV)
Well 30900				
1/23/01	-37	6.79	178	326.9
5/1/01	61	6.34	558	175.3
5/30/01	90	6.29	625	21.1
6/27/01	118	6.12	592	24.3
7/31/01	152	5.8	425	-45.5
8/28/01	180	6.06	327	-35.1
Well 31001				
2/7/01	-22	6.91	0.31	
4/30/01	60	6.34	241	339.8
5/31/01	91	6.34	218	294.7
6/27/01	118	6.08	275	145.1
7/31/01	152	5.9	361	0.1
8/28/01	180	6.19	298	0

Conductivity is also not a direct indicator of biological or chemical degradation. The changes in conductivity do mirror the concentrations of the solvents in the water, which is unusual since the presence of these solvents should have a dampening effect. The change in conductivity probably is caused by an increase in ionic strength. Whether this change is due to an increase in chlorine and/or other ions is not known.

Oxidation potential is a very strong indicator of a chemical environment that favors degradation and a direct measurement of the capability of the environment to chemically reduce contaminants. The drop in oxidation potential indicates that the introduction of HRC[®] into the aquifer has created a very favorable environment for the degradation of contaminants.

Figure 3-11. pH Versus Time

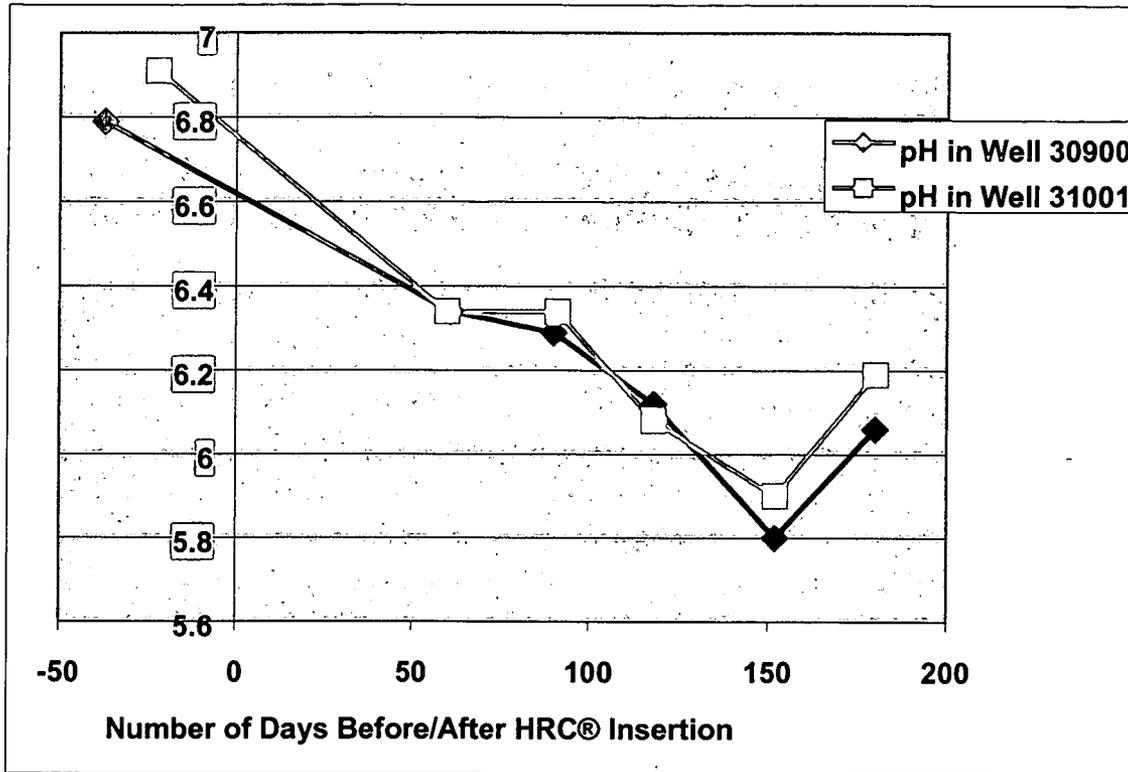
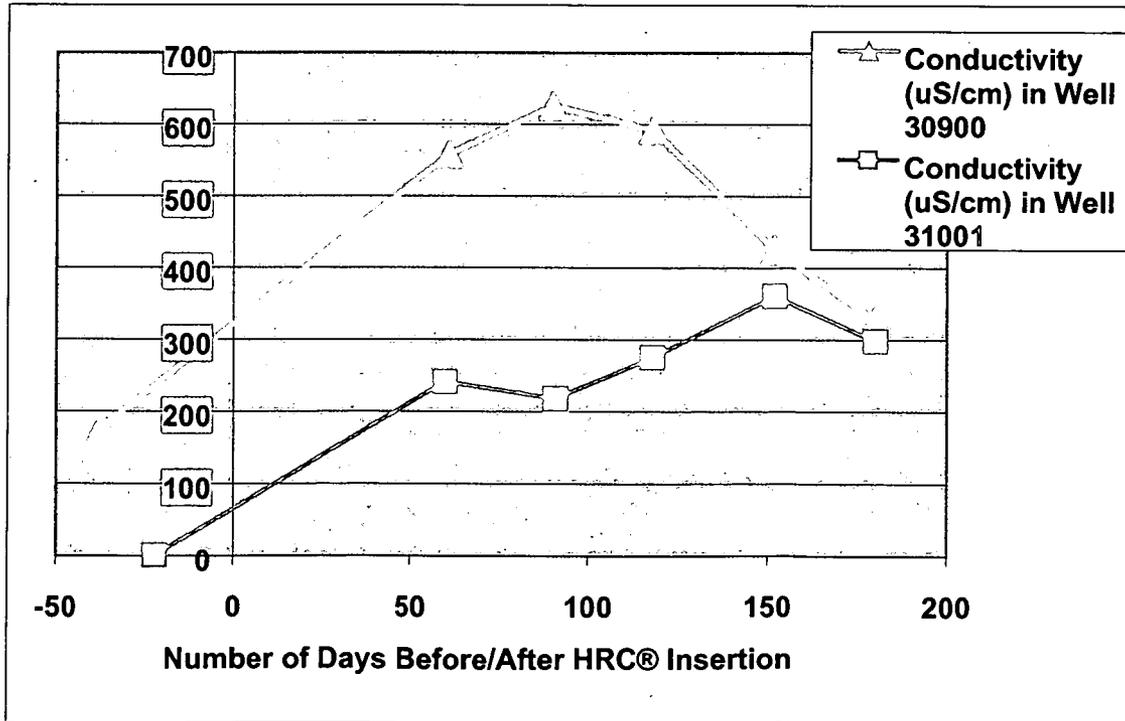
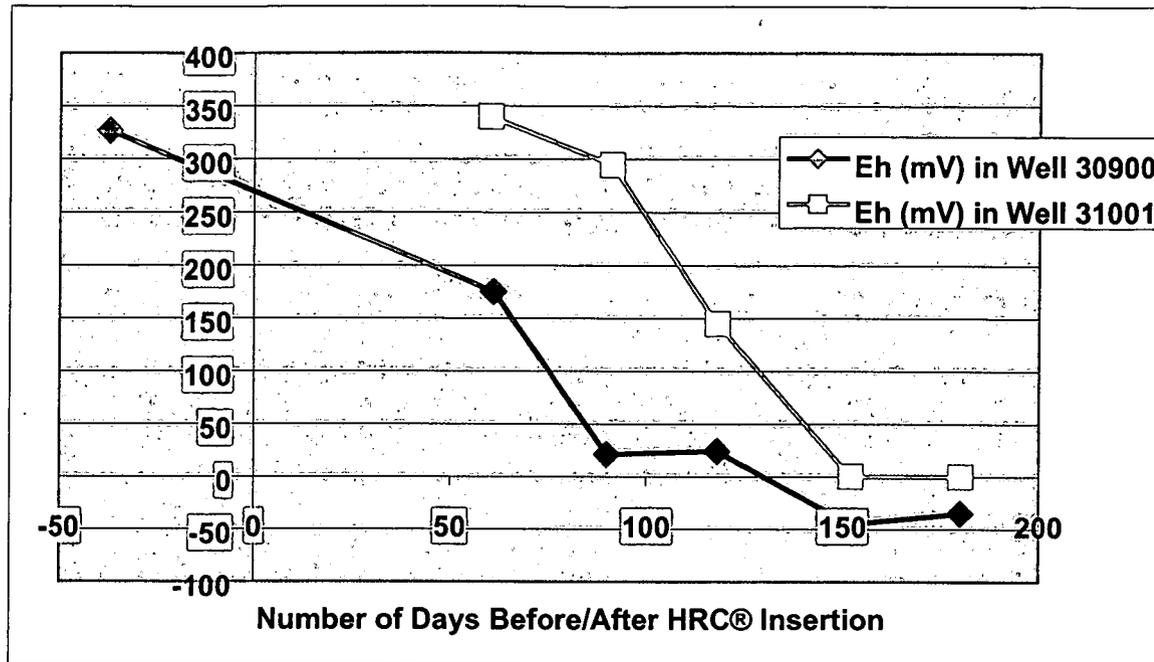


Figure 3-12. Conductivity (microsiemens per centimeter) Versus Time



24

Figure 3-13. Oxidation potential (millivolts) Versus Time



4.0 CONCLUSIONS

At this time it is not possible to make a final conclusion about the effectiveness of HRC®. Additional sampling and analysis is needed to verify that there is a sustained decrease in contaminant concentrations. However, based on the data collected so far, it looks very promising as a remediation technology. The most promising trends are as follows:

- Decreasing concentrations of the principal contaminants.
- The overall concentration trends are similar to other sites where HRC® has been successfully utilized. This includes initial increases in contaminant concentrations, which could reflect the release of free-phase organic liquids that were bound to the soil.
- The appearance of degradation products, some of which have never been previously detected
- The physical evidence at the site that the HRC® went into solution.
- Changes in parameters that are all indicators of biodegradation such as chloride concentration, alkalinity, and oxidation potential.
- Changes in other parameters that indicate significant changes in water chemistry and the subsurface environment such as changes in pH, nitrate concentration, and conductivity

The data suggests that because the HRC® was introduced into the aquifer in the winter, it was warm enough for many of the chemical effects to occur such as liberation of contaminants but it might have been too cold for the equally beneficial biological processes to develop as quickly. The groundwater

temperature difference between February and July was about nineteen degrees Fahrenheit. This might have resulted in a more prolonged and pronounced period of high contaminant concentrations. The contaminants eventually were degraded once warmer weather set in.

An additional conclusion is that, based on the data so far, use of a tremie pipe and MIPs seems to be an effective way of introducing the HRC[®] into the aquifer. It is inexpensive and appears to have allowed a very focused method of insertion allowing control over how much is inserted and where.

5.0 RECOMMENDATIONS

The following preliminary recommendations are based on the data collected so far:

- Monitoring should continue until the data can conclusively prove or disprove the effectiveness of the HRC[®]
- HRC[®] probably should be introduced into aquifers in temperate climates in the warmer months to provide more optimal conditions for bacteria to develop.
- Combining the use of HRC[®] with the soil excavation process should be evaluated either by leaving free-phase HRC[®] in the excavation when remedial activities have been completed or by installing MIPs to introduce HRC[®] after remediation is complete. This would allow the remediation of residual contaminants and could reduce the need for extensive soil removal.
- The use of HRC[®] should be evaluated on inorganic species such as nitrates since at this time there are not many good in situ treatment technologies for nitrates or other inorganic contaminants.

6.0 REFERENCES

DOE, 1992, Final Phase I RCRA Facility Investigation/Remedial Investigation Work Plan, Other Outside Closures, Operable Unit 10, Volume I, Rocky Flats Plant, Golden, Colorado, May.

Kaiser-Hill Company, L.L.C., 1999, Kaiser-Hill Team Quality Assurance Program, Rocky Flats Environmental Technology Site, Golden, Colorado.

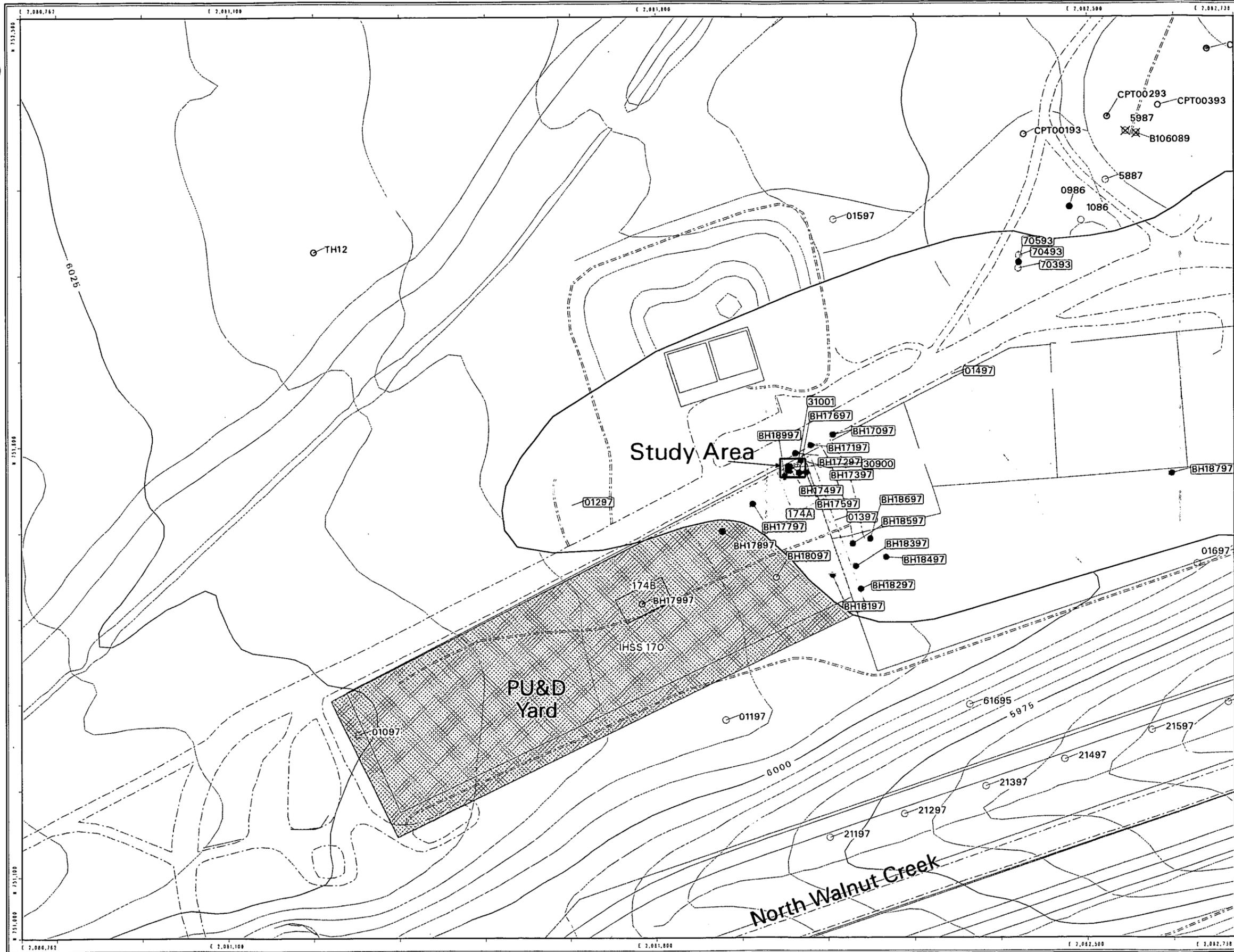
Kaiser-Hill Company, L.L.C., 2001, Final PU&D Yard Plume Enhanced Natural Attenuation Treatability Study Work Plan, Rocky Flats Environmental Technology Site, Golden, Colorado, January.

RMRS, 1997, Data Summary Report for IHSSs 170, 174A, and 174B, Property Utilization and Storage Yard, Rocky Flats Environmental Technology Site, RF/RMRS-97-080.UN.

RMRS, 1999, Technical Memorandum, Monitored Natural Attenuation of the PU&D Yard VOC Plume, Rocky Flats Environmental Technology Site.

RMRS, 2000, Sampling and Analysis Plan for Groundwater Monitoring at the Property Utilization and Disposal (PU&D) Yard, Rocky Flats Environmental Technology Site, MAN123.GRNDWTRMONITSAP.

Figure 1-1
PU&D Yard
Groundwater VOC Plume
Project Area



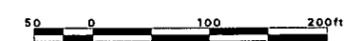
- EXPLANATION**
- PU&D Yard Monitoring Well
 - Groundwater Monitor Well UHSU Surficial Material
 - ⊕ Groundwater Monitor Well UHSU Bedrock
 - Groundwater Monitor Well LHSU Bedrock
 - Borehole Locations
 - × Abandoned Monitor Well
 - ◆ Material Insertion Point
 - ▭ Composite VOC Groundwater Plume (concentration equal to MCL)
 - ▨ PU&D Yard IHSS

- Standard Map Features**
- ▭ Buildings and other structures
 - ▭ Landfill Pond
 - Streams, ditches, or other drainage features
 - Fences and other barriers
 - Topographic Contour (5-Foot)
 - Paved roads
 - - - Dirt roads

NOTES:
 Source of GIS data available upon request.



Scale = 1 : 1890
 1 inch represents approximately 158 feet



State Plane Coordinate Projection
 Colorado Central Zone
 Datum: NAD27

U.S. Department of Energy
 Rocky Flats Environmental Technology Site

Prepared by:
DynCorp
 THE ART OF TECHNOLOGY

Prepared for:

 KAISER-HILL
 COMPANY

MAP ID: 01-0904

September 27, 2001

**Figure 2-1
PU&D Yard
Groundwater VOC Plume
Material Insertion Point Configuration**

- EXPLANATION**
- PU&D Yard Monitoring Well
 - Groundwater Monitor Well UHSU Surficial Material
 - ⊕ Groundwater Monitor Well UHSU Bedrock
 - Groundwater Monitor Well LHSU Bedrock
 - Borehole Locations
 - × Abandoned Monitor Well
 - ◆ Material Insertion Point
 - ▭ Composite VOC Groundwater Plume (concentration equal to MCL)
 - ▨ PU&D Yard IHSS

- Standard Map Features**
- ▭ Buildings and other structures
 - ▭ Landfill Pond
 - Streams, ditches, or other drainage features
 - Fences and other barriers
 - Topographic Contour (5-Foot)
 - Paved roads
 - Dirt roads

NOTES:
Source of GIS data available upon request.



Scale = 1 : 40
1 inch represents approximately 3 feet



State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

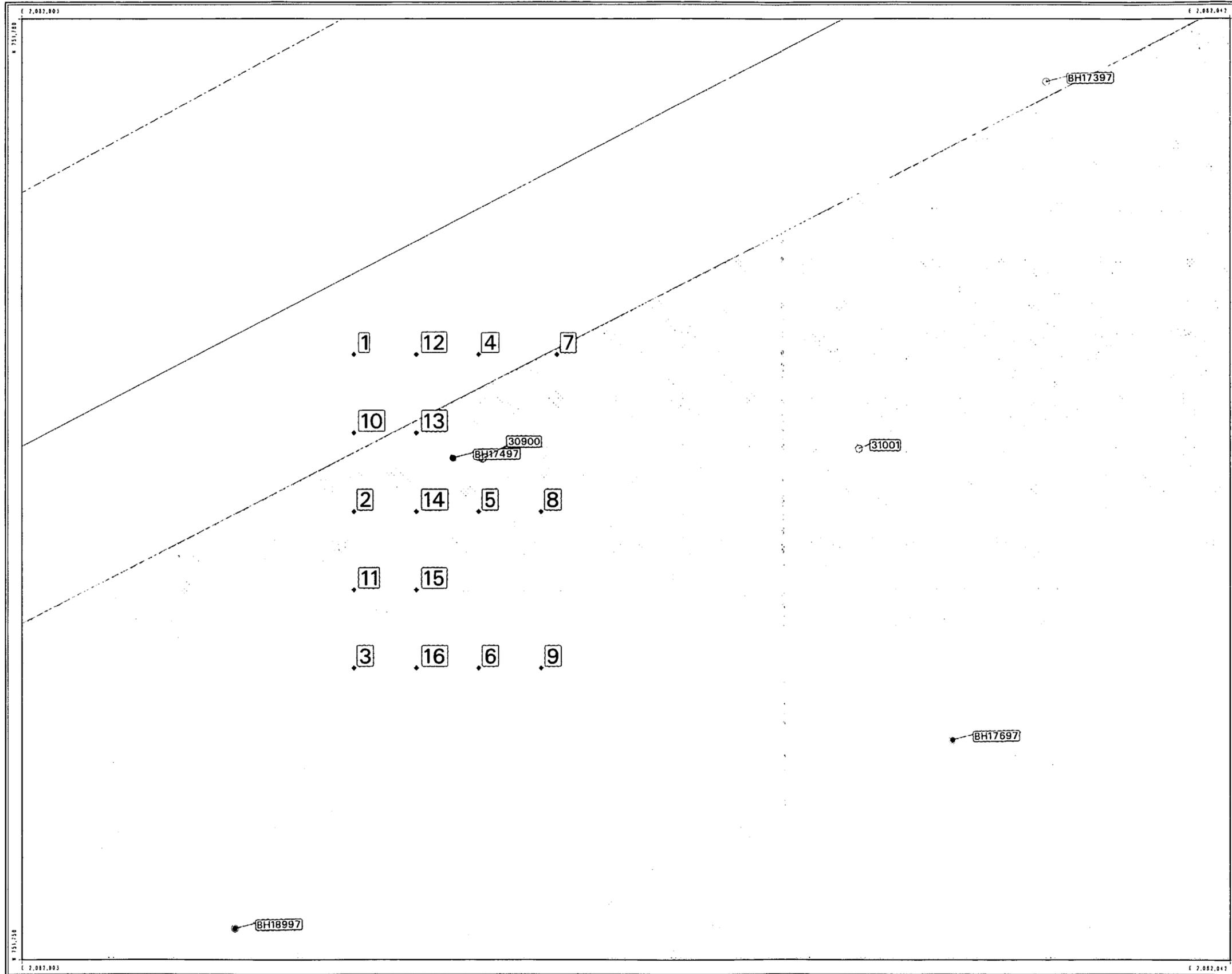
GIS Dept. 303-866-7707

Prepared by:
DynCorp
THE ART OF TECHNOLOGY

Prepared for:
KAISER-HILL
CORPORATION

MAP ID: 01-0904

September 26, 2001



14

NT_Srv_w:\projects\fy2001\01-0904\pud-yard-mip.aml