

ENVIRONMENTAL  
PROTECTION

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REMEDIAL ACTION WORK PLAN  
FOR  
CREDIT WORLD AUTO SALES  
2345 E. 14TH STREET  
OAKLAND, CA 94601

*9-15-99*

Prepared For:  
MESSRS. AARON AND STANLEY WONG  
2200 E. 12TH STREET  
OAKLAND, CA 94606

*(510) 535-1672*

Submitted By:  
TANK PROTECT ENGINEERING  
Of Northern California, Inc.  
2821 WHIPPLE ROAD  
UNION CITY, CA 94587  
(510) 429-8088

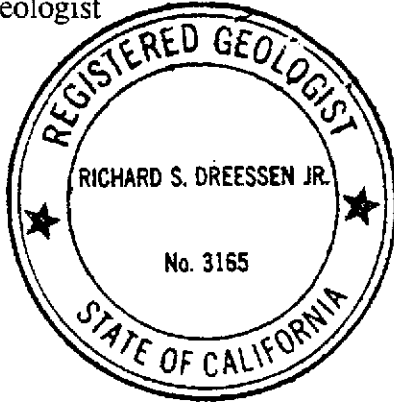
September 15, 1999

Project Number 267

(925) 820-3502

*Richard S. Dreessen Jr.*

Richard S. Dreessen Jr.  
Registered Geologist



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This report has been prepared by the staff of **Tank Protect Engineering of Northern California, Inc.** under direction of an Engineer and/or Geologist whose seal(s) and/or signature(s) appear hereon.

*Jeff J. Farhoomand*  
Jeff J. Farhoomand, M.S.  
Principal Engineer

The findings, recommendations, specifications or professional opinions are presented, within the limits prescribed by the client, after being prepared in accordance with generally accepted professional engineering and geologic practice. We make no other warranty, either expressed or implied.

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## 1.0 INTRODUCTION

The subject site is located at 2345 E. 14th Street in the City of Oakland in Alameda County, California (see Figure 1) and is owned by Messrs. Aaron and Stanley Wong [(Wong), telephone number (510) 532-1672]. A used car dealership know as Credit World Auto Sales occupies the site. Previous work by others and Tank Protect Engineering of Northern California, Inc. (TPE) has documented soil and groundwater contamination due to leaks or spills associated with a former underground gasoline tank complex.

Figure 2 shows a site plan presenting the locations of an onsite building which includes an office and automotive service bay, the former underground fuel tanks location, soil borings, and groundwater monitoring wells. The site has been inactive since 1991.

There are presently five (5) 2-inch monitoring wells installed on the site. To date, free product has been detected in four (4) of these monitoring wells with product thickness highly variable, but in general, decreasing over time. Product is presently detected in only one well at a thickness of 0.005 feet. Recent well sampling indicates that a plume of dissolved fuel hydrocarbons is still present.

The purpose of this Remedial Action Work plan (RAWP) is to:

- Summarize the information and revise the recommended remediation strategy as discussed in the original REMEDIAL ACTION PLAN, (RAP) presented to the Alameda County Health Care Services Agency (ACHCSA) on October 20, 1997.
- Respond to a March 11, 1999 letter to Wong, Request for Work Plan for Enhanced Bio-remediation at 2345 E. 14th St., Oakland 94601, requested by ACHCSA.

The October 1997 RAP recommended that a recovery well be installed at the site to remove floating product, followed by conversion of the well to a bioremediation well containing oxygen release compound (ORC<sup>™</sup>) socks. The RAP was to be followed by a detailed work plan to be prepared in the future to present well and equipment specifications, field and system installation schedule, injection rates and other details

concerning chemical and biological compounds. This RAWP fulfills that role. However, the bioremediation strategy has been changed to one remedial well for product recovery and containing ORC\* socks, and then ORC\* slurry injection through approximately 135 geoprobe location at 12 -foot grid spacing throughout the site.

## 2.0 SITE HISTORY

### 2.1 ACHCSA Correspondence

February 1, 1994: ACHCSA letter to Wong regarding Request for Technical Reports for 2345 E. 14th St., Oakland, CA 94601, Former Taxi Site.

February 18, 1994: ACHCSA letter to Wong regarding Comment on November 4, 1993 Preliminary Site Assessment Report for 2345 14th St., Oakland, CA 94601, Credit World Auto Sales. The ACHCSA recommended quarterly groundwater monitoring and initiation of excavation activities.

January 10, 1995: TPE presented SITE ASSESSMENT REPORT, CREDIT WORLD AUTO SALES, 2345 E. 14TH ST., OAKLAND, CA 94601 which detailed soil excavation and remediation activities.

May 17, 1995: The ACHCSA requested an additional groundwater investigation in a letter titled Status of Subsurface Investigation at 2345 E. 14th St., Oakland, CA 94601, Former Taxi Site.

August 4, 1995: TPE submitted WORK PLAN FOR GROUNDWATER INVESTIGATION, 2345 E. 14TH ST., OAKLAND, CA 94601.

October 26, 1995: ACHCSA approved TPE's work plan in a letter titled Comment on August 4, 1995 Work Plan for Soil and Groundwater Investigation at 2345 E. 14th St., Oakland, CA 94601.

October 3, 1996: Due to delay in soil excavation activities, ACHCSA issued Status of Subsurface Investigation at 2345 E. 14th St., Oakland, CA 94601, Former Taxi Site.

February 7, 1997: TPE submitted ADDENDUM TO AUGUST 4, 1995 WORK PLAN, CREDIT WORLD AUTO SALES, 2345 E. 14TH ST., OAKLAND, CA 94601 to ACHCSA.

February 10, 1997: ACHCSA approved the Addendum Work Plan.

April 21 - May 2, 1997: TPE pushed five soil holes using the "Geoprobe" method. Details were presented in SITE ASSESSMENT REPORT, CREDIT WORLD AUTO SALES, 2345 E. 14TH ST., OAKLAND, CA 94601.

June 12, 1997: ACHCSA responded with Site Assessment Report for former Credit World Auto Sales, 2345 E. 14th St., Oakland, CA 94601 requesting that natural biodegradation parameters be analyzed from groundwater samples collected during regular quarterly monitoring events and that a Remedial Action Plan be submitted.

September 2, 1997: ACHCSA submitted a letter regarding Remedial Action Plan for Former Credit World Auto Sales 2345 E. 14th St., Oakland, CA 94601, requesting sampling of bio-indicator parameters to evaluate the site for bioremediation. ACHCSA also requested that free product removal be initiated and a work plan be submitted addressing bioremediation.

September 18, 1997: TPE conducted quarterly monitoring for biodegradation parameters in response to ACHCSA. Results are presented in THIRD QUARTER REPORT, 1997, CREDIT WORLD AUTO SALES, 2345 E. 14TH STREET, OAKLAND, CA 94601.

October 29, 1997: TPE submitted REMEDIAL ACTION PLAN FOR CREDIT WORLD AUTO SALES, 2345 E. 14TH ST., OAKLAND, CA 94601 to ACHCSA. The plan recommended that a recovery well be installed at the site to remove floating product, followed by conversion of the well to a bioremediation well containing ORC® socks.

March 11, 1999: ACHCSA responded to the Fourth Quarter 1998 monitoring report with a letter titled Request for Work Plan for Enhanced Bio-remediation at 2345 E. 14th St., Oakland 94601. The letter stated that monitoring results showed the



continual high presence of dissolved gasoline, benzene, toluene, ethylbenzene, and xylene (BTEX) components and free product which indicated that natural bio-remediation was not occurring or occurring at a slow rate. The ACHCSA requested a specific work plan for enhanced bio-remediation along with a time schedule for its implementation.

## 2.2 Quarterly Groundwater Monitoring

TPE has conducted quarterly monitoring since March 31, 1994. The reader is referred to the Second Quarterly Report dated June 28, 1999, for documentation of recent quarterly groundwater monitoring events and results.

## 3.0 SITE STRATIGRAPHY

### 3.1 Regional Setting

The site is located in the East Bay Plain of the Coast Range physiographic province. The surface of the Bay Plain is gently sloping to the southwest and the site is at an elevation of about 27 feet above mean sea level (MSL). The East Bay Plain is an area comprised of flat alluvial lowlands and bay and tidal marshes lying between the bedrock hills of the Diablo Range and East Bay Hills on the east, and San Francisco Bay to the west.

Major groundwater-bearing materials beneath the East Bay Plain occur at depths ranging from 50 feet to 1,000 feet below ground surface (bgs). Groundwater from these aquifers is presently used for irrigation and industrial purposes. Groundwater flow is generally in a direction from the Diablo Range toward San Francisco Bay. The nearest body of surface water to the site is Brooklyn Tidal Canal located about 0.50 miles west of the site.

### 3.2 Site Geology and Hydrogeology

The site hydrogeology has been interpreted from soil boring logs constructed by TPE and others and evaluation of the stabilized groundwater elevations in the five on-site

groundwater monitoring wells (see Section 3.3 Groundwater Flow Direction and Gradient). The site subsurface stratigraphy consists of the following sequence of interfingering deposits of gravel, sand, silt and clay in various combinations from groundwater surface to depth:

- dry, brown, aggregate base material and asphalt;
- dry, grey to black clay ranging to depths of about 7.5 to 12.0 feet;
- damp, light grey to green clay to a depths of about 17.0 feet grading into a green clayey sand;
- water bearing light green to grey clayey sand ranging to depths of about 17.0 to 27.0 feet;
- dry to moist, brown, gravelly clay ranging to depths of about 27.0 to 30.5 feet grading to brown clayey sand;
- light brown, wet sand to a depths of about 32.5 feet; and,
- damp, brown, gravelly clay to total depth explored.

### 3.3 Groundwater Flow Direction and Gradient

On June 15, 1999, as part of the Second Quarter, 1999, monitoring event, depth-to-groundwater was measured from the top of casing (TOC) in all wells to nearest 0.01 foot. When floating product was present, the groundwater elevation was corrected by multiplying the floating product thickness by a density of 0.75 and adding the resultant value to the groundwater elevation. Groundwater elevation, depth-to-groundwater, depth to product, and corrected groundwater elevation are tabulated in attached Table 1.

Attached Figure 2 is a groundwater gradient map constructed from the data collected on June 15, 1999. Groundwater flow direction was northwest with a gradient of 0.01 feet per foot. Average groundwater elevations, changes in average groundwater

elevations, groundwater gradient, and groundwater flow directions are tabulated in attached Table 2.

#### 4.0 EXTENT OF SOIL CONTAMINATION

TPE believes that low concentrations of total petroleum hydrocarbons as gasoline (TPHG) and BTEX remain within the former tank excavation but presently have minimal impact upon groundwater contamination. The reader is referred to the REMEDIAL ACTION PLAN FOR CREDIT WORLD AUTO SALES, 2345 E. 14TH ST., OAKLAND, CA 94601 previously submitted to ACHCSA on October 20, 1997, for a more detailed discussion of soil contamination at the site.

#### 5.0 EXTENT OF GROUNDWATER CONTAMINATION

Floating product was originally observed in wells MW-1, MW-2, MW-3, and MW-5. Product thickness is highly variable, but in general, has been decreasing over time. Product is presently detected in only well MW-1 at a thickness of 0.005 feet. Product thickness appears to be fluctuating with the changing seasonal water table, possibly increasing in thickness as the water table lowers, and decreasing in thickness as the water table rises. Attached Table 3 summarizes the thickness of floating product measured in each well.

Groundwater contamination has been defined to the west, north and east of the site. Groundwater contamination has not been defined to the south of the site based on the results of soil boring SB-2 and MW-3.

##### 5.1 TPHG Dissolved Groundwater Plume Map

Figure 3 presents the average groundwater TPHG concentrations from the last three quarterly sampling events. A statistical average was used for determining input parameters for ORC<sup>®</sup> concentrations and distribution, equipment specifications, and budget analysis. Dissolved concentrations in excess of 147,000 parts per billion (ppb)

TPHG are present. Summary of groundwater sample analytical results are tabulated in Table 4.

## 5.2 Total BTEX Dissolved Groundwater Plume Map

Figure 4 presents the average groundwater BTEX concentrations from the last three quarterly sampling events. A statistical average for total BTEX was used for determining input parameters for ORC® concentrations and distribution, equipment specifications, and budget analyses. Dissolved concentrations in excess of 1,235 ppb total BTEX are present. Summary of groundwater sample analytical results are tabulated in Table 4.

## 6.0 REMEDIAL ACTION OBJECTIVES

The goal of the remedial effort described herein is to reduce the concentration of the various identified contaminants in groundwater to levels which do not pose a significant threat to beneficial groundwater uses or human health and safety.

This RAWP is designed to meet the following objectives: 1) to provide free product removal that may still exist at the site and, (2) to initiate enhanced in-situ bioremediation through the injection of nutrient, oxygen and bacteria. The specifics of the Work Plan were developed by speaking with the various companies specializing in enhanced in-situ bioremediation and free product removal. The present work plan provides for free product removal by the use of at least one in-well remedial separator pump, then dissolved contaminant phase removal by ORC® slurry injection through approximately 135 geoprobe locations throughout the site.

*have as these added*

### 6.1 Groundwater Objectives

Maximum Contaminant Limits (MCLs) are proposed as cleanup levels for each specifically identified constituent present in site groundwater. However, if after one year of operation groundwater conditions have not stabilized and achieving MCLs is compliance (RBCA Tiers 2 and 3) will be established and/or non-attainment closure as described in Section 6.2.2 will be pursued.

*not in*

## 6.2 Human Health Risk Evaluation

Anticipating the possibility that initial cleanup goals (MCLs) may be physically or economically unattainable, a qualitative and quantitative health risk assessment will be presented once groundwater conditions have stabilized, after post-treatment enhance bioremediation monitoring, based on RBCA methodology. Technical feasibility, economics, and the potential for adverse human health effects likely to result from current or potential exposure to chemicals will be considered in establishing final cleanup levels. Potentially impacted receptors are identified in the following paragraphs.

### 6.2.1 Receptor Characterization

According to the Groundwater Basin Plan, the shallow groundwater beneath the site is considered potential drinking water; however, is not actually expected to ever be used for drinking water due to limited yield and quality considerations.

Potential exposure pathways via groundwater entail either direct shallow groundwater ingestion or vertical contaminant migration through intervening aquitards into deep water supply aquifers. Potential exposure associated with either of these scenarios will be qualified, if required, in accordance with RBCA methodology.

### 6.2.2 Non-attainment Closure

The policy promulgated by the Ground Water Basin Plan recognized that achievement of drinking water standards in groundwater may not be technologically feasible, necessary or economically possible in some cases. The Amendments provide preliminary guidance for the establishment of Non-Attainment Areas (NAA) where contaminant reduction to drinking water standards will not be required to obtain closure. The NAA closure requirements, in general, entail compliance with the following conditions:

- ® Site hydrogeology and pollutant dynamics are well understood;
- Soil and free products have been removed;

- Groundwater cleanup system has resulted in asymptotic conditions;
- Groundwater plume does not adversely impact off-site property, and;
- Residual concentrations do not pose a significant health threat.

## 7.0 REMEDIAL ACTION ALTERNATIVES CONSIDERED

What follows is a summary of the remedial options as discussed in the RAP submitted by TPE in October 1997.

- Groundwater Monitoring and Intrinsic Bioremediation: Based upon past concentration trends and the continued observation of floating product, this option was not selected.
- Pump and Treat + Reinjection: Case histories in California show that very few sites have attained closure using this option. ACHCSA commented that groundwater extraction is not recommended, as it has proven not to be cost effective.
- Remedial Trench: Floating product, and dissolved contaminant concentrations would be expected to decrease with implementation of this option; however, engineering feasibility and the costs associated with trench excavation, denaturing and construction make this remedial option less desirable.
- Remedial Well/Enhanced Bioremediation: A six-inch diameter remedial well would be installed and used to remove floating product with a automated downhole skimmer device. Once floating product is removed, this well could be used as a bioremediation well. Dilute ORC<sup>®</sup> socks could be placed into the formation via the well in order to enhance the remediation of the dissolved hydrocarbons in the groundwater. Based upon the results of the biotreatment and radius of influence established possibly two more full scale remedial wells would be designed at a future time.

## 7.1 Remedial Action Selection

Based upon the evaluation of the above remedial options, and as more fully discussed in the October 1997 RAP, TPE determined that the Remedial Well/Enhanced Bioremediation option provided the best solution for remediation of this site. Please refer to Table 5 of the work plan for a comparison summary of remedial options, including cost estimate, technical feasibility, and redevelopment issues.

## 8.0 IMPLEMENTATION OF REMEDIAL ACTIONS

This RAWP is designed to meet the following objectives: 1) to provide free product removal that may still exist at the site; (2) to initiate enhanced in-situ bioremediation through the injection of nutrient, oxygen and/or bacteria; (3) to reduce the concentration of the various identified contaminants in groundwater to levels which do not pose a significant threat to beneficial groundwater uses or human health and safety; and (4) when groundwater conditions have stabilized, perform a human health risk assessment and obtain a subsequent case closure. The specifics of the RAWP were developed by speaking with various companies specializing in enhanced in-situ bioremediation and free product removal. The present work plan provides for free product removal by the use of an in-well separator pump, then dissolved contaminant phase removal by ORC® slurry injection through approximately 135 geoprobe locations throughout the site.

### 8.1 Remedial Action Implemented to Date

Corrective actions implemented to date have included in-situ, natural ("passive") attenuation of contaminants and measurement of bioindicator parameters for subsequent bioremediation of groundwater. Quarterly monitoring suggests that for the past five years dissolved contaminant concentrations have not decreased through natural attenuation. In addition, floating product, although decreasing in thickness in a general sense over the last seven years, has not disappeared from the groundwater. Measurements of floating product may be less a reflection of an actual decrease in product thickness than, 1) rising regional static water levels over the last seven years, 2) continued leaching of the floating free product from overlying fat and organic clays

at high water levels, and/or 3) screened intervals significantly below static water levels in all monitoring wells.

In September 1997, groundwater samples collected by TPE were analyzed for alkalinity, nitrate, sulfate, ferrous, iron and oxidation-reduction potential by Environmental Protection Agency Methods 310.0, 353.3, 375.4, SM3500-FE and ASTM D1498 to look at bioremediation as a possible site remediation method. Baseline parameter analytical results are summarized in Table 6.

## 8.2 Remedial Actions to be Implemented

### 8.2.1 PHASE 1: Remedial Well Installation

A six-inch diameter remedial well (RW #1) will be installed in a down-gradient direction in the vicinity of monitoring well MW-2 (see Figure 5) where historic floating product appears the thickest and longest lasting. Due to fluctuating free product thickness and rising static water levels observed in the past, the screen will be set from five feet to 25 feet bgs (present SWL is approximately 13 feet bgs). An inspection of boring log descriptions indicate that the dissolved contaminant phase in groundwater is limited to less than 25 feet bgs possibly correlating to the approximate depth of the lower sand.

Present quarterly sampling events appear to indicate that floating product is not present. However, due to "drowned" screen intervals, this may be due to long term rising regional water levels due to El Nino and seasonal fluctuations in groundwater level, rather than actual disappearance of floating product. In order for PHASE 2 [enhanced bioremediation by ORC\* (OXYGEN RELEASE COMPOUND)] of the remedial action to be implemented, floating product will need to be insignificant or totally removed (ORC\* should not be used when more than a sheen of free product is evident). Monitoring well MW-2 presently records no floating product, although historically it has been most consistent with the presence of floating product. An initial remedial well (RW #1) will be placed near MW-2 to verify the absence/presence of product and the validity of floating product measurements during past quarterly monitoring events. Based upon floating product observations in RW #1, subsequent actions may proceed to completion of PHASE 1 (floating product recovery)



or PHASE 2 (if no product or sheen is present, or product is effectively removed). Up to two additional remedial wells (RW #2, RW #3) may be located onsite based upon the effective radius of influence calculated by RW #1 performance. During implementation of PHASE 2, all remedial wells will be converted to enhanced bioremediation wells by adding ORC<sup>®</sup> socks over the screened interval.

*How all radius of influence  
be determined*

Remedial well RW-1 will initially be used to remove floating product with an automated 4-inch Ferret<sup>™</sup> in-well separator pump, manufactured by QED Environmental Systems, Inc. of Ann Arbor, Michigan. The Ferret<sup>™</sup> provides a more effective way to remove floating hydrocarbon layers. Using a unique separator valve to sense differences in specific gravity, the Ferret<sup>™</sup> pumps out pure hydrocarbon and rejects any water back in the well so that large volumes of water do not have to be treated or disposed of. Set-up and operation are easy and safe because the Ferret<sup>™</sup> is air-powered, small diameter (4 inches), and lightweight.

Unlike other devices, the Ferret<sup>™</sup> does not rely on hydrophobic screens, which often clog, or belts, which are messy and work only with high viscosity floating hydrocarbons. The Ferret<sup>™</sup> technology was developed for, and proven in, groundwater clean-up projects at spill leak sites. These projects demanded that no water be pumped from the well, in order to avoid the high cost of treating and disposing contaminated water.

The basic sequence of operation for the Ferret<sup>™</sup> is as follows:

- **Refill Cycle:**  
As the pumping chamber in the Ferret<sup>™</sup> fills, hydrocarbon droplets naturally separate from the water, floating to the top and coalescing.
- **Water Discharge:**  
Compressed air is sent to the Ferret<sup>™</sup> from the compressor. This air forces water out of the bottom of the Ferret<sup>™</sup> because the water discharge check ball at the bottom of the Ferret<sup>™</sup> floats in water.
- **Product Discharge:**  
As the water is driven out, the water discharge check ball becomes immersed in product. Now, it sinks and seats, diverting the product into the discharge

line and up to the surface. The Controller shuts off air to the Ferret™ and allows the pump to begin the next refill cycle.

The Ferret™ combines proven pump design with a unique water-rejecting valve to ensure that only floating hydrocarbon is pumped to the surface. Reliability and durability far exceed that delivered by devices using hydrophobic screens. Low maintenance field service objectives are met by eliminating the hydrophobic screen, which often requires frequent attention due to clogging. The use of this in-well separator system gets all the gasoline-even the sheen, and combines reliability, durability, serviceability, and performance. Refer to Appendix A for manufacturer and supplier fact sheets.

### 8.2.2 PHASE 2: Enhanced Bioremediation by ORC\*

It is proposed that ORC\* Saturated Zone Source Treatment by slurry injection be initiated to address the saturated dissolved zone contaminant plume. ORC\* will be injected by advancing approximately 135 geoprobes at 12-foot grid spacing, throughout the accessible portion of the site, which overlies the contaminant plume (see Figure 5). Saturated zone clayey lithology, apparent lack of permeability, minimal groundwater gradient, and lack of historic down-gradient transport of the contaminant plume all suggest insignificant groundwater velocity. Thus, the grid spacing of 12 by 12 feet was determined by assuming that saturated transport was by slow diffusion, rather than dispersion.

Geoprobes will be advanced to 25 feet bgs with ORC\* placed from 10 to 25 feet bgs. Static water level measurements will be made during geoprobe advancement to ensure proper placement of ORC\* across the groundwater interface, capillary fringe, and smear zone.

*may not be contaminated*

#### About Oxygen Release Compound, ORC\*

ORC\* is a patented formulation of magnesium peroxide,  $MgO_2$  which slowly releases oxygen when moist. The hydrated product is magnesium hydroxide,  $Mg(OH)_2$ . Generally, the product will continue to release oxygen for about 6 months.

Oxygen is the limiting factor in aerobic bioremediation. The microorganisms, nutrients and moisture are typically present, but most sites are oxygen deficient with bioremediation proceeding anaerobically. The addition of oxygen significantly increases the rate of remediation, by one or two orders of magnitude (10 to 100 times). A conservative 3:1 ratio of oxygen usage to carbon contamination has been used to calculate the amount of ORC\* needed to remediate groundwater at the site.

ORC\* will not harm an aquifer and is virtually insoluble. Biofouling is inhibited by an elevated, but localized pH; Iron fouling is avoided, particularly when compared to air sparging, by the long, gently release of dissolved oxygen, which is dispersed widely. The hydrated product is a solid form of ordinary Milk of Magnesia.

ORC\* is useful as a slow release source of oxygen in the remediation of any compound that is aerobically degradable. It has been used in the successful remediation of dissolved phase compounds such as BTEX, MTBE, PAH's and certain chlorinated compounds such as vinyl chloride and PCP. ORC\* is most frequently used to address dissolved phase contamination plus sorbed material in the saturated, capillary fringe, and smear zones. It should not be used when more than a sheen of free product is evident.

ORC\* can be applied to meet several objectives as follows.

1. The product may be used in the bottom of a tank excavation to create a oxygenated zone near the original source of the contamination, reducing the contaminant mass, and thereby collapsing the plume so that compliance may be achieved at a point closer to the source.
2. The product can be applied as an "oxygen barrier" which prevents contaminant migration off site. ORC\* can be configured to form a barrier across the leading edge of a contaminant plume. A properly placed row of wells or boreholes containing ORC\* can cut off the plume in the oxygenated zone.
3. The product can be applied in existing monitoring or remedial wells (well conversion). When utilizing existing wells, ORC\* is mixed with a carrier matrix and contained in inert filter socks. A string of ORC\* filter socks is lowered

into the well through the length of the contaminated saturated zone where contact with groundwater releases the oxygen. When exhausted the socks can be removed and if necessary, replaced with new socks.

4. The product can be applied to create a highly oxygenated zone in the "heart of the plume" quickly, easily and at a low cost, thus collapsing the plume by allowing aerobic degradation processes to occur within the plume's anaerobic core. The ORC<sup>®</sup> saturated zone source treatment targets dissolved phase contamination and sorbed material within the saturated zone and capillary fringe. In this application, ORC<sup>®</sup> powder is mixed with water to create a smooth slurry that is pumped or poured into narrow, direct-push or augered bore holes that have been placed in an array in and around the contaminant plume. A concentrated ORC<sup>®</sup> slurry can be used to backfill the boreholes, similar to a grout or cement. Dilute solutions of the ORC<sup>®</sup> slurry can be pumped under pressure to force the mixture into the aquifer and increase the radius of influence (ORC<sup>®</sup> slurry injection).

Applications 3 and 4 have been chosen as PHASE 1 and PHASE 2 of the remediation method at the Credit World Auto Sales site. More specific information about ORC<sup>®</sup> beyond what is discussed in this RAWP may be found in the work plan appendices, or at the Regensis<sup>®</sup> web site which may be accessed at <http://www.regensis.com>, and is best viewed through MS Explorer v. 3.0, Netscape v.3.0, or AOL v. 3.0. Refer to Appendix B for ORC<sup>®</sup> Slurry Injection Case Histories, Appendix C for ORC<sup>®</sup> Source Treatment Application, Appendix D for Protocol for Use of ORC<sup>®</sup> for In-situ Bioremediation, Appendix E for ORC<sup>®</sup> Slurry Injection Instructions, and Appendix F for Directions for ORC<sup>®</sup> Slurry Mixing.

### 8.2.3 Protocol for Use of ORC<sup>®</sup> for IN-SITU Bioremediation

#### Baseline Parameters

The majority of the site-specific data required to pre-screen the site for ORC<sup>®</sup> technology has been evaluated from the previous assessment efforts and quarterly sampling events. In some instances, some of the qualitative data was standardized from input by experienced Regensis<sup>®</sup> technical personnel in Pleasant Hill, California.

The following list of parameters was collected from the five monitoring wells on-site. The on-site monitoring wells (4 down-gradient and one up-gradient) will also be used for subsequent treatment monitoring. The Following parameters are required for baseline assessment and pre-screening:

<u>PARAMETER</u>	<u>GROUP</u>	<u>STATUS</u>
•	Lithologic/Hydrogeologic/Microbiological	Data
	Minimum Required Data	
	Aquifer soil classification	CL/SL
	Groundwater Flow Direction	Northwest
	Dissolved Oxygen (DO)	0.89-1.82
	pH	6.5
	Temperature	66.6
	Alkalinity	430-1,000
	Additional Data for Greater Control	
	Concentration of alternate terminal e- acceptors	
	Nitrate	<0.10-14.0
	Iron	<0.01
	Sulfate	<0.10-11.0
	Soil microbial enumerations	standardized
	Biological oxygen demand (BOD)	standardized
	Oxidation/Reduction (Redox) potential or Eh	70-240
	Percent porosity	standardized
	Conductivity	1,310
•	Compounds of Concern (COCs)	Data
	Minimum Required Data	
	Dissolved concentration of Total BTEX	1,400 ppb
	Dissolved concentration of MBTE	<0.50 ppb
	Dissolved concentration of TPHG	147,000 ppb

#### 8.2.4 Application Protocol

The ORC<sup>®</sup> application approach to be used at this site reflects the remedial goal for the site, which is sufficient contaminant mass and plume reduction followed by RBCA closure. ORC<sup>®</sup> will be applied across the entire plume "footprint" within the property boundaries. To avoid under-performance, modeled parameters used in the Regensis<sup>®</sup> application software package for this site have been maximized to decrease clean-up time and avoid multiple application of ORC<sup>®</sup>. The following list of issues have been addressed:

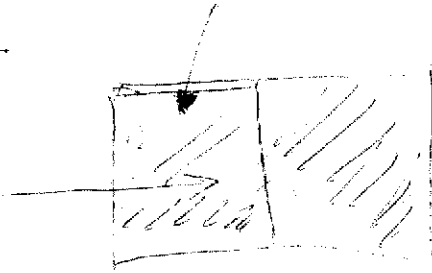
- Vertical (thickness of the contaminated saturated zone) and lateral extent of the hydrocarbon plume. The vertical extent is critical because ORC<sup>®</sup> releases oxygen, which moves laterally from ORC<sup>®</sup>. Where you put ORC<sup>®</sup> is where you provide the oxygen. Dissolved oxygen does not rise through the water column; it remains within the interval in which the ORC<sup>®</sup> is placed.
- Evaluation and selection of optical application approach.
- Regensis<sup>®</sup> application software was used to estimate the hydrocarbon mass present within the system as well as the amount of DO/ORC<sup>®</sup> necessary to remediate the calculated hydrocarbon mass. It is important to evaluate the DO/ORC<sup>®</sup> requirement based on the mass of the hydrocarbons present as well as the proper distribution of DO in the aquifer. Fewer source points containing large dosages of ORC<sup>®</sup> (DO) are less effective in plume reduction than greater numbers of point sources containing smaller dosage of ORC<sup>®</sup> (DO).

### 9.0 GROUNDWATER REMEDIATION MONITORING

#### 9.1 Post-Application Treatment Monitoring

The treatment monitoring process is designed to quantify the degradation of dissolved COCs. Respirometry measurements also provide evidence that bioremediation is the primary mode of destruction of the COCs. The respirometry monitoring is monthly for the first quarter after start-up, and bimonthly for the remainder of the first year.

$$\frac{D_i^* - D_a}{P}$$



BOD ↓

ORC\* application outlined in this work plan has been designed to reduce concentrations of COCs in groundwater over a one-year period to levels that do not pose a significant threat to beneficial groundwater uses or human health and safety. At that time, a human health risk assessment will be initiated and case closure requested. If necessary, monitoring can be conducted semi-annually during an optional second year, if necessary. The following parameters will be taken to analyze treatment monitoring:

- Microbiological/Respirometry Data

- Minimum Required Data

- Biological oxygen demand (BOD) ← *what does this data mean*

- Oxidation/Reduction (RedOx) potential or Eh

- Dissolved oxygen (DO)

- pH, temperature and conductivity

- Concentrations of alternate terminal electron acceptors (nitrate, iron, sulfate)

- Compounds of Concern (COCs)

- Minimum Required Data

- Dissolved concentrations of total BTEX

- Dissolved concentrations of MTBE

- Dissolved concentrations of TPHG

The five on-site monitoring wells will be used to monitor treatment progress.

## 10.0 REMEDIAL ACTION SCHEDULE

The tasks outline in the RAWP will require approximately 44 weeks. Should unanticipated conditions be encountered during the remedial action of the site, and should such conditions potentially impact the budget and/or schedule, the ACHCSA and California UST Fund will be notified as soon as is practical prior to any changes being made. The project schedule is as follows:

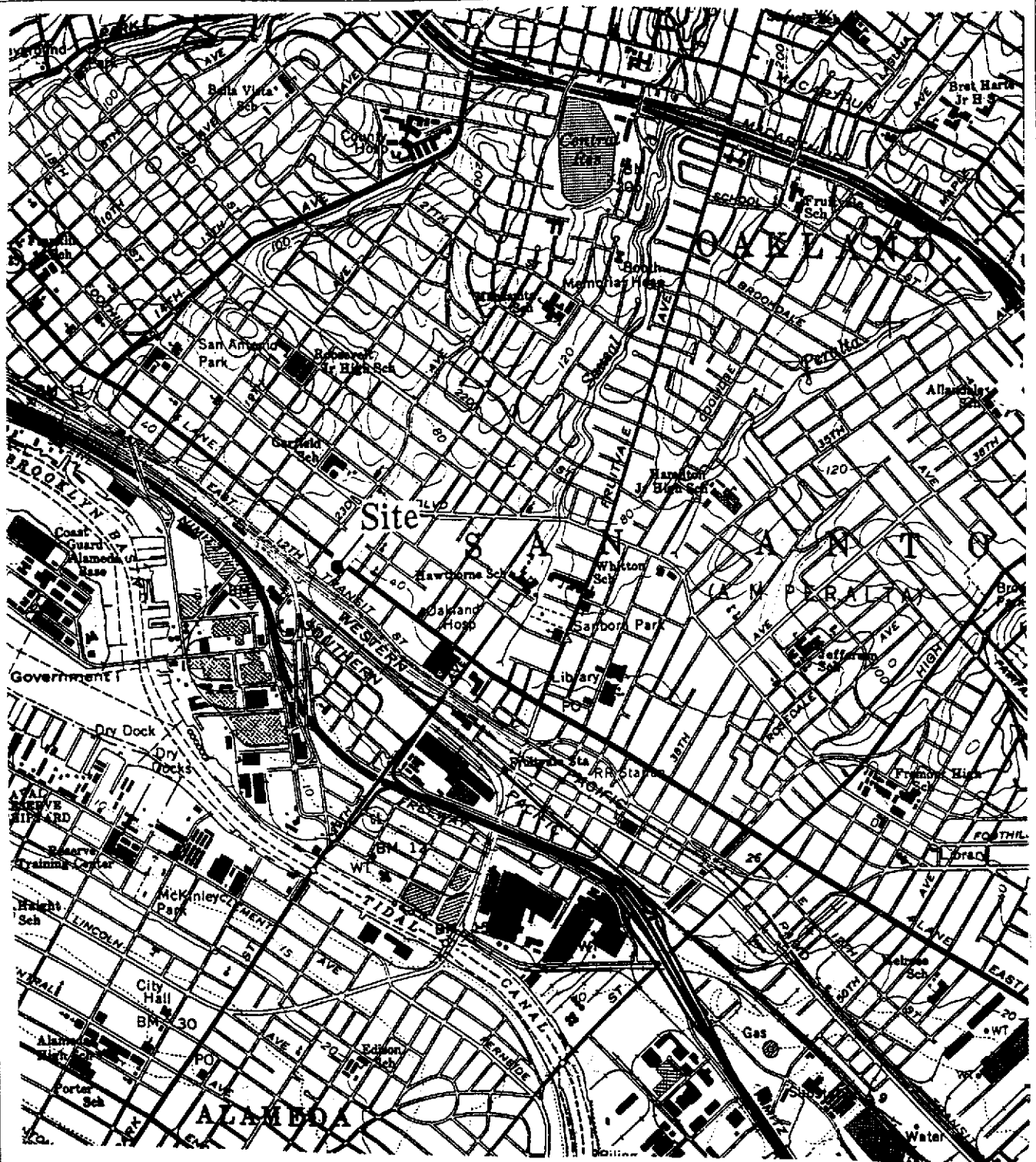


Task	Week
• Submit final RAWP to ACHCSA	0
• Obtain ACHCSA and Fund Approval of RAWP	4
• Obtain necessary drilling permits and utility clearances	6
• Complete procurement of subcontractor(s) for Remedial Well Installation and Pump Placement	7
• Begin drilling RW-1 of PHASE 1	8
• Complete drilling and pump installation state of PHASE 1	9
• Perform one-month startup observation of RW-1 for free product removal	10
• Complete one-month observation of RW-1 for free product removal	14
• Submit PHASE 1 Data Evaluation Report to ACHCSA concerning PHASE 1 fieldwork, monitoring results, conclusions, and recommendations.	17

Additional remedial wells RW-2 and RW-3 will be installed at this point of the remedial action if warranted by the continued significant presence of free product on the groundwater table. If free product removal has been completed by remedial well RW-1, the remedial action will proceed to PHASE 2, enhanced bioremediation of dissolved contaminants in groundwater.

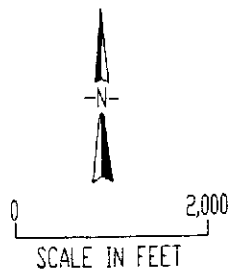
• Complete procurement of subcontractors for geoprobe advancement, ORC <sup>®</sup> slurry injection, and groundwater contaminant analyses	19
--------------------------------------------------------------------------------------------------------------------------------------------	----

- Begin PHASE 2, Geoprobe drilling and ORC\* slurry injection 22
- Complete PHASE 2 and remedial well RW-1 ORC\* conversion 26
- Perform monthly respirometry monitoring and submit results to ACHCSA 29
- Perform bi-monthly respirometry monitoring and submit results to ACHCSA 36
- Submit PHASE 2 Data Evaluation Report to ACHCSA concerning PHASE 2 monitoring results, conclusions, and recommendations for site closure based upon attaining MCL's or in accordance with RBCA methodology 40
- Perform and submit a health based risk assessment in accordance with RBCA methodology and recommendation for site closure. 44



LEGEND

REFERENCE: USGS 7.5 MINUTE  
 SERIES QUADRANGLE MAP  
 OAKLAND EAST, CALIFORNIA  
 PHOTOREVISED 1980

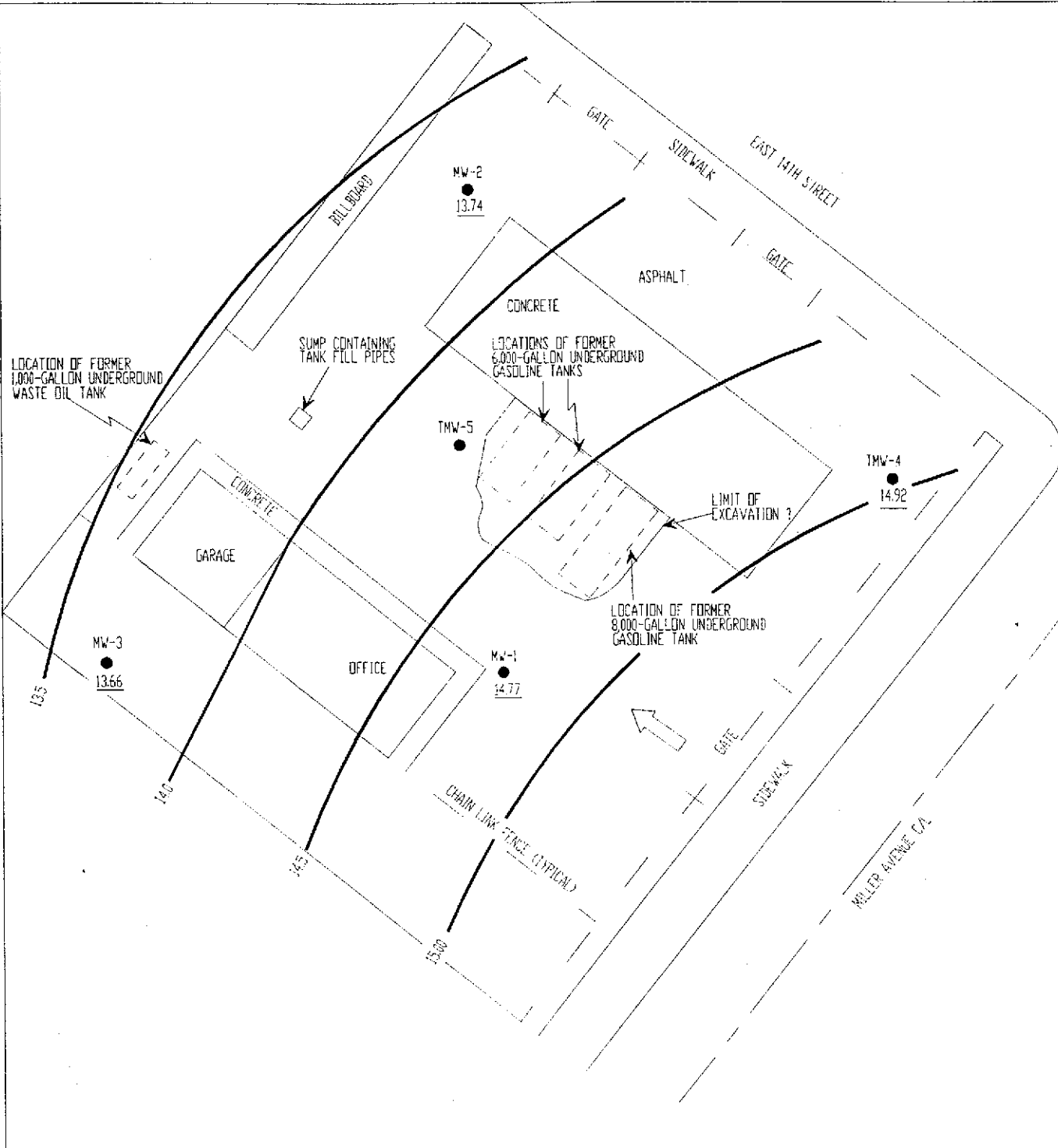


TANK PROTECT ENGINEERING

SITE VICINITY MAP

CREDIT WORLD AUTO SALES  
 2345 E. 14TH STREET  
 OAKLAND, CA 94601

DATE	5/21/97
FIGURE	1
FILE #	267-IN
DRAWN BY	VK
CHECKED BY	LNH



LEGEND

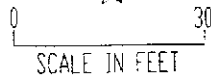
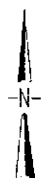
● TMW-4 NAME AND LOCATION OF MONITORING WELL INSTALLED BY TPE

● MW-1 NAME AND LOCATION OF MONITORING WELL INSTALLED BY OTHERS

14.77 POTENTIOMETRIC ELEVATION

—15.0 POTENTIOMETRIC CONTOUR

← GROUNDWATER FLOW DIRECTION

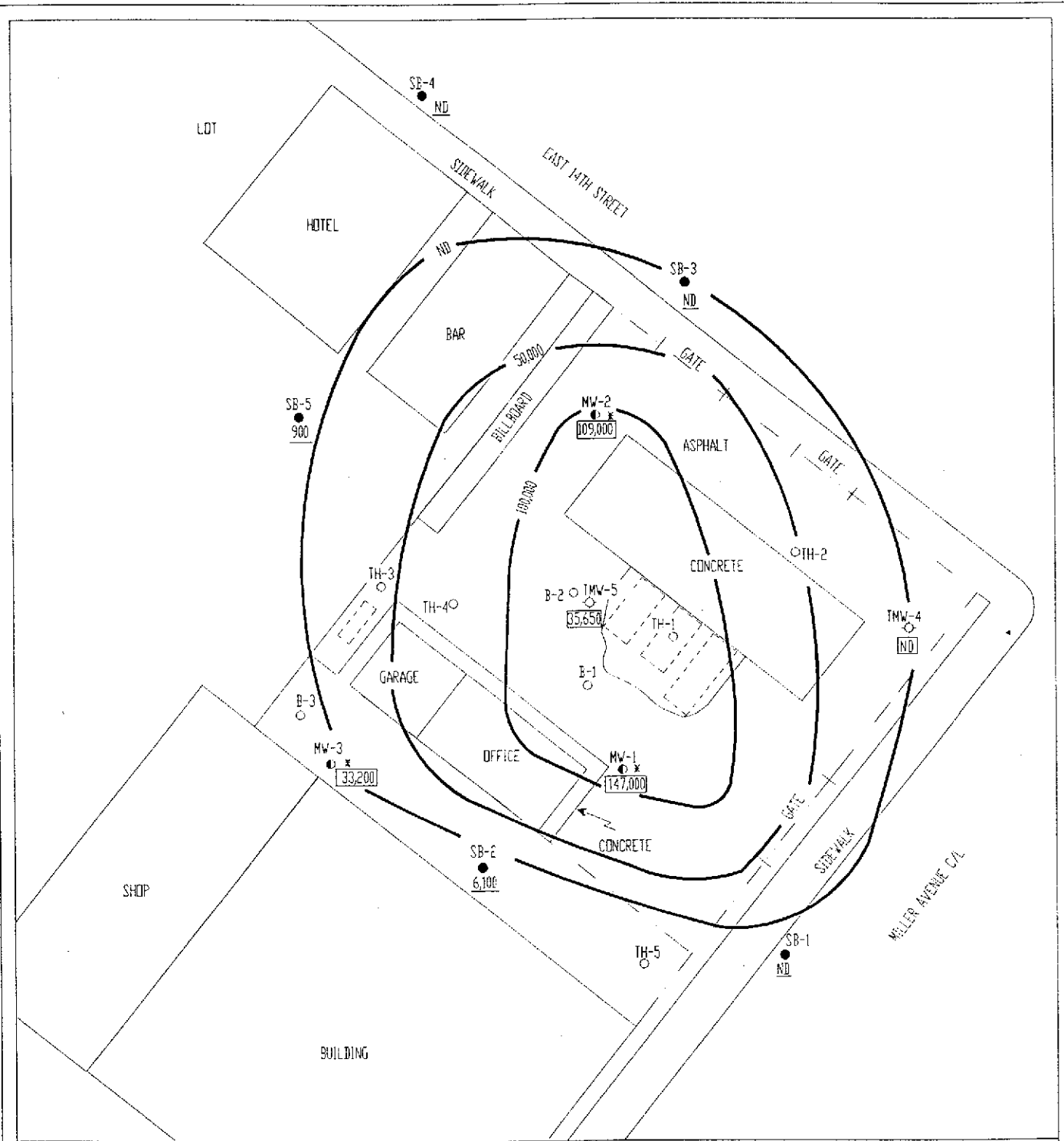


TANK PROTECT ENGINEERING

SITE PLAN:  
GROUNDWATER GRADIENT MAP (06/10/99)

CREDIT WORLD AUTO SALES  
2345 E. 14TH STREET  
DAKLAND, CA 94601

DATE	06/18/99
FIGURE	2
FILE #	267-1-T
DRAWN BY	VK
CHECKED BY	RD



**LEGEND**

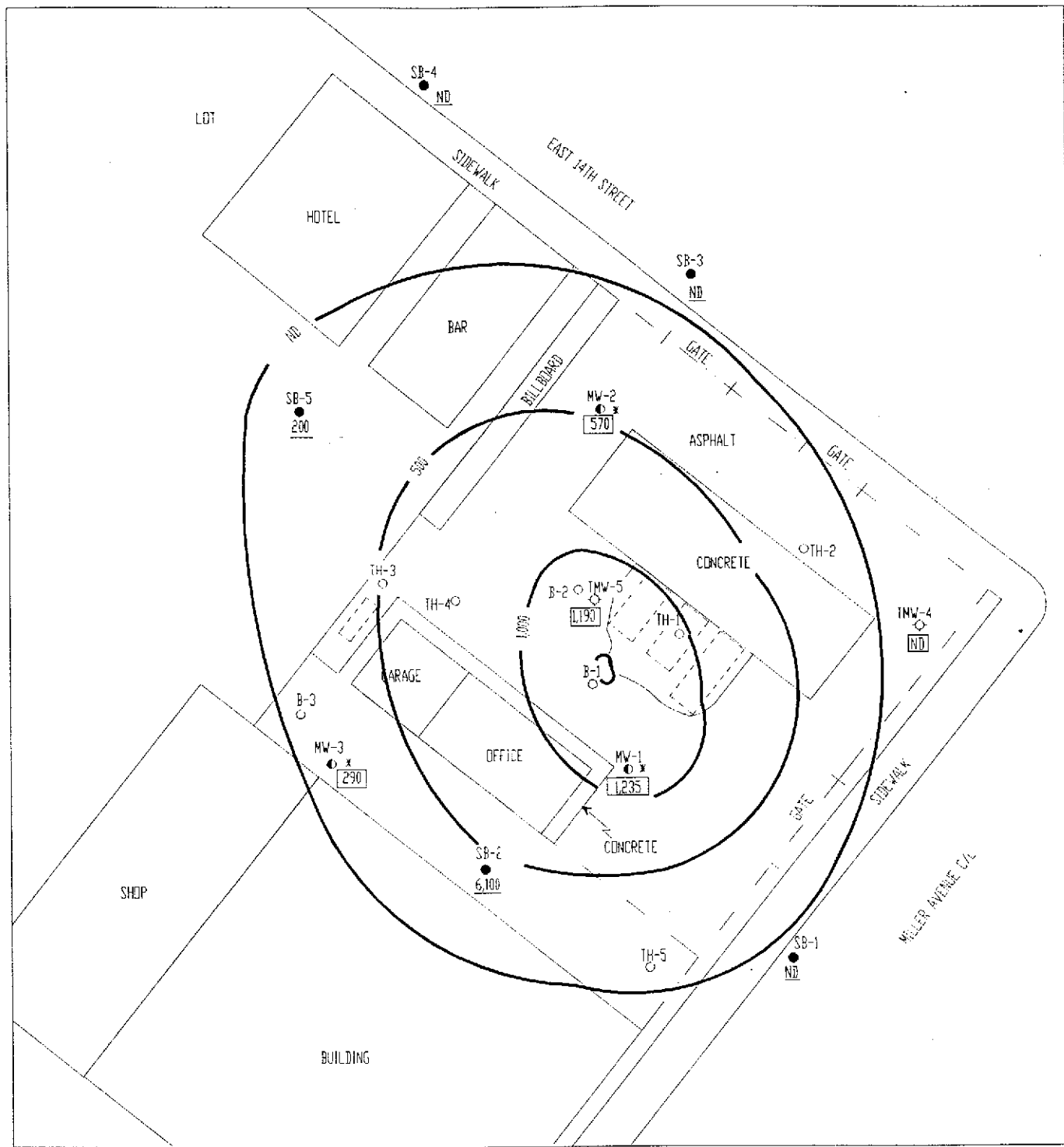
- MW-4** NAME AND LOCATION OF MONITORING WELL INSTALLED BY TPE
- MW-1** NAME AND LOCATION OF MONITORING WELL INSTALLED BY OTHERS
- B-1** NAME AND APPROXIMATE LOCATION OF SOIL BORING DRILLED BY OTHERS
- SB-1** LOCATION OF PROPOSED SOIL BORING
- LOCATION OF FORMER UNDERGROUND STORAGE TANK
- 1,700** CONCENTRATION (ppb)
- 5,000** CONCENTRATION CONTOUR
- 30,000** AVERAGE 12/10/98, 03/26/98, 06/11/99
- ND** NDN DETECTABLE

0 40  
SCALE IN FEET

**TANK PROTECT ENGINEERING**

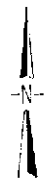
AVERAGE GROUNDWATER GASOLINE CONCENTRATION  
(03/26/98, 12/10/98, 06/11/99)

<b>CREDIT WORLD AUTO SALES</b>	DATE	09/14/99
2345 E. 14TH STREET	FIGURE	3
DAKLAND, CA 94601	FILE #	267-03T
	DRAWN BY	VK
	CHECKED BY	RD



LEGEND

- TMW-4 NAME AND LOCATION OF MONITORING WELL INSTALLED BY TPE
- MW-1 NAME AND LOCATION OF MONITORING WELL INSTALLED BY OTHERS
- B-1 NAME AND APPROXIMATE LOCATION OF SOIL BORING DRILLED BY OTHERS
- SB-1 LOCATION OF PROPOSED SOIL BORING
- LOCATION OF FORMER UNDERGROUND STORAGE TANK
- 1,700 CONCENTRATION (ppb)
- 30,000 CONCENTRATION CONTOUR
- AVERAGE 12/10/98, 03/26/98, 06/11/99
- ND NON DETECTABLE

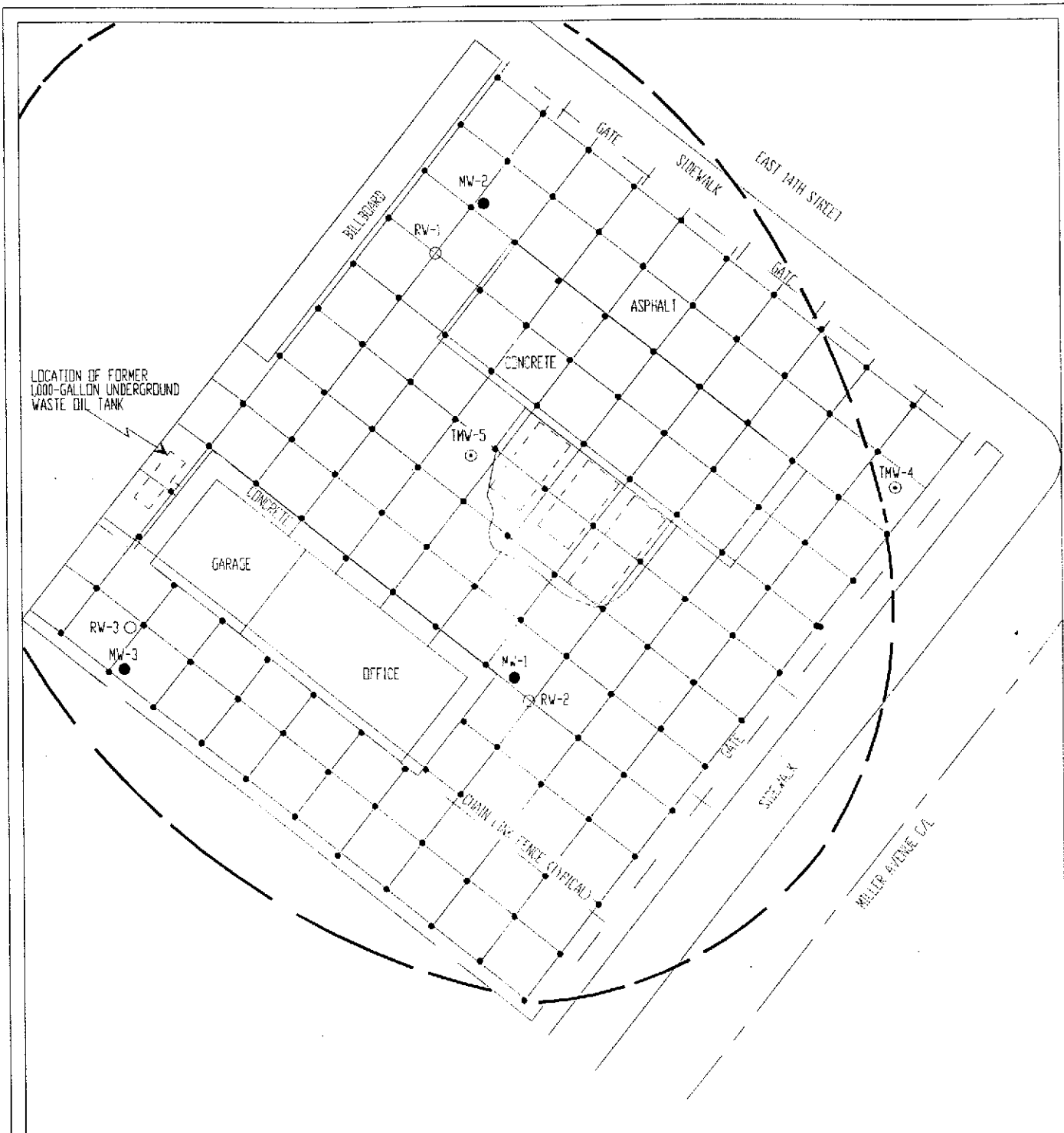


TANK PROTECT ENGINEERING

AVERAGE TOTAL BTEX, LAST 3 QUARTERLY EVENTS  
(03/26/98, 12/10/98, 06/11/99)

CREDIT WORLD AUTO SALES  
2345 E. 14TH STREET  
OAKLAND, CA 94601

DATE	09/14/99
FIGURE	4
FILE #	267-041
DRAWN BY	VK
CHECKED BY	RD



LEGEND

RW-1 PROPOSED REMEDIAL WELL (RW-2, RW-3 CONTINGENT)



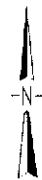
TMW-4 NAME AND LOCATION OF MONITORING WELL INSTALLED BY TPE



MW-1 NAME AND LOCATION OF MONITORING WELL INSTALLED BY OTHERS



• PROPOSED ORC GEOPROBE LOCATION



TANK PROTECT ENGINEERING

PROPOSED ORC GEOPROBE AND REMEDIAL WELL LOCATIONS

CREDIT WORLD AUTO SALES  
2345 E. 14TH STREET  
OAKLAND, CA 94601

DATE	09/14/99
FIGURE	5
FILE #	267-051
DRAWN BY	VK
CHECKED BY	RD

TABLE 1  
GROUNDWATER ELEVATION

Well Name	Date	TOC <sup>1</sup> Elevation (Feet MSL <sup>4</sup> )	Depth-to-Water From TOC (Feet)	Depth to Product From TOC (Feet)	Corrected <sup>3</sup> Groundwater Elevation (Feet MSL)
MW-1	08/23/91 <sup>5</sup>	100.00 <sup>2</sup>	15.42	NA <sup>9</sup>	84.58
	04/16/92 <sup>6</sup>	27.33 <sup>7</sup>	16.66	11.54	14.51 <sup>8</sup>
	06/11/93		12.61	12.60	14.73
	08/17/93		14.40	13.63	13.50 <sup>7</sup>
	03/31/94		12.64	ND	14.69
	06/27/94		14.32	13.16	13.88
	09/16/94		15.86	13.64	13.14
	03/31/95		11.82	9.48	17.27
	06/28/95		13.50	12.60	14.51
	09/28/95		14.27	13.96	13.29
	12/26/95		11.77	11.62	15.67
	03/22/96		10.52	10.44	16.87
	06/20/96		13.38	12.49	14.63
	09/24/96		14.60	13.40	13.63
	12/27/96		9.17	9.08	18.23
	03/06/97		12.35	ND	14.98
	06/28/97		10.93	10.60	16.65
	09/18/97		13.10	12.93	14.36
	12/30/97		10.96	10.79	16.50
	03/24/98		9.33	ND	18.00
06/29/98		12.20	ND	15.13	
10/02/98		13.46	ND	13.87	
12/10/98		10.49	ND	16.84	
03/26/99		9.44	ND	17.89	
06/11/99		12.56	12.55	14.77	
MW-2	08/23/91 <sup>5</sup>	98.585 <sup>2</sup>	13.77	NA	84.815
	04/16/92 <sup>6</sup>	25.92 <sup>7</sup>	15.38	12.57	12.65 <sup>8</sup>
	06/11/93		13.185	ND <sup>10</sup>	12.74



TABLE 1  
GROUNDWATER ELEVATION

Well Name	Date	TOC <sup>1</sup> Elevation (Feet MSL <sup>4</sup> )	Depth-to-Water From TOC (Feet)	Depth to Product From TOC (Feet)	Corrected <sup>3</sup> Groundwater Elevation (Feet MSL)
MW-2	08/17/93	25.92 <sup>7</sup>	14.04	14.03	11.89
	03/31/94		13.61	13.07	12.72 <sup>8</sup>
	06/27/94	25.92 <sup>7</sup>	14.24	13.44	12.28
	09/16/94		17.82	13.36	11.45
	03/31/95		16.72	9.28	14.78
	06/28/95		13.50	12.77	12.97
	09/28/95		14.63	14.09	11.70
	12/26/95		12.58	11.68	14.01
	03/22/96		11.46	11.31	14.57
	06/20/96		13.08	12.71	13.12
	09/30/96		16.67	12.92	12.06
	12/27/96		15.74	8.17	15.86
	03/06/97		12.55	ND	13.37
	06/28/97		11.98	11.94	13.97
	09/18/97		13.44	13.44	12.48
	12/30/97		11.31	ND	14.61
	03/25/98		10.02	ND	15.90
	06/29/98		11.96	ND	13.96
	10/02/98		13.74	ND	12.18
	12/10/98		12.91	10.81	14.58
	03/26/99		9.06	8.86	16.86
	06/11/99		12.18	ND	13.74
MW-3	08/23/91 <sup>5</sup>	99.25 <sup>2</sup>	15.07	NA	84.18
	04/16/92 <sup>6</sup>	27.57 <sup>7</sup>	14.14	13.98	13.55 <sup>8</sup>
	06/11/93		14.275	ND	13.30
	08/17/93		15.77	ND	11.80
	03/31/94		14.35	ND	13.22
	06/27/94		14.77	ND	12.80

TABLE 1  
GROUNDWATER ELEVATION

Well Name	Date	TOC <sup>1</sup> Elevation (Feet MSL <sup>4</sup> )	Depth-to-Water From TOC (Feet)	Depth to Product From TOC (Feet)	Corrected <sup>3</sup> Groundwater Elevation (Feet MSL)
MW-3	09/16/94	27.57 <sup>7</sup>	15.42	15.37	12.19
	03/31/95		12.98	12.52	14.94
	06/28/95		14.20	14.15	13.41
	09/28/95		15.17	ND	12.40
	12/26/95		13.33	13.27	14.28
	03/22/96		12.81	12.77	14.79
	06/20/96		13.95	13.88	13.67
	09/24/96		14.86	14.82	12.74
	12/27/96		11.04	10.98	16.58
	03/07/97		13.80	ND	13.77
	06/28/97		13.72	13.66	13.89
	09/18/97		14.76	ND	12.81
	12/30/97		12.97	ND	14.60
	03/24/98		11.75	ND	15.82
	06/29/98		13.38	ND	14.19
	10/02/98		14.42	ND	13.15
	12/08/98		12.55	ND	15.02
03/26/99		10.54	ND	17.03	
06/15/99		13.91	ND	13.66	
TMW-4	08/17/93	26.50 <sup>7</sup>	13.26	ND	13.24
	03/31/94		12.40	ND	14.10
	06/27/94		12.84	ND	13.66
	09/16/94		13.58	ND	12.92
	03/31/95		10.23	ND	16.27
	06/28/95		12.21	ND	14.29
	09/28/95		13.38	ND	13.12
12/26/95		11.32	ND	15.18	
03/22/96		10.54	ND	15.96	

TABLE 1  
GROUNDWATER ELEVATION

Well Name	Date	TOC <sup>1</sup> Elevation (Feet MSL <sup>4</sup> )	Depth-to-Water From TOC (Feet)	Depth to Product From TOC (Feet)	Corrected <sup>3</sup> Groundwater Elevation (Feet MSL)
TMW-4	06/20/96	26.50 <sup>7</sup>	12.14	ND	14.36
	09/24/96		13.01	ND	13.49
	12/27/96		9.51	ND	16.99
	03/07/97		11.92	ND	14.58
	06/28/97		10.70	ND	15.80
	09/18/97		12.94	ND	13.56
	12/30/97		10.92	ND	15.58
	03/25/98		9.60	ND	16.90
	06/29/98		11.32	ND	15.18
	10/02/98		12.56	ND	13.94
	12/08/98		10.44	ND	16.06
	03/26/99		9.38	ND	17.12
	06/15/99		11.58	ND	14.92
	TMW-5	08/17/93	26.51 <sup>7</sup>	12.98	12.95
03/31/94			11.39	ND	15.12
06/27/94			12.24	ND	13.53
09/16/94			13.02	12.97	13.53
03/31/95			7.38	ND	19.13
06/28/95			11.31	11.25	15.25
09/28/95			14.42	ND	12.09
12/26/95			10.16	10.11	16.38
03/22/96			7.59	7.54	18.96
06/26/96 <sup>11</sup>			7.12	ND	NA
09/30/96 <sup>11</sup>			7.42	ND <sup>10</sup>	NA <sup>9</sup>
12/27/96 <sup>11</sup>		6.38	ND	NA	
03/07/97 <sup>11</sup>		11.12	ND	NA	
08/17/93 <sup>11</sup>		12.98	12.95	13.55	
09/18/97 <sup>11</sup>		12	ND	---	

TABLE 1  
GROUNDWATER ELEVATION

Well Name	Date	TOC <sup>1</sup> Elevation (Feet MSL <sup>4</sup> )	Depth-to-Water From TOC (Feet)	Depth to Product From TOC (Feet)	Corrected <sup>3</sup> Groundwater Elevation (Feet MSL)
TMW-5	12/30/97 <sup>11</sup>	26.51 <sup>7</sup>	8.97	ND	---
	03/25/98 <sup>11</sup>		7.32	ND	---
	06/29/98 <sup>11</sup>		11.50	ND	---
	10/02/98 <sup>11</sup>		12.56	ND	---
	12/08/98 <sup>11</sup>		10.14	ND	---
	03/26/99		7.08	ND	---
	06/11/99		11.40	ND	---

<sup>1</sup> TOP-OF-CASING.

RELATIVE TO SITE DATUM ESTABLISHED BY ESE.

ELEVATION CORRECTED FOR FLOATING PRODUCT USING 0.75 DENSITY FOR GASOLINE.

<sup>4</sup> MEAN SEA LEVEL.

WATER LEVEL MEASUREMENTS BY ESE.

WATER LEVEL MEASUREMENTS BY NKJ.

<sup>7</sup> TOC SURVEYED 8/10/93 BY PROFESSIONAL ENGINEER.

CORRECTED GROUNDWATER ELEVATION BY TANK PROTECT ENGINEERING.

<sup>9</sup> NOT AVAILABLE.

<sup>10</sup> NOT DETECTED.

<sup>11</sup> WELL TOP DESTROYED DURING REMEDIATION, UNSURVEYED

<sup>12</sup> NOT MEASURED - WELL OBSTRUCTED

TABLE 2  
GROUNDWATER GRADIENTS, FLOW DIRECTIONS,  
AND ELEVATION DATA

Date	Average Groundwater Elevation (Feet-MSL <sup>1</sup> )	Change in Average Groundwater Elevation (Feet)	Groundwater Gradient	Groundwater Flow Direction
04/16/92	13.57	---	.021	NW
06/11/93	13.59	0.02	.026	NW
08/17/93	12.80	-0.79	.029	RADIAL
03/31/94	13.97	+1.17	.050	RADIAL
06/27/94	13.38	-0.59	.020	RADIAL
09/16/94	12.65	-0.73	.0179-.0411	RADIAL
03/31/95	16.48	+3.83	.075	RADIAL
06/28/95	14.09	-2.39	.025-.053	RADIAL
09/28/95	12.52	-1.57	.025	NW
12/26/95	15.09	+2.57	.048	RADIAL
03/22/96	16.23	+1.14	.034-.132	RADIAL
06/20/96 <sup>2</sup>	13.95	-2.28	.016	NW
09/30/96 <sup>2</sup>	12.98	-0.97	.019	NW
12/27/96 <sup>2</sup>	16.41	+3.43	.024-.029	N-NW
03/07/97 <sup>2</sup>	14.18	-2.23	.020-.035	N-NW
06/28/97 <sup>2</sup>	15.07	+.89	.027-.04	NW
09/18/97 <sup>2</sup>	13.30	-1.77	.02-.026	RADIAL
12/30/97 <sup>2</sup>	15.32	+2.02	.025-.030	N-NW
03/25/98 <sup>2</sup>	16.65	+1.34	.021-.033	RADIAL
06/29/98 <sup>2</sup>	14.69	-1.96	.013-.019	NW
10/02/98 <sup>2</sup>	13.35	-1.34	.011-.019	NW
12/08/98 <sup>2</sup>	15.77	+2.42	0.23	NW
03/26/99	17.225	+1.455	0.01	N-NW
06/15/99	14.27	-2.95	0.01	NW

<sup>1</sup> MEAN SEA LEVEL.

<sup>2</sup> DOES NOT INCLUDE DATA FOR TMW-5; WELL TOP DESTROYED DURING REMEDIATION ACTIVITIES.

TABLE 3  
SUMMARY OF FLOATING PRODUCT THICKNESS

Well Name	Date	Depth-to-Water From TOC <sup>1</sup> (Feet)	Depth-to-Product From TOC (Feet)	Product Thickness (Feet)
MW-1	04/16/92 <sup>2</sup>	16.66	11.54	5.12
	06/11/93	12.61	12.60	0.01
	08/17/93	14.40	13.63	0.77
	03/31/94	12.64	ND	---
	06/27/94	14.32	13.16	1.16
	09/16/94	15.86	13.64	2.22
	03/31/95	11.82	9.48	2.34
	06/28/95	13.50	12.60	0.90
	09/28/95	14.27	13.96	0.31
	12/26/95	11.77	11.62	0.15
	03/22/96	10.52	10.44	0.08
	06/20/96	13.38	12.49	0.089
	09/24/96	14.60	13.40	1.20
	12/27/96	9.17	9.08	0.09
	03/06/97	12.35	ND	---
	06/28/97	10.93	10.60	0.33
	09/18/97*	13.10	12.93	.17
	12/30/97	10.96	10.79	0.17
	03/24/98	9.33	ND	---
	06/29/98	12.20	11.78	0.42
	10/02/98	13.46	13.21	0.25
	12/08/98	10.49	ND	---
	03/26/99	9.44	ND	---
	06/11/99	12.56	12.55	0.005
MW-2	04/16/92 <sup>2</sup>	15.38	12.57	2.81
	06/11/93	13.185	ND <sup>3</sup>	---
	08/17/93	14.04	14.03	0.01
	03/31/94	13.61	13.07	0.54

TABLE 3  
SUMMARY OF FLOATING PRODUCT THICKNESS

Well Name	Date	Depth-to-Water From TOC <sup>1</sup> (Feet)	Depth-to-Product From TOC (Feet)	Product Thickness (Feet)
MW-2	06/27/94	14.24	13.44	0.80
	09/16/94	17.82	13.36	4.46
	03/31/95	16.72	9.28	7.44
	06/28/95	13.50	12.77	0.73
	09/28/95	14.63	14.09	0.54
	12/26/95	12.58	11.68	0.90
	03/22/96	11.46	11.31	0.15
	06/20/96	13.08	12.71	0.37
	09/30/96	16.67	12.92	3.75
	12/27/96	15.74	8.17	7.57
	03/06/97	12.55	ND	---
	06/28/97	11.98	11.94	0.04
	09/18/97*	13.44	13.44	TRACE
	12/30/97	11.31	ND	---
	03/25/98	10.02	ND	---
	06/29/98	11.96	ND	---
	10/02/98	13.74	13.55	.187
	12/08/98	12.91	10.81	2.1
	03/26/99	9.06	8.86	0.20
	06/15/99	12.18	ND	---
MW-3	04/16/92 <sup>2</sup>	14.14	13.98	0.16
	06/11/93	14.275	ND	---
	08/17/93	15.77	ND	---
	03/31/94	14.35	ND	---
	06/27/94	14.77	ND	---
	09/16/94	15.42	15.37	---
	03/31/95	12.98	12.52	0.46
	06/28/95	14.20	14.15	0.05

TABLE 3  
SUMMARY OF FLOATING PRODUCT THICKNESS

Well Name	Date	Depth-to-Water From TOC <sup>1</sup> (Feet)	Depth-to-Product From TOC (Feet)	Product Thickness (Feet)
MW-3	09/29/95	15.7	ND	---
	12/26/95	13.33	13.27	0.06
	03/22/96	12.81	12.77	0.04
	06/20/96	13.95	13.88	0.07
	09/24/96	14.86	14.82	0.04
	12/27/96	11.04	10.98	0.06
	03/07/97	13.80	ND	---
	06/28/97	13.72	13.66	---
	09/18/97	14.76	ND	---
	12/30/97	12.97	ND	---
	03/24/98	11.75	ND	---
	06/29/98	13.38	ND	---
	10/02/98	14.42	ND	---
	12/08/98	12.55	ND	---
	03/26/99	10.54	ND	---
	06/15/99	13.91	ND	---
TMW-4	08/17/93	13.26	ND	---
	03/31/94	12.40	ND	---
	06/27/94	12.84	ND	---
	09/16/94	13.58	ND	---
	03/31/95	10.23	ND	---
	06/28/95	12.21	ND	---
	09/28/95	13.38	ND	---
	12/26/95	11.32	ND	---
	03/22/96	10.54	ND	---
	06/20/96	12.14	ND	---
	09/24/96	13.01	ND	---
	12/27/96	9.51	ND	---



TABLE 3  
SUMMARY OF FLOATING PRODUCT THICKNESS

Well Name	Date	Depth-to-Water From TOC <sup>1</sup> (Feet)	Depth-to-Product From TOC (Feet)	Product Thickness (Feet)
TMW-4	03/07/97	11.92	ND	---
	06/28/97	10.70	ND	---
	09/18/97*	12.94	ND	---
	12/30/97	10.92	ND	---
	03/25/98	9.60	ND	---
	06/29/98	11.32	ND	---
	10/02/98	12.56	ND	---
	12/08/98	10.44	ND	---
	03/26/99	9.38	ND	---
	06/15/99	11.58	ND	---
	TMW-5	08/17/93	12.98	12.95
03/31/94		11.39	ND	---
06/27/94		12.24	ND	---
09/16/94		13.02	12.97	0.05
03/31/95		7.38	ND	---
06/28/95		11.31	11.25	0.06
09/28/95		14.42	ND	---
12/26/95		10.16	10.11	0.05
03/22/96		7.59	7.54	0.05
06/20/96 <sup>11</sup>		7.12	ND	---
09/30/96 <sup>11</sup>		7.42	ND	---
12/27/96 <sup>11</sup>		6.38	ND	---
03/07/97 <sup>11</sup>		11.12	ND	---
06/28/97 <sup>12</sup>		NM <sup>12</sup>	ND <sup>12</sup>	---
09/18/97*		12.00	ND	---
12/30/97		8.97	ND	---
03/25/98	7.32	ND	---	

TABLE 3  
SUMMARY OF FLOATING PRODUCT THICKNESS

Well Name	Date	Depth-to-Water From TOC <sup>1</sup> (Feet)	Depth-to-Product From TOC (Feet)	Product Thickness (Feet)
TMW-5	06/29/98	11.50	ND	---
	10/02/98	12.56	ND	---
	12/08/98	10.14	ND	---
TMW-5	12/08/98	10.14	ND	---
	03/26/99	7.08	ND	---
	06/11/99	11.40	ND	---

<sup>1</sup> TOP-OF-CASING.

<sup>2</sup> RELATIVE TO SITE DATUM ESTABLISHED BY ESE.

ELEVATION CORRECTED FOR FLOATING PRODUCT USING 0.75 DENSITY FOR GASOLINE.

<sup>4</sup> MEAN SEA LEVEL

<sup>5</sup> WATER LEVEL MEASUREMENTS BY ESE.

<sup>6</sup> WATER LEVEL MEASUREMENTS BY NKJ.

<sup>7</sup> TOC SURVEYED 8/10/93 BY PROFESSIONAL ENGINEER.

<sup>8</sup> CORRECTED GROUNDWATER ELEVATION BY TANK PROTECT ENGINEERING.

<sup>9</sup> NOT AVAILABLE.

<sup>10</sup> NOT DETECTED.

<sup>11</sup> WELL TOP DESTROYED DURING REMEDIATION

<sup>12</sup> NOT MEASURED - WELL OBSTRUCTED

\* VISUAL MEASUREMENTS FROM BAILER

TABLE 4  
SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS  
(ppb<sup>1</sup>)

Sample ID Name	Date	TPHG	Methyl t-Butyl Ether	Benzene	Toluene	Ethyl-benzene	Xylenes
MW-1	08/17/93	110,000	NA <sup>2</sup>	270	690	730	3,100
	03/28/94	34,000	NA	4,900	1,800	1,200	4,000
	06/27/94	21,000	NA	12,000	810	760	2,500
	09/16/94	37,000	NA	7,900	2,400	1,300	3,300
	03/31/95	43,000	NA	8,100	1,900	1,000	4,200
	06/28/95	80,000	NA	7,900	3,200	1,800	7,300
	09/28/95	24,000	<1,200	4,900	470	470	1,700
	12/26/95	61,000	<1,200	12,000	4,200	1,500	5,500
	03/22/96	19,000	<2,500	6,000	47	260	<750
	06/20/96	15,000	910	2,900	100	240	98
	09/24/96	20,000	340	4,800	220	300	770
	12/27/96	24,000	<5.0	5,900	440	310	740
	03/07/97	30,000	<5.0	5,700	370	290	780
	06/28/97	54,000	<5.0	5,200	1,300	1,000	4,900
	09/18/97	54,000	<5.0	5,300	1,200	1,100	4,600
	12/30/97	61,000	1,400	4,300	1,800	1,600	6,900
	03/24/98	24,000	2,000	1,000	1,000	1,300	4,300
	06/29/98	130,000	3,300	3,800	370	1,200	4,200
	10/02/98	22,000	<0.50	66	21	26	140
	12/10/98	32,000	<250	4,600	970	1,700	4,900
	03/26/99	230,000	<0.50	370	290	280	720
	06/11/99	180,000	<0.50	210	170	220	400
MW-2	08/17/93	49,000	NA	94	240	250	980
	03/28/94	14,000	NA	4,200	<250	910	1,400
	06/27/94	24,000	NA	4,400	72	1,100	1,700
	09/16/94	40,000	NA	2,300	250	2,000	4,100
	03/31/95	28,000	NA	4,000	<120	1,100	1,400
	06/28/95	40,000	NA	2,700	130	1,700	2,900

TABLE 4  
SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS  
(ppb<sup>1</sup>)

Sample ID Name	Date	TPHG	Methyl t-butyl ether	Benzene	Toluene	Ethylbenzene	Xylenes
MW-2	09/28/95	7,500	< 62	420	14	250	190
	12/26/95	22,000	< 250	1,300	88	950	1,800
	03/22/96	9,800	< 1,200	2,200	< 120	400	< 380
	06/20/96	35,000	550	770	< 0.50	240	< 0.50
	09/30/96	58,000	< 5.0	1,600	230	2,200	4,000
	12/27/96	29,000	< 5.0	2,100	< 0.50	1,200	1,800
	03/07/97	13,000	< 5.0	1,300	37	290	180
	06/28/97	12,000	< 5.0	840	< 0.50	640	360
	09/18/97	12,000	< 5.0	680	< 0.50	320	84
	12/30/97	13,000	< 5.0	1,100	40	350	220
	03/25/98	8,100	670	1,300	51	410	230
	06/29/98	12,000	430	880	13	180	72
	10/02/98	47,000	< 0.50	140	100	110	200
	12/10/98	26,000	< 1,000	1,000	210	1,500	1,900
	03/26/99	110,000	< 0.50	190	150	120	380
	06/11/99	190,000	< 0.50	310	250	320	540
MW-3	08/17/93	9,600	NA	4.1	17	28	54
	03/28/94	8,400	NA	2,400	56	67	200
	06/27/94	9,900	NA	3,300	< 22	< 25	73
	09/16/94	16,000	NA	2,300	80	620	240
	03/31/95	16,000	NA	2,800	70	< 25	920
	06/28/95	11,000	NA	2,300	32	81	240
	09/28/95	6,300	< 420	1,900	< 42	200	< 120
	12/26/95	25,000	< 250	3,800	97	94	1,600
	03/22/96	16,000	250	3,100	75	69	350
	06/20/96	8,500	220	1,400	28	140	15
	09/24/96	12,000	< 5.0	2,400	87	340	110
	12/27/96	5,800	240	1,700	28	< 0.50	42
	03/10/97	9,000	< 5.0	1,700	< 0.50	110	< 0.50
	06/28/97	15,000	< 5.0	2,200	< 0.50	160	190

TABLE 4  
SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS  
(ppb<sup>1</sup>)

Sample ID Name	Date	TPHG	Methyl t-butyl ether	Benzene	Toluene	Ethyl-benzene	Xylenes
MW-3	09/18/97	28,000	<5.0	3,800	<0.50	100	<0.50
	12/30/97	21,000	300	2,200	<0.50	31	<0.50
	03/24/98	2,300	85	870	7.2	20	<0.50
	06/29/98	6,500	140	1,300	12	62	14
	10/02/98	11,000	<0.50	31	27	35	69
	12/10/98	<2,500	<250	2,800	68	42	55
	03/26/99	10,000	<0.50	21	14	10	41
	06/15/99	87,000	<0.50	90	71	92	180
TMW-4	03/28/94	<50	NA	<0.50	<0.50	<0.50	<1.5
	06/27/94	<50	NA	<0.50	<0.50	<0.50	<1.5
	09/16/94	<50	NA	<0.50	<0.50	<0.50	<1.5
	03/31/95	<50	NA	<0.50	<0.50	<0.50	<1.5
	06/28/95	<50	NA	<0.50	<0.50	<0.50	<1.5
	09/28/95	<50	<5.0	<0.50	<0.50	<0.50	<1.5
	12/26/95	<50	<5.0	<0.50	<0.50	<0.50	<1.5
	03/22/96	<50	<5.0	<0.50	<0.50	<0.50	<1.5
	06/20/96	<50	<5.0	<0.50	<0.50	<0.50	<0.50
	09/24/96	<50	<5.0	<0.50	<0.50	<0.50	<0.50
	12/27/96	<50	<5.0	<0.50	<0.50	<0.50	<0.50
	03/10/97	<50	<5.0	<0.50	<0.50	<0.50	<0.50
	06/27/97	<50	<5.0	<0.50	<0.50	<0.50	<0.50
	09/18/97	<50	<5.0	<0.50	<0.50	<0.50	<0.50
	12/30/97	<50	<5.0	<0.50	<0.50	<0.50	<0.50
	03/25/98	<50	<5.0	<0.50	<0.50	<0.50	<0.50
06/29/98	<50	<5.0	<0.50	<0.50	<0.50	<0.50	
10/02/98	<50	<0.50	<0.50	<0.50	<0.50	<0.50	
12/10/98	<50	<5.0	<0.50	<0.50	<0.50	<0.50	
03/26/99	<50	<0.50	<0.50	<0.50	<0.50	<0.50	
06/15/99	<50	<0.50	<0.50	<0.50	<0.50	<0.50	
TMW-5	08/17/93	120,000	NA	640	730	790	3,600

TABLE 4  
SUMMARY OF GROUNDWATER SAMPLE ANALYTICAL RESULTS  
(ppb<sup>1</sup>)

Sample ID Name	Date	TPHG	Methyl t-butyl ether	Benzene	Toluene	Ethyl-benzene	Xylenes
TMW-5	03/28/94	70,000	NA	23,000	1,500	4,100	15,000
	06/28/94	56,000	NA	26,000	940	5,500	26,000
	09/16/94	96,000	NA	17,000	720	3,500	12,000
	03/31/95	64,000	NA	13,000	470	3,500	6,100
	06/28/95	65,000	NA	9,000	240	2,600	5,300
	09/28/95	79,000	<1,200	17,000	1,800	2,700	7,000
	12/26/95	110,000	<1,200	11,000	800	2,300	4,500
	06/26/96	30,000	830	4,000	180	1,500	2,500
	09/30/96	6,900	<5.0	1,600	79	130	370
	12/27/96	78,000	<5.0	12,000	1,900	2,900	9,700
	03/10/97	84,000	<5.0	9,900	1,100	2,600	8,800
	06/28/97	NA	NA	NA	NA	NA	NA
	09/18/97	65,000	<5.0	8,000	<0.5	2,000	4,700
	12/30/97	79,000	<5.0	6,400	340	2,300	5,500
	03/25/98	20,000	2,400	6,000	260	2,700	5,800
	10/08/98	46,000	<0.50	120	98	120	240
	12/10/98	46,000	<1,200	5,900	320	2,200	5,400
	03/26/99	35,000	<0.50	69	61	37	120
	06/11/99	26,000	<0.50	29	32	43	72
TMW-6	09/18/97 <sup>3</sup>	<50.0	<5.0	<0.5	<0.5	<0.5	<0.5
	12/30/97 <sup>3</sup>	<50.0	<5.0	<0.5	<0.5	<0.5	<0.5
	03/25/98 <sup>3</sup>	<50.0	<5.0	<0.5	<0.5	<0.5	<0.5
	06/29/98 <sup>3</sup>	<50.0	<5.0	<0.5	<0.5	<0.5	<0.5
	10/02/98 <sup>3</sup>	NA	NA	NA	NA	NA	NA
	12/10/98 <sup>3</sup>	NA	NA	NA	NA	NA	NA
	03/26/99 <sup>3</sup>	<50	<0.50	<0.05	<0.50	<0.50	<0.50
	06/15/99 <sup>3</sup>	<50	<0.50	<0.50	<0.50	<0.50	<0.50

<sup>1</sup> PARTS PER BILLION.<sup>2</sup> NOT ANALYZED.<sup>3</sup> TRIP BLANKS.

TABLE 5  
COMPARISON SUMMARY OF REMEDIAL OPTIONS FOR GASOLINE RESIDUALS  
CREDIT WORLD AUTO SALES, 2345 E. 14TH STREET, OAKLAND

COMPONENT	OPTION 1 GROUNDWATER MONITORING AND INTRINSIC BIOREMEDIATION	OPTION 2 REMEDIAL WELL/ORC- ENHANCED BIOREMEDIATION	OPTION 3 REMEDIAL TRENCH	OPTION 4 PUMP & TREAT + REINJECTION
Yearly Cost to Closure	\$8,000-\$12,000	\$80,000-\$120,000	\$100,000-\$150,000	\$50,000-\$100,000
Total Cost <sup>1</sup> (Closure= 5 Yrs.)	\$40,000-\$60,000	\$80,000-\$120,000(Closure in one year)	\$500,000-\$750,000	\$250,000-\$500,000
Technical Feasibility	Limited positive anaerobic parameters: Limited dissolved oxygen. Does not achieve reduction in groundwater concentration or the goal of source removal	Proven case histories with significantly accelerated biodegradation	Engineering feasibility and cost associated with excavation, disposal, dewatering, and construction make this option less desirable	Case histories in California show that very few sites have attained closure using this option. ACHCSA also has commented that groundwater extraction is not recommended, as it has proven not to be cost effective.
Redevelopment Issues	Fully compatible	Fully compatible	Space and noise conflicts from on-grade system	Space and noise conflicts from on-grade system
Fund Position <sup>2</sup>	Has lowest initial cost but not viable based upon past concentration trends and the continued observation of floating product	Full acceptance since most cost-effective overall and final results are most immediate	Will not approve since not cost-effective	Will not approve since not cost-effective
SUMMARY	Appears not be working. This option may be very slow approach, not viable solution, or cost effective over the long term.	Best, most cost-effective option for timely remediation within one-year period.	Significant disposal and fuel control issues. Not long-term cost-effective.	Inefficiency concerns and not cost-effective over the long term anticipated for remediation.

<sup>1</sup> Estimates are preliminary and for general purposes only. Cost ranges primarily reflect range of time needed for remediation. Cost are in today's dollars without present value adjustment.

<sup>2</sup> Underground Storage Tank Cleanup Fund- State program for reimbursing remedial costs funded by fuel taxes. The program has a number of conditions including approval of costs as reasonably necessary and cost-effective. Remedial option to be implemented also requires ACHCSA approval.

TABLE 6  
MEASUREMENT OF BASELINE PARAMETERS

Well Name	Alkalinity	Nitrate	Sulfate	Ferrous Iron	RedOx Potential	Dissolved Oxygen
MW-1	800	<0.10	<0.10	<0.01	80	0.89
MW-2	740	<0.10	<0.10	<0.01	120	1.04
MW-3	770	<0.10	<0.10	<0.01	90	1.82
TMW-4	430	<0.10	<0.10	<0.01	240	1.34
TMW-5	1,000	<0.10	<0.10	<0.01	70	0.99



APPENDIX A

QED FERRET™ PUMP DATA SHEETS



## Ferret™ In-Well Separators: Free Product Recovery -- from QED



*New system recovers floating hydrocarbons without water -- and without hydrophobic screens -- guaranteed.*

Ferret™ In-Well Separators from QED deliver the 100% product-only recovery you've been waiting for. Unlike any other system, they actively draw in water and free product, but reject the water downwell, sending only product to the surface.

Ferret models fit wells as small as 2", and recover a broad range of light hydrocarbons... gasoline, diesel, JP4, #2 and #3 fuel oil, and more. Floating and fixed-inlet versions are available with performance characteristics to match your application.

### RBCA-Ready Remediation

With Ferret systems, you get the gasoline and the sheen, leaving no free product in your wells. This makes it an ideal RBCA (Risk Based Corrective Action) cleanup method.

- \* No water pumping or discharge permits.
- \* No contaminated water disposal costs.
- \* No oil/water separators, strippers, or carbon.

### Ferret In-Well Separator Benefits

- Recover up to 300 gallons (1137 liters) of free product per day — without water.
- Low-maintenance automatic system: no controller to adjust or hydrophobic screen to

### Avoid the drawbacks of hydrophobic screens

If you've tried and been dissatisfied with other devices, the Ferret system is for you -- designed without hydrophobic screens, to ensure reliable, trouble-free operation with extremely low maintenance.

The hydrophobic inlet screens used in other devices are often blinded by particulates, scum and bio-growth, slowing product recovery rates to a trickle. They are also prone to let water through if they are even slightly submerged or their special surface coatings are altered by inorganics or contaminants in the well. In either case, site cleanup goals are missed and costs go up.

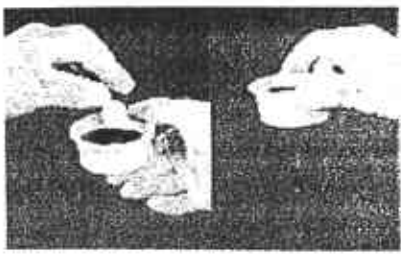
### True automatic operation

The automatic Ferret pump has no factory preset internal timers, above-well controllers, downwell probes or level sensors. It responds to changes in well conditions, delivering optimum performance without requiring attention.

Call the leaders in innovative remediation. Find out how simple it can be to specify, purchase, and operate a Ferret system--and end your product recovery problems forever.

## HOW THEY WORK

### *Ferret In-Well Separators*



**FREE TEST KIT**  
*Two simple, do-it-yourself tests with this free test kit show if your product density and viscosity are compatible with Ferret recovery. The kit comes with full, easy-to-follow instructions; call or e-mail QED today for yours.*

### A unique recovery approach

Previous technologies have tried recovery with various attempts to exclude water from the pump or collector inlet. Hydrophobic screens and floating inlets are the main examples. Unfortunately, field performance of these devices has often been disappointing.

Unlike these devices, the Ferret process actively draws in water, as well as free and dispersed product. The inward pull causes water and product to move toward the Ferret inlet, enhancing recovery.

Once the product/water mixture is taken inside the Ferret inlet, separation takes place; specific gravity is used to split the product and water into separate pumping paths.

**matic system: no controller to adjust or hydrophobic screen to clean.**

- **Reduces treatment costs — no oil/water separators, air strippers, or carbon required.**
- **Guaranteed to work if your product passes a simple do-it-yourself test.**

**Basic sequence of operation**

**Refill Cycle** -- As the Ferret body fills, hydrocarbon droplets separate from the water, float to the top and coalesce.

**Water Discharge** -- When the Ferret is full, the rising internal float triggers the air drive mechanism, and compressed air enters the pump. The discharge check ball floats in water and doesn't seat while water is present, allowing it to be forced out and back into the well.


**Product Discharge** -- When the discharge check ball is immersed in product, it sinks and seats, diverting product into the discharge line to the surface. When the float falls, it shuts off the air and starts the next refill cycle.

**FERRET IN-WELL SEPARATOR SPECIFICATIONS**

	<b>STANDARD FERRET</b>	<b>SHORT FERRET</b>
<b>Model No.</b>	IWS26 (2" wells)	IWS46 (w/4" well adapter)
<b>Overall Length</b>	72" (183 cm)	50" (127 cm)
<b>O.D.</b>	1.75" (45 mm)	1.75" (45 mm)
<b>Min. Well Diameter</b>	2" (50 mm) or larger	2" (50 mm) or larger
<b>Inlet Port</b>	60" (152 cm) above bottom of device	Stationary
<b>Inlet Type</b>	Floating, 12" (31 cm) range	45" (114 cm) above bottom of device
<b>Materials</b>	Stainless steel, brass, Delrin, Teflon®, and epoxy, with O-rings made of Viton® and Tygon tubing	Stainless steel, brass, Delrin, polypropylene, epoxy, with O-rings made of Viton®
<b>Fittings:</b>		
<b>Type</b>	Brass Compression	Brass Compression
<b>Sizes:</b>		
<b>Discharge</b>	1/2" (13 mm)	1/2" (13 mm)
<b>Exhaust</b>	3/8" (9 mm)	3/8" (9 mm)
<b>Air Supply</b>	1/4" (6 mm)	1/4" (6 mm)
<b>Level Gauge</b>	1/4" (6 mm)	1/4" (6 mm)
<b>Max. Flow Rate</b>	Up to 100 GPD (379 LPD) possible with 6" (15 cm) or more of product submergence over inlet. Rate will vary depending on conditions.	Up to 300 GPD (1137 LPD) possible with 6" (15 cm) or more of product submergence over inlet. Rate will vary depending on conditions.
<b>Discharge Amount</b>	Maximum product volume per cycle 0 - 0.07 gal (250 ml), varies with how much water enters and is expelled by the separator. <b>THE IN-WELL SEPARATOR WILL ONLY DISCHARGE PRODUCT TO THE SURFACE.</b>	Maximum product volume per cycle 0 - 0.07 gal (250 ml), varies with how much water enters and is expelled by the separator. <b>THE IN-WELL SEPARATOR WILL ONLY DISCHARGE PRODUCT TO THE SURFACE.</b>
<b>Oper. Pressure Range</b>	50 - 100 psi (350 - 700 kPa)	50 - 100 psi (350 - 700 kPa)
<b>Estimated Air Flow</b>	0.5 - 1.0 SCFM (0.85 - 1.7 m <sup>3</sup> /h) @ 50psi (350kPa)	0.5 - 1.0 SCFM (0.85 - 1.7 m <sup>3</sup> /h) @ 50psi (350kPa)
<b>Maximum Lift</b>	200 ft. (60 m)	150 ft. (45 m)
<b>Product</b>	0.7 - 0.9 g/cc	0.7 - 0.9 g/cc

<b>Pumped Den.</b>		
<b>Viscosity Range</b>	Recommended for liquids with kinematic viscosities less than 4 centistokes @ 55 degrees F (13 degrees C). Compatible liquids include fresh gasoline, JP4, JP5, kerosene, diesel fuel, #2 fuel oil. Incompatible liquids include #3 (and above) fuel oil, SAE 10 (and above) motor oil, and hydraulic fluids.	Recommended for liquids with kinematic viscosities less than 40 centistokes. Compatible liquids: same as standard Ferret, plus #3 fuel oil and weathered diesel.
<b>Solvent Compatibility</b>	The Tygon tubing is compatible with most hydrocarbon fuels, but may be attacked by high concentrations of MEK, acetone, other ketones, and some alcohols -- consult QED.	The short Ferret doesn't use Tygon tubing, so solvent compatibility should not be a concern in most cases.

## FERRET JACKETED TUBING



QED's exclusive Jacketed Tubing, with a continuous nylon sheath, helps prevent hangups and loops, makes installation easier (especially in narrow or obstructed casing), and is lightweight with exceptional chemical resistance, outside and in.

Tubing sets are supplied cut to custom lengths. Jacketed tubing and sheath are both Nylon 12, which doesn't swell in water and provides excellent resistance to most liquids and cleanup conditions, including hydrocarbons, fuels, and alkalies. For extremes of acidity, consult QED for alternatives. The MINTUBE set, with three tubes, is standard for both Ferret models.

<b>Model</b>	<b>MINTUBE</b>
<b>Description</b>	Set for 2"(50 mm) well pumps contains three tubes
<b>Discharge O.D.</b>	1/2" (13 mm)
<b>Air Supply O.D.</b>	3/8" (9 mm)
<b>Unused O.D.</b>	1/4"
<b>Min. Bend Radius</b>	6" (15 cm)
<b>Max. Pressure</b>	360 psi (2,500 kPa)
<b>Max. Cont. Length</b>	250' (60 m)

FERRET WELL CAPS		
MODEL**	WELL DIAMETER	DESCRIPTION
S2M	2"	Slip Fit Cap
4M	4"	Slip Fit Cap
V2M	2"	Vacuum Cap
V4M	4"	Vacuum Cap

\*\*Add "F" after Model Number to include Filter/ Regulator/Gage with cap (recommended).

FERRET ACCESSORIES	
Model	DESCRIPTION
WSSH	Ferret shroud (used to fit Ferret to wells over 2" diameter, or where other items are present in well -- i.e. probe, drawdown pump, etc.)
37342	Portable Positioning Tool (Hand Pump with Pressure/Depth gage)
35715	1/4" Nylon Positioning Tubing
35097	1/2" UV-Protected Nylon Surface Tubing
35647	Connector (1/2" surface tubing to well cap)
2500	Heavy Duty Tubing Cutter
1374	Tank Full Shut Off Module

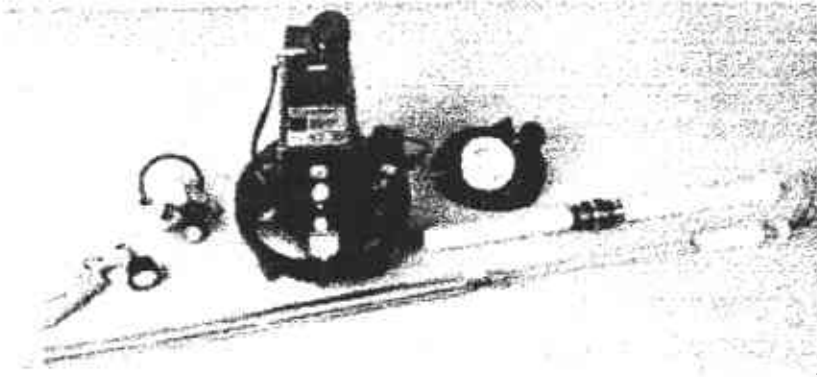
**FERRET COMPRESSOR SYSTEM**

MODEL	DESCRIPTION
TH3	3/4 HP Oilless Compressor
THDRAIN	Electric Auto Drain Kit
THDRYER	Refrigerated Air Dryer Kit
THWATRP	Automatic Water Trap
THDESDRYER	Desiccant Air Dryer for Freezing Climates

Note: TH3 air output is sufficient to run up to 3 Standard Ferret systems or 1 Short Ferret.

## FERRET PRODUCT RECOVERY PACKAGE

This ready-to-use equipment package is like a gas station/UST cleanup and recovery kit in a box! It delivers all you need for easy setup and reliable floating product recovery from a 2" or 4" well -- at considerable savings from the total price of the components.



### FPR15 Kit includes:

MODEL	DESCRIPTION
IWS26*	Ferret In-Well Separator (standard)
S2MF#	2" Slip Fit Well Cap w/Filter/Regulator/Gage
37342	Ferret Positioning Tool (Hand Pump w/Pressure/Depth Gage)
TH3	3-4 HP Oilless Compressor
L374	Tank Full Shut Off Module

\* Short Ferret can be substituted for standard.

# 4" Slip Fit Cap or 2" or 4" Vacuum Cap can be substituted.

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**NEW** *Ferret Separator Pump Removes Floating Layers from Any Tank or Sump*

**Proven Ground Water Cleanup Technology Is Lightweight, Portable and Explosion-proof**

The Ferret provides a new, more effective way to remove floating hydrocarbon layers from any tank or sump. Using a unique separator valve to sense differences in specific gravity, the Ferret pumps out pure hydrocarbon and rejects any water back into the tank, sump, or well so that large volumes of water do not have to be treated or disposed of. Set-up and operation are easy and safe because the Ferret is air-powered, small diameter, and lightweight.

Unlike other devices, the Ferret does NOT rely on hydrophobic screens, which often clog, or belts which are messy and work only with high viscosity floating hydrocarbons. The Ferret technology was developed for, and proven in, ground water clean-up projects at spill leak sites. These projects demand that no water be pumped from the well, in order to avoid the high cost of treating and disposing contaminated water. The Ferret has set a new standard in these applications based on its proven effectiveness.

**Will the Ferret meet my site's specific requirements?**

To determine whether the Ferret fits your application, the viscosity and density of the floating layer and the desired flow rate need to be determined. A FREE test kit is available to let you check the viscosity and density of your site's hydrocarbon layer. Call 1-800-624-2026 today for expert assistance in putting the Ferret to work for your application.

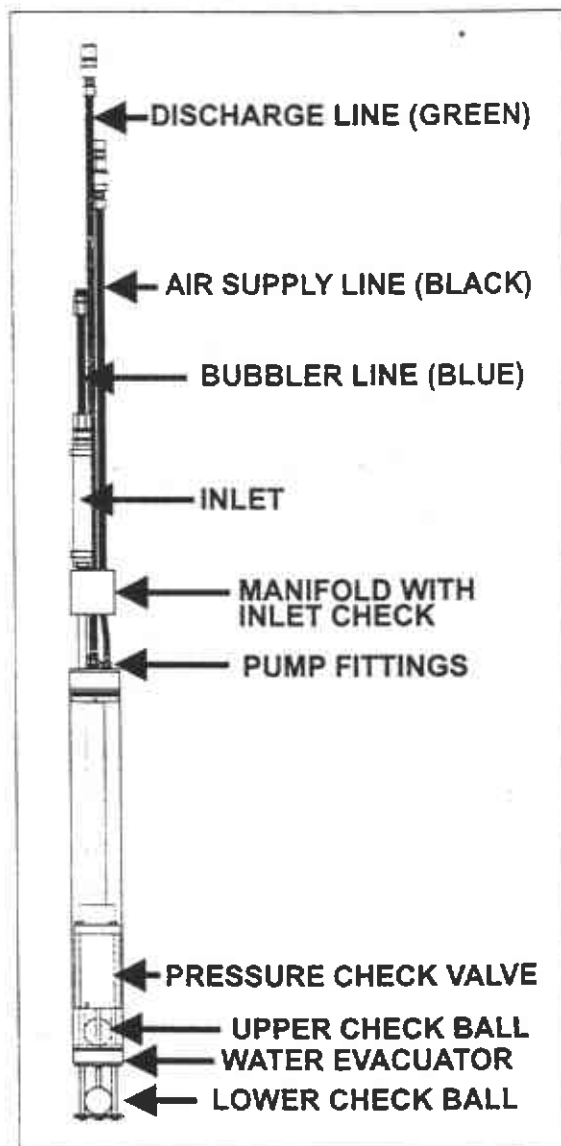
- **No water pumping or discharge permits.**
- **No contaminated water disposal costs.**
- **No hydrophobic screens or messy belts to clean.**

**▼ QED Environmental Systems, Inc.**

P.O. Box 3726, Ann Arbor, Michigan 48106  
 734-995-2547 800-624-2026 Fax: 734-995-1170  
 E-Mail: [info@qedenv.com](mailto:info@qedenv.com) Website: <http://www.qedenv.com>



The NEW Ferret Model TIWS21 pneumatic oil/water separator eliminates the cleaning of belts or hydrophobic screens.





The Ferret In Well Separator takes a unique approach to recovering floating hydrocarbon without water.

Previous technologies have attempted to achieve product-only recovery by using various strategies to try to exclude water from the pump or collector inlet. Hydrophobic screens and floating inlets are the main examples. Unfortunately, actual field performance of these devices has often been disappointing.

Unlike these devices, the Ferret process actively draws in water, as well as free and dispersed product. The inward pull actually causes water and product in the formation to move toward the Ferret inlet, enhancing recovery.

Once the product/water mixture is taken inside the Ferret inlet, HydroPrism separation takes place, using specific gravity to separate the product from water.™

### BASIC SEQUENCE OF OPERATION

#### 1. Refill Cycle

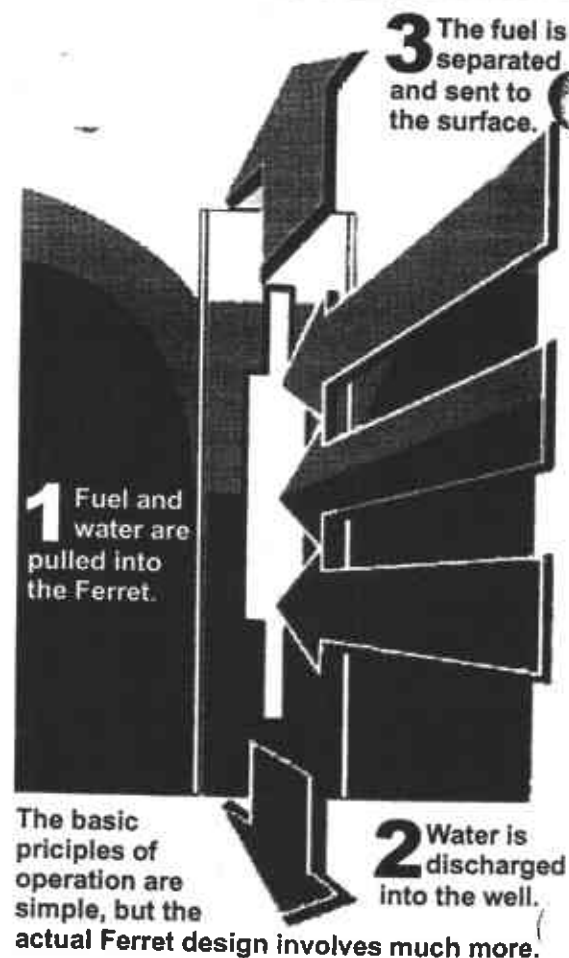
As the pumping chamber in the Ferret fills, hydrocarbon droplets naturally separate from the water, floating to the top and coalescing.

#### 2. Water Discharge

Compressed air is sent to the Ferret from the compressor. This air forces water out of the bottom of the Ferret because the water discharge check ball at the bottom of the Ferret floats in water.

#### 3. Product Discharge

As the water is driven out, the water discharge check ball becomes immersed in product. Now, it sinks and seats, diverting the product into the discharge line and up to the surface. The MPS360 Controller shuts off air to the Ferret and allows the pump to begin the next refill cycle.



## SPECIFICATIONS:

**Separator Type:** Positive Air Displacement

### Dimensions:

**O.D.:** 1.75" (45 mm)

**Length:** 20" (51 cm)

**Weight:** 2.5 lbs.

**Min. Well Diameter:** 2" (50 mm) or larger

**Inlet Port:** 15" (38 cm) above bottom of device

### Materials:

Stainless Steel, Brass, Delrin, Polypropylene and Viton O-rings.

### Fittings:

**Type:** Brass Compression

**Discharge Size:** 1/2" O.D. (13 mm)

**Air Supply Size:** 1/4" O.D. (6 mm)

**Level Gauge:** 1/4" O.D. (6 mm)

### Separator Performance:

**Operating Pressure Range:** 50-120 P.S.I.™ (350-840 kPa)

**Maximum Lift:** 200 FEET (60 m)

**Estimated Air Flow:** 0.5-1.0 S.C.F.M. at 50 P.S.I. (350 kPa)

### Separator Flow Rates:

Up to 50 G.P.D. (190 L.P.D.) possible with 6" (15 cm) or more of product submergence over inlet. Rate will vary depending on conditions.

### Discharge Amount:

Maximum product volume per cycle 100 ml, varies depending upon amount of water that enters and is expelled by the separator. **THE IN-WELL SEPARATOR WILL ONLY DISCHARGE PRODUCT TO THE SURFACE.**

**Product Pumped Density:** 0.7-0.90 g/cc

### Viscosity Range:

The short In-Well Separator is recommended for liquids with kinematic viscosities < 100 centistokes. Suitable liquids that may meet the viscosity recommendations are gasoline, JP4, JP5, Kerosene, Diesel Fuel, #2 through #5 Fuel Oil, SAE 10 (and above) Motor Oil, and Hydraulic Fluids. Incompatible liquids include water soluble fluids such as cutting fluids

**Controller:** \*MPS 360 Electrical/Pneumatic Controller 120V AC 0-120 P.S.I.

\*For more technical data see the tech/data sheet for the MPS 360

**QED Environmental Systems, Inc.**

P.O. Box 3728, Ann Arbor, Michigan 48106 313-995-2547 800-624-2026 Fax: 313-995-1170  
E-Mail: info@qedenv.com Website: http://www.qedenv.com

APPENDIX B

ORC® SLURRY INJECTION CASE HISTORIES

# ORC TECHNICAL BULLETIN # 3.1.12

## Slurry Injection BTEX Remediation in California

Contaminants	Application Method	Soil Type	Groundwater Velocity
BTEX	Slurry Injection	Sandy Silt	<0.5 ft./day

A former service station in downtown San Francisco, California was contaminated with high levels of BTEX. Groundwater contamination was the result of leaking underground storage tanks and dispenser islands. The aquifer material consists of interbedded silt and sandy silt overlying a cemented fine- to medium-grained sand interval. The depth to groundwater is approximately 25 feet below ground surface. Groundwater flow direction is predominantly to the south at a velocity ranging up to 0.5 foot per day.

Following approximately one year of soil vapor extraction the majority of the soil contamination was removed. Due to the presence of residual hydrocarbons in groundwater, approximately 2,500 pounds of ORC slurry was injected via 50 push points using a cone penetrometer rig (June, 1997). Approximately 50 pounds of ORC was injected into each push point extending from 10 feet below groundwater through the capillary fringe. Existing wells MW-1, MW-2, MW-3, and MW-4 were used to monitor the reduction of BTEX. A map of the site detailing the injection array and monitoring well locations is presented in Figure 1. The reduction of BTEX at the four wells is graphically presented in Figures 2 through 5. Five months following the installation of ORC, the overall reduction of BTEX was 17% in MW-1, 100% in MW-2, 100% in MW-3, and 66% in MW-4. It is important to note that there was a 67% reduction of BTEX (due to a 74% reduction of TPH) in MW-1 after three months of treatment. Apparently, BTEX levels began to rebound through the fifth month because the well is in an unresolved source area with high oxygen demand and recharge potential. Based on these results, this site has been submitted for closure.

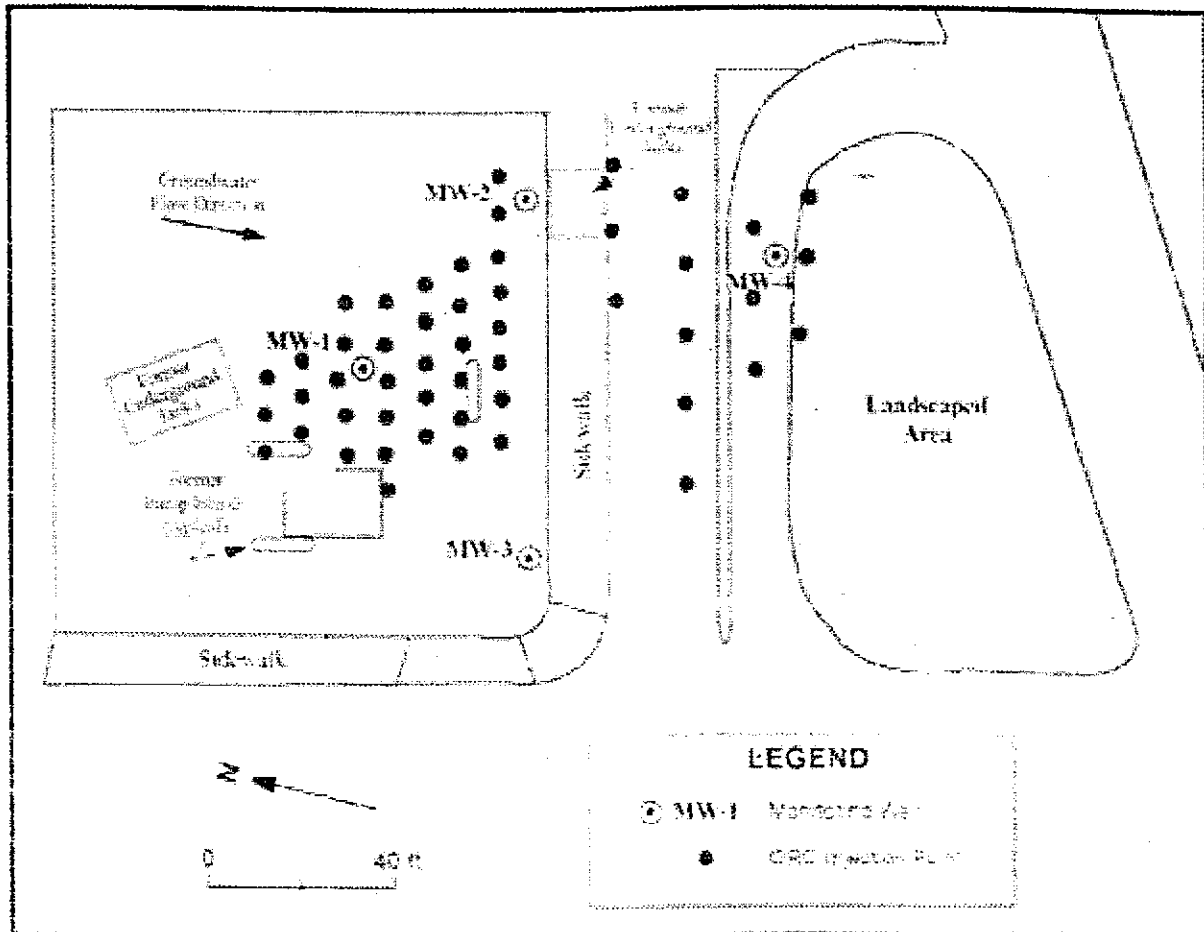


Figure 1

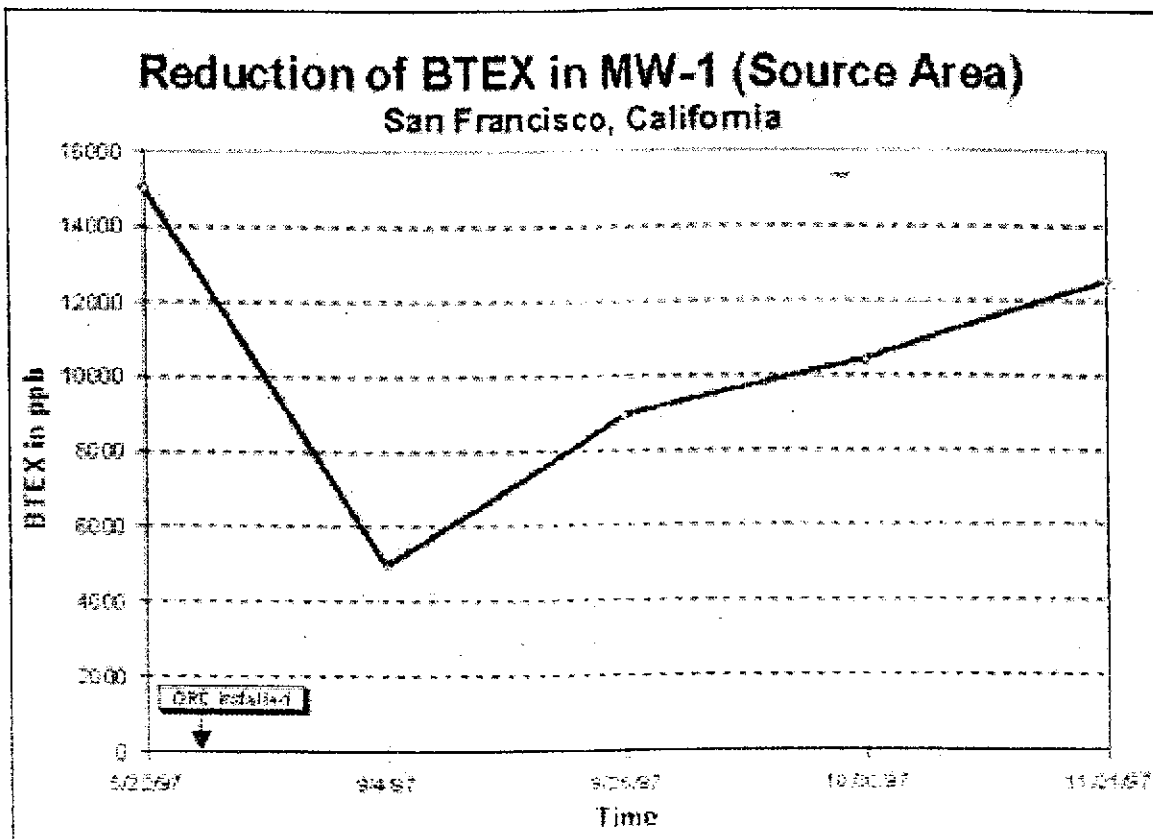


Figure 2

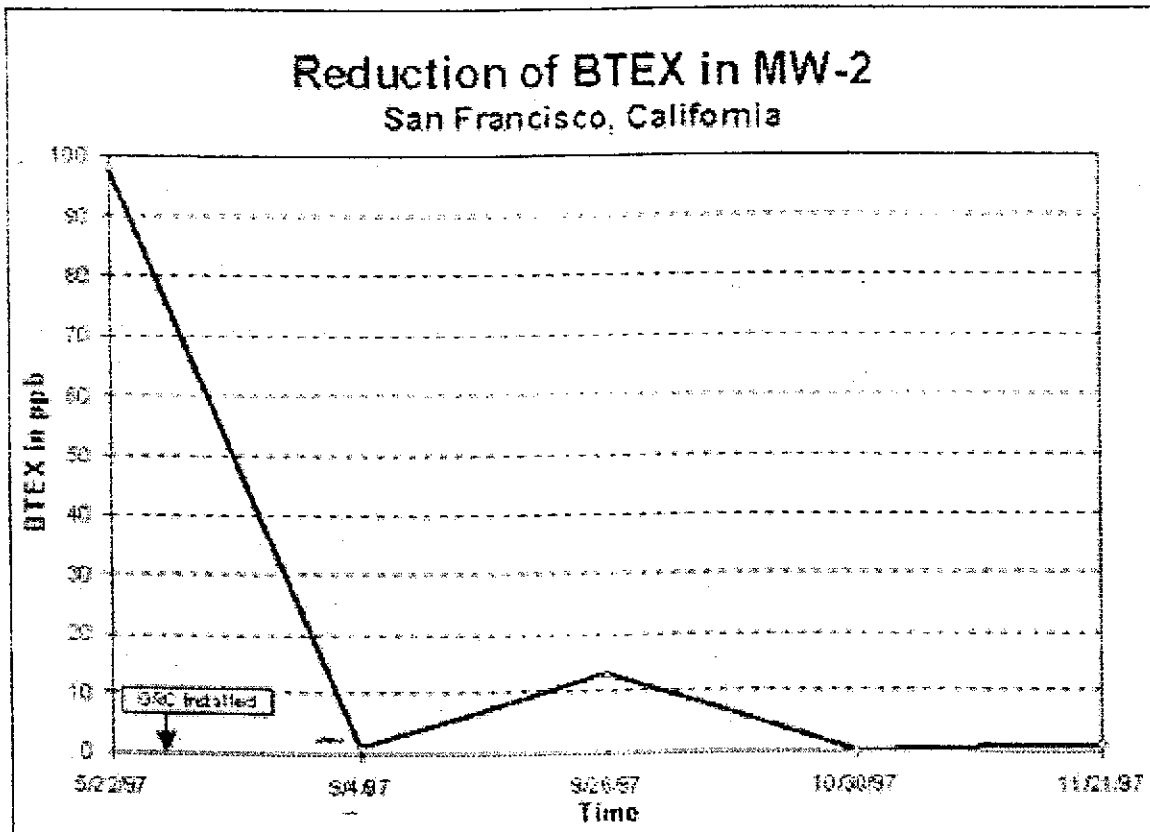


Figure 3

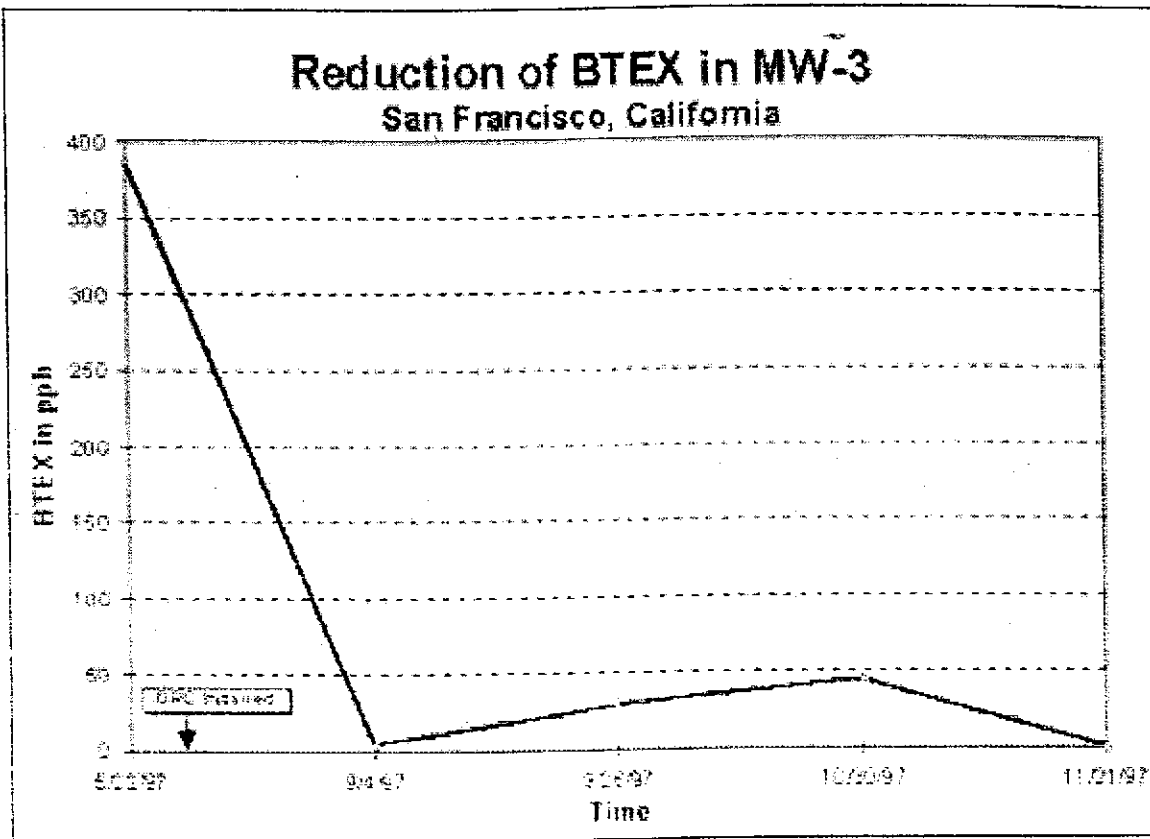


Figure 4

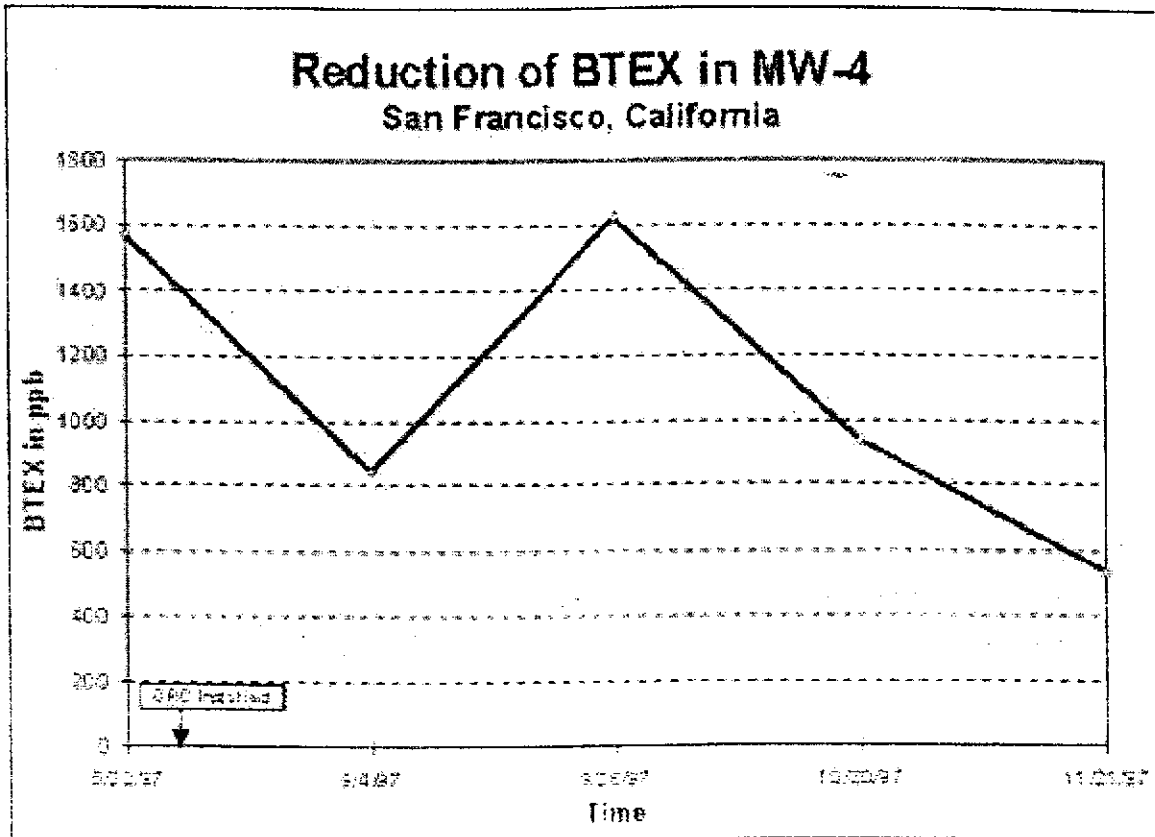


Figure 5

[Technical Bulletin Index](#) | [Regenesis Home Page](#)

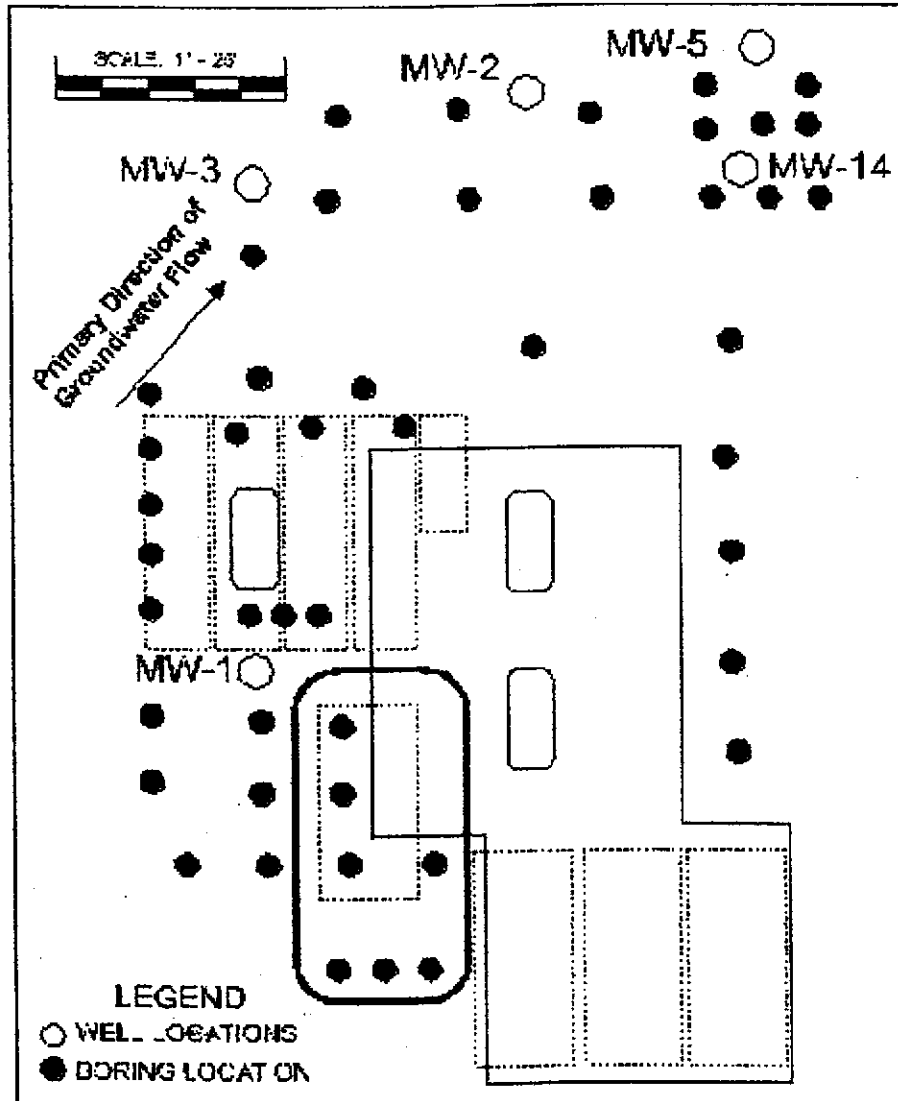
ORC TECHNICAL BULLETIN # 3.1.2

Slurry Injection BTEX Remediation in Michigan

Contaminants	Application Method	Soil Type	Groundwater Velocity
BTEX	Slurry Injection	Clay	0.15 ft/day

Site Description and Remedial Design

A convenience store site impacted by a leaking UST was demolished for reconstruction, leaving a static ground water plume which needed to be addressed. The area of the plume was about 120' x 68', with a 10' thick contaminated saturated zone containing about 25 ppm BTEX. The total mass of BTEX in the system was estimated to be on the order of 46 pounds.





Regulatory authorities, recognizing the site was static with a defined mass in place, allowed for the placement of 47 bore holes which were filled with ORC slurry. The bore holes were drilled with a 5 1/4 inch hollow stem auger with a 4 inch core in the array illustrated above. The amount of oxygen placed in the system was enough to handle twice the BTEX concentration present in the plume. The site was paved for new construction immediately after the ORC was in place.

### Results

In the first 200 days there was a significant reduction of benzene, toluene and ethylbenzene in the sentinel well (MW-14). Significant reduction continued to the latest sampling event at day 315. The reduction in B,T and E is presented in Figure 1 and the corresponding risk reduction calculation in Figure 2. This decrease was correlated with a rise in the microbial degrader populations as noted in Figure 3. The consulting firm was satisfied with the results such that another remediation plan is in development using the source treatment approach on a second site. The firm also featured the ORC technology and these results at a convenience store owners conference that addressed environmental concerns.

Figure 1

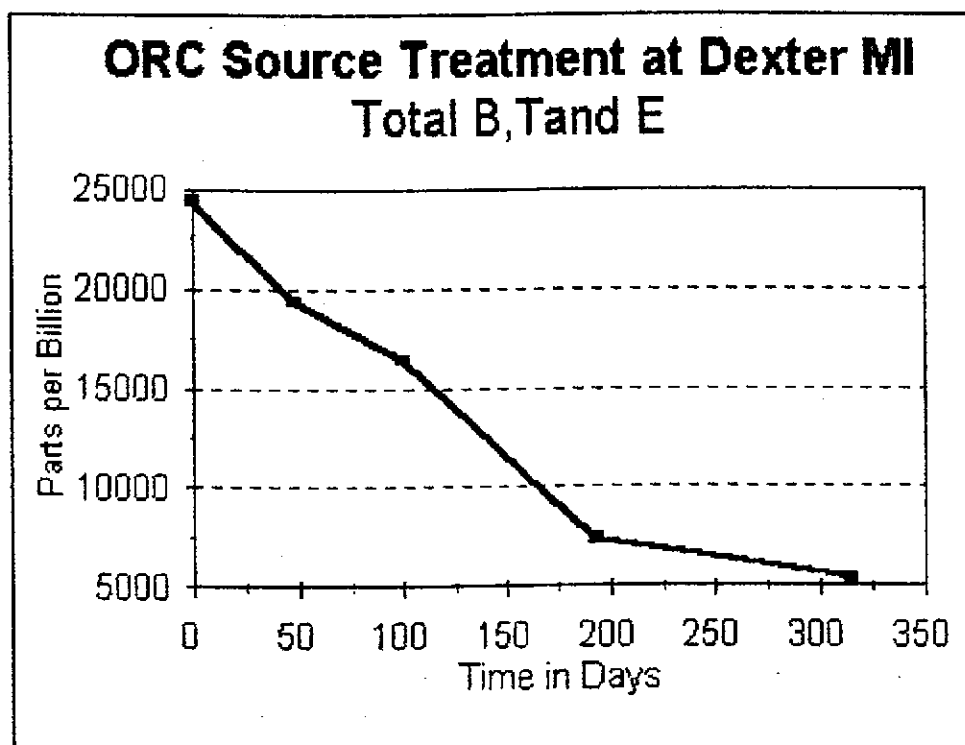


Figure 2

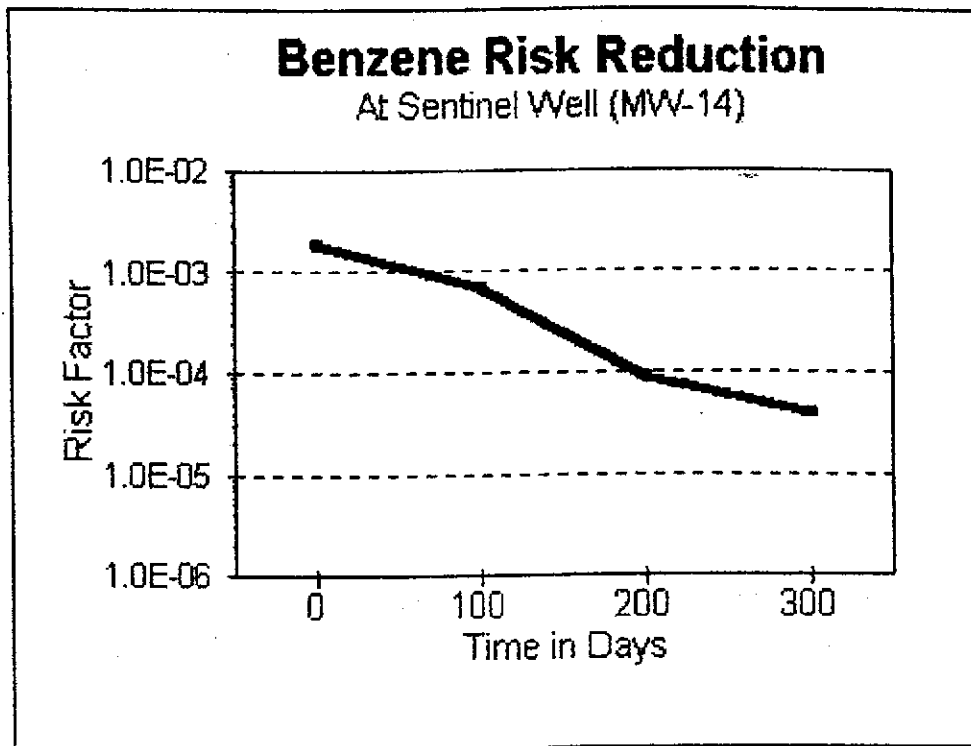
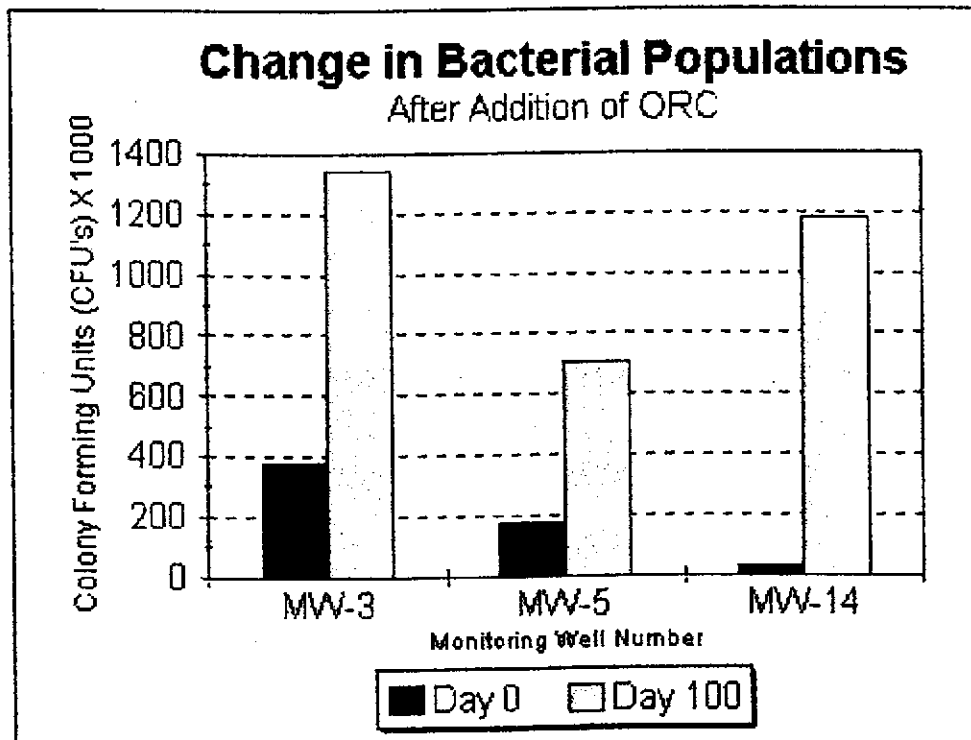


Figure 3



[Technical Bulletin Index](#) | [Regenesis Home Page](#)

one compound to another. In the case of petroleum hydrocarbons, microorganisms use the hydrocarbons as an energy source, producing  $\text{CO}_2$  and water as the end product. Biodegradation rates are variable but, under the proper conditions, may be accelerated to speed site cleanup. One method for accelerating the biodegradation of petroleum hydrocarbons in groundwater is through the use of oxygen supplementation (OS).

Biodegradation is the general term used to describe the cumulative effect of numerous small biotransformational steps. The process involves sequential biotransformations, during which the metabolic activity of living organisms converts contaminants into different compounds, for example, benzene to cis-benzene dihydrodiol. In petroleum hydrocarbon biodegradation, the microorganisms use hydrocarbons for energy and degrade them to less toxic compounds ( $\text{CO}_2$  and water) in a process known as mineralization. The general sequence of biodegradation of one-, two-, and three-ring aromatic hydrocarbons is illustrated in Figure 1.

It is usually unnecessary to introduce non-native organisms to a groundwater system for biodegradation to occur. Groundwater systems have a diverse population of native microorganisms, some of which are predisposed to consuming hydrocarbon compounds. If the native organisms have plentiful new food source, petroleum hydrocarbons, the species of organisms best adapted to use this food source will multiply to a population that can be supported by the food source. If a site has been affected by one of the numerous compounds that can be biologically degraded, chances are good that biodegradation of those compounds is occurring.

A primary factor limiting the biodegradation rate of petroleum hydrocarbons in a groundwater system is the availability of dissolved oxygen (DO). Biodegradation can occur either in the presence of DO (aerobic) or the absence of DO (anaerobic). For petroleum hydrocarbons, aerobic biodegradation can occur at rates up to two orders of magnitude faster than anaerobic biodegradation rates.

With aerobic biodegradation, oxygen is used as the terminal electron acceptor (TEA) for electrons transferred during the metabolic processes of the microorganisms. Under anaerobic biodegradation, other compounds such as iron, sulfate and nitrate are used as the TEA. In most petroleum hydrocarbon plumes, both aerobic and anaerobic conditions exist simultaneously. The typical dissolved hydrocarbon plume consists of an anaerobic core surrounded by an aerobic fringe.

The total capacity of the groundwater system to mineralize hydrocarbons typically is greater in the anaerobic core than in the aerobic fringe, despite the fact mineralization occurs at significantly lower rates under anaerobic than aerobic conditions. This difference in capacity to mineralize contaminants can be attributed to the greater mass of contaminant in the anaerobic core relative to the aerobic fringe and the greater abundance of anaerobic TEAs relative to aerobic TEAs in the groundwater system.

Therefore, at sites where the natural biotransformation rate and contaminant reduction are adequate to meet site risk management goals, unenhanced IR may be acceptable. However, at a site where an accelerated remedial time frame or more aggressive plume migration control are required, it is desirable to increase the zone of aerobic biodegradation.

This can be accomplished by supplying an ongoing source of DO to a petroleum-contaminated groundwater system. By removing oxygen availability as a limiting factor and converting the anaerobic

core to an aerobic zone, it is possible to significantly increase overall biodegradation rates and contaminant mass mineralization.

### Oxygen supplementation advantages

Oxygen supplementation (OS) can be applied at a wide variety of sites and, where appropriate, has numerous advantages over other remedial technologies. The primary advantages of enhanced IR through OS include:

- Significant savings in capital costs and ongoing operations and maintenance (O&M) costs.
- Reduced human exposure to contaminants.
- Complete in-situ mineralization or destruction of contaminants.
- Less disruption of site operations.

Enhanced IR does have limitations in its application. While enhanced IR will address dissolved-phase contamination, it has not been demonstrated to be effective in addressing non-aqueous phase liquids (NAPLs). In the case of NAPLs, the limiting factor for enhanced IR is the rate at which the mass of the NAPL is reduced by dissolution into groundwater. In general, when a NAPL is present, active remediation of the NAPL -- excavation, pumping for source control -- should be used in conjunction with enhanced IR to address the dissolved-phase contaminants.

The use of IR in general, and enhanced IR in particular, requires good site characterization data and the ability to perform long-term monitoring of the groundwater system. The site characterization data needed to support the implementation of enhanced IR differ only slightly from data needed for the design and implementation of other groundwater remedial technologies. These data include an understanding of the local hydrogeologic regime and groundwater chemistry and contaminant distribution.

### Implementing an OS system

One of the simplest applications of OS is the placement of solid phase oxygen-releasing compound within the contaminated saturated zone. Solid phase oxygen-releasing formulations contain a magnesium peroxide that slowly releases  $O_2$  as it is converted to magnesium hydroxide. This release occurs when the magnesium peroxide comes in contact with groundwater less than fully saturated with  $O_2$ . The released  $O_2$  is then distributed within the aquifer by mechanical dispersion and diffusion.

The  $O_2$  release rate by the oxygen-releasing compounds is self-regulating in contrast to other OS approaches, such as liquid hydrogen peroxide feed systems, which require metering. This time-release/kinetically mediated approach also has the advantage of maximizing the amount of DO in the system. If the system is not saturated with  $O_2$ , more will dissolve from the solid phase. With liquid hydrogen peroxide systems that require metering, overdosing the system with  $O_2$  can actually oxidize and destroy beneficial microorganisms.

Oxygen-releasing compounds can be introduced into the saturated zone using a number of methods. Replaceable socks containing the material can be placed within existing or new monitoring wells. The oxygen-releasing compound also can be placed directly into the saturated zone in a slurry form, by placing the material within a drilled borehole or by using hydraulically driven hollow probe rods as in direct-push techniques. If direct-push techniques are used, a high pressure grout pump must be used to inject the slurry through the probe rods into the saturated soils.

The use of socks in wells is generally best suited to smaller plumes with slow groundwater velocities where smaller doses of  $O_2$  are sufficient. The use of oxygen-releasing compounds in slurry form is more suitable for situations where a large dose of  $O_2$  is required, where groundwater migration rates are somewhat more rapid and the contaminant plume more widespread. Faster groundwater migration rates will result in faster depletion of the  $O_2$  from the oxygen releasing source. Groundwater migration rate, the configuration of the contaminant plume, site development and accessibility all influence the OS system design and configuration.

The dose of  $O_2$  required to meet site remediation needs also has a direct influence on the OS system design and configuration. A direct stoichiometric relationship of three pounds of available DO to mineralize one pound of petroleum hydrocarbons is typically used to estimate the OS system dosing requirements. To permit calculation of the contaminant mass present within the plume, it is necessary to adequately characterize the contaminant concentration distribution within the plume. It is equally important to assess the DO replenishment capacity of the natural groundwater system before calculating the dose of oxygen-releasing compound required. Natural groundwater systems where  $O_2$  is replenished very slowly require greater OS than a more highly aerobic system.

To estimate the dispersion of the  $O_2$  supplied to the system, it also is necessary to understand the groundwater velocity and the length of time the applied dose of  $O_2$  will be effective. Once the necessary data have been obtained, it is possible to design an OS approach, estimate the cost of site remediation using OS and compare these costs to those of other remedial technologies.

*Thomas C. Morin is a project manager/geologist with Kennedy/Jenks Consultants in Federal Way, Wash., 206-874-0555; e-mail, [thommorin@kennedyjenks.com](mailto:thommorin@kennedyjenks.com).*

## Definitions

**Intrinsic remediation (IR):** The result of several natural processes, such as biodegradation, abiotic transformation, mechanical dispersion, sorption and dilution that reduce contaminant concentrations in the environment.

**Biodegradation:** The key component of IR, biodegradation is the result of biologically mediated processes that change one compound to another, eventually reducing contaminant mass.

**Mineralization:** The end result of biodegradation processes where a contaminant is biodegraded to basic components. For example, petroleum hydrocarbons degraded to  $CO_2$  and water.

**Oxygen supplementation (OS):** The addition of bio-available dissolved oxygen to a groundwater system to augment the capacity of the aquifer system to aerobically biodegrade and mineralize contaminants.

**Terminal electron acceptor (TEA):** Chemicals necessary for electron transfer during the metabolic processes in which microorganisms biodegrade contaminants. Biodegradation will not occur in the absence of necessary TEAs. Oxygen is the TEA during aerobic biodegradation of petroleum hydrocarbons and iron, sulfate and nitrate are TEAs during anaerobic biodegradation.

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## Taking Advantage of Natural Site Conditions

An oxygen supplementation (OS) system was recently implemented to address a large dissolved phase petroleum hydrocarbon plume. See Figure 2. Prior to implementing the OS system, site investigations were performed to obtain the characterization data described above. The site data indicated that the saturated zone to be treated was relatively thin and became progressively thinner from east to west. The aquifer materials were relatively porous and groundwater flow rates were on the order of 1 to 10 feet per day.

The site characterization data indicated that total dissolved benzene, toluene, ethylbenzene and xylene (BTEX) concentrations in the central anaerobic core of the contaminant plume were as high as 10,000 micrograms/liter ( $\mu\text{g/L}$ ) but generally ranged between 500 and 2000  $\mu\text{g/L}$ . The aquifer system was naturally aerobic with background  $\text{O}_2$  concentrations as high as 5 milligrams/liter (mg/L). The contaminant plume configuration had apparently achieved a steady state as shown by four quarterly monitoring events in which the plume had not increased in size. An overlay of BTEX concentration contours onto  $\text{O}_2$  concentration contours showed a very strong correlation between highest BTEX concentrations and depleted  $\text{O}_2$ . The site data strongly suggested the hydrocarbon plume had achieved steady state configuration, natural biodegradation of contaminants was occurring and an IR approach site management was technically applicable and appropriate.

However, other considerations at the site made the extended timeframe required by IR unacceptable. The engineering consultant assessed several remedial technologies for application at the site, but the engineering estimates placed the costs for implementing active remedial technologies such as air sparging/soil vapor extraction and groundwater pump-and-treat in the neighborhood of \$250,000. By contrast, the cost for implementing OS at the site to date has been about \$40,000.

The OS system designed for the site took advantage of the natural conditions and processes at the site. It was apparent from the site characterization data that the aquifer had a significant aerobic degradation capacity and the rapid groundwater velocities at the site could be used to disperse dissolved oxygen from the hydraulically upgradient portions of the contaminant plume to the downgradient portions.

A fence of 15 borings was installed near the upgradient portion of the oxygen depleted zone or anaerobic core. The saturated portion of each boring was filled with a slurry of oxygen releasing compound. A total dose of about 100 pounds of available  $\text{O}_2$  was placed in these borings based on an estimate that approximately 33 pounds of petroleum hydrocarbons were present within the anaerobic

core of the contaminant plume. An estimated 18 to 36 months will be required to attain cleanup levels for benzene and total petroleum hydrocarbons.

The site is currently undergoing quarterly groundwater monitoring to confirm the performance of the oxygen-releasing compounds and the resulting reduction in contaminant mass. Since OS has been implemented, data available from the first quarterly groundwater monitoring event demonstrate an increase in dissolved oxygen in the previously anaerobic core of the plume from 0.79 mg/L to 4.9 mg/L. Several of the on-site wells downgradient of the oxygen releasing compound fence show significant decreases in the concentration of gasoline-range petroleum hydrocarbons and benzene. Benzene concentrations have decreased significantly in four of five wells where it was previously detected. One well location has shown concentration reductions in gasoline-range petroleum hydrocarbon from 72 mg/L to 39 mg/L, benzene from 410  $\mu$ g/L to 200  $\mu$ g/L, toluene from 810  $\mu$ g/L to 410  $\mu$ g/L, ethylbenzene from 1800  $\mu$ g/L to 1000  $\mu$ g/L and total xylenes from 11,000  $\mu$ g/L to 4600  $\mu$ g/L. This represents a 58 percent decrease in total BTEX concentrations over three months.

Pollution Engineering - Feb 01, 1997

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# Enhanced Intrinsic Bioremediation of Dissolved Phase Hydrocarbons Using An Oxygen Releasing Compound: Quantitative Field Demonstration in Belen, New Mexico

Joseph E. Odencrantz, Jeffrey G. Johnson, and Stephen S. Koenigsberg

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## Abstract

An "Oxygen Barrier" was formed by depositing an oxygen releasing compound in a series of wells that were placed perpendicular to the direction of groundwater flow. The objective was to enhance the intrinsic bioremediation of dissolved phase BTEX contamination in the aquifer and to quantify the results. The oxygen was supplied by a controlled release formulation of magnesium peroxide called Oxygen Release Compound (ORC<sup>®</sup>), a virtually insoluble powder which is packaged in polyester filter socks. 342 of the ORC socks (1' x 5 3/8") were strung together and lowered into the screened intervals of 20 PVC wells that were 6 inches in diameter. 45 monitoring points were placed downgradient of the contaminant source and the system was monitored for changes in dissolved oxygen and BTEX. The areal distributions of the initial concentrations of dissolved oxygen and BTEX were measured and compared to the concentration changes at various times in the first 93 days of system operation. The dissolved oxygen mass increased to a maximum in first 10 days and remained relatively constant for the next 30 days; by 93 days approximately half of the oxygen placed in the system was utilized. The concomitant reduction in BTEX can be seen in a series of contour plots. In 93 days dissolved oxygen had dispersed at least 20 feet downgradient from the ORC source wells based on the pattern of decreasing BTEX concentrations. At a larger scale, the leading edge of the hydrocarbon plume was pulled back toward the source. This was evidenced by a reduction of BTEX levels to non-detect at a well 120 feet downgradient of the Oxygen Barrier.

## Introduction

Traditional methods for the remediation of source areas, and the control of downgradient movement of contamination, are being increasingly replaced or augmented by bioremediation and other emerging technologies (Norris, 1995); this shift has resulted from issues of efficiency and economics. Furthermore, there has been increasing interest in approaching the wide variety of impacted sites with a risk reduction philosophy (ASTM RBCA, 1994). In concert with these changes, intrinsic bioremediation is becoming a well established and scientifically defensible strategy for risk reduction or full clean-up. At sites where total reliance on intrinsic methods is questionable, because of the existence of limiting factors, certain enhancement practices become attractive.

In groundwater remediation systems, dissolved oxygen can be the major factor limiting biodegradation (Salinitro, 1993). Where this occurs, the use of supplemental oxygen becomes an imperative. Traditionally, supplemental oxygen is provided by active systems that include air sparging and the continuous addition of hydrogen peroxide (Reference). Recently, solid peroxygen compounds, such as sodium percarbonate, calcium peroxide and magnesium peroxide have become useful as a basis for more passive oxygen delivery



systems. These materials can be deposited where needed for continuous release of oxygen in soil or groundwater systems.

Materials like calcium and magnesium peroxide are virtually insoluble and can be deposited by various means, using wells or trenches, into an aquifer to make contact with contaminated groundwater. When contacted with water, ordinary calcium and magnesium peroxide will release oxygen for a period of several weeks and proprietary formulations of magnesium peroxide, such as ORC can release oxygen on the order of several months to a year. The rate control feature is a function of the synthesis of the molecular matrix and not achieved by a coating process. While the technology can be applied to several other solid peroxygens, only calcium and magnesium peroxide are feasible to use in bioremediation. The higher solubility and pH of calcium peroxide directed efforts on magnesium peroxide as the peroxygen of choice in the preparation of ORC (reference technical bulletin?).

Since the solid peroxygens simply release oxygen when hydrated they are ultimately converted to their respective hydroxides. ORC therefore becomes ordinary magnesium hydroxide which, like magnesium peroxide, is also virtually insoluble. ORC is packaged in exchangeable filter socks. Since the average life of an ORC sock is approximately 6 months as shown in Figure 1, this operation only has to be done twice a year. Therefore, the use of ORC is the basis for passive treatment of subsurface hydrocarbon contamination with biologically based source treatments and migration barriers.

A quantitative field demonstration (QFD) of ORC's ability to function as the basis for a passive groundwater bioremediation system was conducted at an abandoned service station site in Belen, New Mexico in the Spring/Summer of 1995 (Actual Dates: April 1, 1995 to July 5, 1995). Figure 2 is the overall site plan which shows the QFD region and the location of the excavated source area. Figure 3 details the placement of the oxygen barrier and the array of monitoring points. This paper describes the changes in areal distribution of the concentrations of dissolved oxygen and BTEX as they occurred at various times in the first 93 days of system operation.

## Site History

Initial contamination at the site was discovered in the Winter of 1989. An unknown amount of gasoline had leaked into the subsurface for an unknown length of time. A site assessment was performed in the Spring of 1993 and indicated that petroleum hydrocarbon contamination had impacted soil and groundwater (ATEC Associates, Inc. 1993). The contaminated groundwater had migrated offsite to the southeast. In June 1994, a hydrogeological investigation was conducted and indicated, with reference to Figure 2, that the groundwater contamination extended downgradient to SH-6 and MW-2. The vertical extent of the contamination was approximately 15 feet below ground surface (bgs).

In September, 1994, a study with ORC was conducted (GRAM, Inc., 1994). A single six-inch diameter PVC source well was installed for the placement of ORC and 26 monitoring points were placed at various positions downgradient to monitor changes in dissolved oxygen (DO) and BTEX. After four months of operation it was apparent that oxygen was being released from ORC, that it was being distributed downgradient and that BTEX was being remediated. Based on these results, the UST Bureau of the New Mexico Environment Department approved a full scale ORC mediated oxygen barrier.

The full barrier was designed around the pilot source well. In March, 1995, 19 PVC wells plus an additional array of monitoring points were installed as illustrated in Figure 3. Contaminated soil in the vicinity of the former tank pit was excavated to minimize recharge of the aquifer with additional contamination.

### **Site Description**

The site is situated in the lower section of the Albuquerque-Belen Basin within the Rio Grande Rift. The rift is bordered by the Lucero uplift and the Rio Puerco fault zone on the west and by the Sandia/Manzano uplift to the east. The sediments that exist beneath the site are of alluvial origin and reflect the geomorphic setting. The soils at the site consist of interbedded clays, sand and gravel.

The aquifer is shallow and unconfined and is comprised mainly of well sorted sands. The depth to groundwater is approximately five feet below ground surface (bgs). The average groundwater gradient at the site was 0.0016 in February, 1994 and 0.0015 in November 1994, both towards the south-southeast. The hydraulic conductivity from SH-6 was measured to be 15.5 ft./day as determined by a slug test (Geohydrology Associates, 1994). Assuming the average hydraulic gradient and a range of possible effective porosities from 25% to 30%, the range of interstitial velocity at the site is 0.13 to 0.15 ft./day. This corresponds to 12 to 14 feet travel distance during the 93 days the system was being monitored.

### **Design and Construction of the Source and Monitoring Network**

Figure 3 illustrates the ORC oxygen barrier which is comprised of 20 ORC source wells and a variety of monitoring points. Due to the existence of an overhead power line on the east side of the site, the oxygen barrier was split into two unequal sections as shown. The main objectives of the two lines of ORC wells were to create an oxygen barrier to control the plume and draw the leading edge back toward the source.

The placement of the ORC source wells is perpendicular to the prevailing groundwater flow direction. One row of monitoring points (MPs) is located 10 feet downgradient of the source wells. These include MP-4 to MP-18 which are spaced two feet on center and the series consisting of MP-1 to MP-4, MP-18 to MP-27, and MP-101 to MP-106 which are spaced four feet on center. Another series of monitoring points, MP-201 to MP-210, is 20 feet downgradient with a 3 foot on center spacing.

The source wells have three KVA miniature shield points fastened to the outside of the well casings. The shield point is made of aluminum and is six inches long, 1/4 inch in diameter, and has 0.010 in. slots. The source wells had these probes placed at 7 feet, 14 feet and 21 feet below ground surface (bgs). The average vertical position of these probes are referred to as the C-zone, B-zone and A-zone respectively.

### **Material and Methods**

ORC filter socks were purchased from the manufacturer (Regenesis Bioremediation Products, San Juan Capistrano, CA). The socks are composed of a tight weave polyester

which is the same material used for well screen filter sock. Each sock, containing a 1:1 mixture of ORC and #90 silica sand, weighs 12.6 pounds and is 4% oxygen by weight.

Water levels were measured at the site prior to sampling. One-eighth inch diameter Teflon line tubes were connected to each of the probes. A peristaltic pump was used for water sampling and the first 100 mL of sample drawn up was discarded. The second 100 mL drawn was measured for temperature, pH, and electrical conductivity. A 300 mL BOD bottle was then filled as the sample for dissolved oxygen and a 40 mL VOA was filled for the Ohmicron BTEX immunoassay with mercuric chloride preservation.

Six sampling points were selected as QA/QC points and an additional 40 mL VOA was filled for outside laboratory analysis. BTEX was analyzed using EPA method 8020. The laboratory BTEX readings were correlated with the significantly lower cost field immunoassay assays, enabling the collection a much larger number of samples than would have otherwise been possible. All samples indicated were collected during eleven sampling events; before the ORC was installed at Day 0 and at Days 3, 5, 9, 12, 20, 30, 47, 60, 75 and 93. Monitoring wells were sampled using dedicated HDPE tubing.

### Field Screening

Field screening of environmental samples was accomplished using three different methods. A Hydac digital tester was used to measure pH, conductivity, and temperature of the samples in the field. Dissolved oxygen was measured using Hach modified Winkler digital titration method in the field. BTEX was screened using Ohmicron RaPID Assays total BTEX kits upon returning from the field. Each of the methods are discussed in detail in the following sections.

QA/QC. QA/QC of field screening procedures was accomplished by running duplicates of ten percent of all samples collected for all field screening methods.

Hydac Meter. A Hydac digital conductivity/temperature/pH tester was used to measure pH, conductivity, and temperature of all water samples collected in the field. The Hydac tester was calibrated in the field before the start of each sampling event.

Dissolved Oxygen. Dissolved oxygen was measured using the Hach modified Winkler Digital Titration Method. The azide modification of the Winkler Method is the standard test for dissolved oxygen. In the analysis,  $Mn^{2+}$  (manganous ion) reacts with the dissolved oxygen present in the alkaline solution to form a  $Mn^{4+}$  oxide/hydroxide flocculent. Azide is added at this time to suppress interference from any nitrate present which would react with the iodide. The solution is then acidified and the manganese floc is reduced by iodide to produce  $Mn^{2+}$  and free iodine as  $I_3^-$  ( $I_2 + I^-$  in solution) in proportion to the oxygen concentration. The iodine gives the clear supernatant a brown color. Thiosulfate is then used to titrate the iodine to a colorless end point.

The samples were collected in 300 mL BOD bottles and the DO was measured in the field.

The thiosulfate titrate was checked before each sampling event by performing an accuracy check using an Iodate-Iodide Standard Solution equivalent to 10 mg/L dissolved oxygen.

BTEX. BTEX field screening was performed using the Ohmicron RaPID Assay Total BTEX kits. The kits are immunoassay based technology. The antibodies are attached to microscopic magnetic particles. The substances to be analyzed from the water samples are mixed with the antibodies. After incubation the antibodies are magnetically separated. The amount of analytes are indicated by the color change. The results are shown by a reverse curve indicating the inverse relationship between the analyte concentration and the amount of color. The results are quantitative within the limits of the calibration, 0.02 - 3.0 ppm, and qualitative outside of the range. Results greater than the highest calibration point, 3.0 ppm, are qualitative because it is not known what happens to the calibration curve in that range.

For each batch of samples, a maximum of 60 samples including calibration and control samples, run for BTEX screening the RPA-1 RaPID Analyzer was calibrated. Calibration curves were run using duplicates of four standards, 0.0, 0.09, 0.35, and 3.0 PPM. A control sample was also included as part of each batch. Replicate samples were sent to the laboratory for analysis by EPA method 8020 as noted.

## Results and Discussion

The results will be presented as a time series of contour plots and mass curves for BTEX and DO. The data interpretation followed decisions with respect to the use of certain contouring algorithms, geostatistical methods, and selection of boundaries. The areal distribution of BTEX and DO was contoured using two kriging algorithms. GEOEAS (1988), an environmental geostatistical package, was used initial to examine the spatial correlation features of the data sets. An exponential model fit the variograms for BTEX and DO quite adequately. The main purpose of implementing GEOEAS was to provide the most realistic representation across the computational domain where sampling information was unavailable. The kriging algorithm within SURFER was used to contour the data across the site for the purpose of generating mass estimates.

Contour plots of oxygen and BTEX were made for the eleven sampling events, however, it is not necessary or practical to show them all in this paper. Four contour plots of BTEX and DO were selected from the total series based upon the following rationale. The initial (background) and final snapshot were selected for obvious reasons. The first intermediate time, 20 days, was selected because the oxygen mass was established at its peak for two previous sampling events and there was significant BTEX degradation from background conditions. The second intermediate time, 47 days, was selected because of a slight apparent increase in BTEX concentration in the well samples coupled with the first sign of appreciable oxygen mass depletion.

Figure 4 is a plot of the contoured dissolved oxygen concentrations at the 0, 20, 47, and 93 day sampling events. The average background concentration of DO in the domain was approximately 1 mg/L with a maximum of concentration of 4.54 mg/L at MP-106. The need for adding oxygen is clear. Salanitro (1993) states that there may be a minimum threshold concentration for which BTEX degradation is slowed, even at levels greater than 1 to 2 mg/L of DO. The contour plots at 20 and 47 days show a buildup of dissolved oxygen around the barriers with some skewness in the direction of flow. A small amount

of fingering is apparent from the complete time history of data at 515 to 530 ft, i.e. MP-6 to MP-14. There is obvious oxygen migration to the monitoring wells ten feet downgradient and less evidence of reaching the well series located twenty feet downgradient. The 3 mg/L contour line was chosen as the threshold concentration for new oxygen. Dissolved oxygen concentrations fluctuate above the background levels in well MP-201 to MP-210, however, they are generally below 3 mg/L. The significant decrease in the size of the oxygen plume at 93 days as well as a lower maximum concentration is a result of consumption due to the remediation of BTEX.

Figure 5 presents the same series of contour plots for BTEX. The background concentration is approximately 2 mg/L of BTEX and most of the mass appears to be located upgradient of the barriers. There is a shift in the areal distribution of BTEX throughout the time periods presented. There is a region of higher concentration near the east side of the large barrier and a region of lower concentration near the west side of the barrier at Day 20. At Day 47, there appears to be a separate plume forming toward the east side of the large barrier as well as a pinched off plume near the small barrier. The increase in concentration near the west side of the large barrier is most likely the result of a recharge of BTEX to the aquifer. At Day 93, there appear to be two plumes remaining, one near the east side of the large barrier, the other toward the west side. The plume located near the small barrier has below 0.50 mg/L of BTEX.

The macroscopic behavior of BTEX and DO in the system is illustrated succinctly with the mass curves shown in Figure 6. The mass was calculated by assuming the C-zone concentrations are depth-averaged, a total porosity of 37.5%, and a saturated thickness of 17 ft. The volume was calculated using the routines in SURFER and the unit conversions were performed in a spreadsheet. The dissolved oxygen mass reached its peak in approximately 9 days, remained relatively constant for the next month and then started to decline. The total dissolved oxygen mass in the system increased by about an order of magnitude and remained at approximately five times its initial mass at Day 93.

The effect of the increase in DO mass in the system is seen by examining the total BTEX mass curve. There was a reduction in BTEX mass of approximately 50% in the first 30 days without a significant change in the maximum oxygen mass. There is a slight increase in BTEX mass from Day 47 to Day 75 as a result of recharge of BTEX into the aquifer, which was discussed previously. This is confirmed by the relatively rapid decrease in oxygen mass from day 47 to day 75. The new slug of BTEX essentially increased the kinetics of oxygen release by exerting a large demand. The comparison of the two curves simultaneously presents a textbook description of aerobic bioremediation dynamics.

As a sideline to the data analysis presented thus far, consideration should be given to the normalized mass curves for the large barrier in cross-section. The A-zone, B-zone, and C-zone oxygen and BTEX concentrations were used to estimate the mass across a vertical slice of the aquifer. Figure 7 is a plot of the normalized mass curves of BTEX and dissolved oxygen at the large barrier. The normalized curves are necessary due to the large oxygen mass compared to the small BTEX mass. Thus, the same general behavior can be observed at the wall as areally with the C-zone data. With respect to Figure 6- while the oxygen concentration at the barrier represents the vast majority of the oxygen in the system it is also important to note that the BTEX concentrations away from the barrier represent the vast majority of the BTEX mass in the system

One hypothesis to explain the increase in BTEX mass from Day 30 to 47 in Figure 6 is a lowering of the water table between the two time periods. Figure 8 is a time history of water levels at the large barrier over the duration of data collection. The water table dropped approximately 0.24 ft. in 17 days or 0.014 ft./day. The decline continued for the remainder of the QFD (Day 47 to Day 93) at an average rate of 0.0081 ft./day (75% slower). The average increase in water table elevation for the first 20 days was 0.0075 ft./day. When the fixed position of the C-zone probes is considered, combined with a decrease in sampling volume above the probe, the hypothesis is supported.

### **Micro-Scale versus Macro-Scale Oxygen Release**

Although there may be some issues related to measuring the dissolved oxygen concentrations, there is no question that the mass curve for oxygen presented in Figure 6 represents a macroscopic average condition in the system. The kinetics of oxygen release must be combined with the demand for oxygen exerted by the BTEX, the recharge of groundwater passing by the source wells, and the local mixing characteristics such as those caused by well screen effects.

Figure 1 represents the laboratory generated kinetics of oxygen release in the form of cumulative oxygen release from ORC versus time. If the ORC were placed in the wells with no BTEX, a relatively constant source of oxygen would be supplied to the aquifer for a period of approximately 300 days. The rate of mass transfer of release would be largely a function of the groundwater recharge rate flowing pass the source wells. We previously demonstrated that the average groundwater velocity at the site is approximately 12 to 14 feet for a 93 day time period or 0.14 ft./day. This velocity is relatively slow and therefore would lead us to conclude that molecular diffusion plays a fairly significant role for ORC release (Peclet number=0.21; assuming a particle diameter of 0.5mm and a molecular diffusion coefficient of 1 cm<sup>2</sup>/day). We have shown that there is a supply of BTEX upgradient of the source wells for the duration of the QFD and, considering this demand on the kinetics of oxygen removal from the ORC, we are left with two conclusions: a) there was enough oxygen released to cause an increase in dissolved oxygen concentrations in monitoring wells located 10 ft, and 20 ft. downgradient, and b) as the mass curve of oxygen in Figure 6 suggests, there was significant BTEX demand, resulting in a shortened life for the ORC. These conclusions are evident without the use of a groundwater transport model which accounts for advection, dispersion, sorption, and biodegradation.

### **Hydrocarbon Bacterial Concentration Across the Large Barrier**

On August 15, 1995 samples were collected from selected source wells and monitoring points across the site. Figure 9 is a plot of the suspended hydrocarbon degrading bacterial concentration starting at MP-303 and ending at MP-203. There is an increase in concentration of approximately three orders of magnitude across the barrier. Although there is no background data support the contention of ORC induced bacterial growth, such large concentrations of aerobic hydrocarbon degrading bacteria would not be thriving in the absence of oxygen.

### **Conclusions**

The following conclusions can be made regarding the performance of an ORC mediated oxygen barrier in Belen, New Mexico:

- 1 The oxygen mass increased an order of magnitude near the leading edge of the dissolved phase BTEX plume.
- 1 The increase in dissolved oxygen concentration had a significant impact on the dissolved phase hydrocarbon plume.
- 1 An ORC mediated oxygen barrier appears to be one means of achieving enhanced intrinsic aerobic bioremediation and overall risk reduction of dissolved phase hydrocarbon plumes in groundwater.

## **Discussion**

This work is the largest of several field studies that have demonstrated the use of ORC in passive bioremediation systems and have highlighted the potential of these methods for the prevention of the migration, and/or reducing the source, of aerobically biodegradable contaminants. These systems are alternatives to slurry wall or pump and treat installations where intrinsic remediation is not applicable or reliable. ORC based systems can also be viewed as a lightly engineered and cost effective method of enhancing intrinsic remediation. ORC systems can be used a sole treatment method or be employed in conjunction with more conventional technologies, that might be planned for- or that already exist on a site. These efforts may serve to supplement limits that exist with air-sparging arrays, or pump and treat systems, or to function as a polishing step- as when pump and treat systems reach a treatment asymptote.

The use of ORC has been focused on typical petroleum hydrocarbon spills such as those found at gas stations, however, a wide range of other problems are candidates for solutions based on passive oxygen release systems. With respect to DNAPLs, it is hoped that efforts may soon begin in areas such as a) the control of TCE and PCE by co-metabolic strategies that require oxygen, b) the prevention of the anaerobic formation of vinyl chloride from TCE and PCE and c) the control of vinyl chloride by aerobic biodegradation once it is formed.

## **Acknowledgments**

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## **Biographical Sketches**

Joseph E. Odencrantz is a registered civil engineer with approximately fifteen years experience in the fields of environmental engineering and water resources. He received his M.S. and Ph.D. in Civil and Environmental Engineering from the University of Illinois at Urbana-Champaign and his B.S. in Civil Engineering from the University of Maine at Orono. Dr. Odencrantz is the founder and President of TRI-S Environmental, Newport Beach, California, a consulting firm specializing in environmental risk reduction, treatment

system design, and site closure. He has been an Associate Editor of the Journal of Groundwater since 1994.

Jeffrey G. Johnson is a civil engineer with more than six years of experience in the environmental field. He received his B.S. in Civil Engineering at the US Military Academy and is currently completing his M.S. in Civil Engineering at the University of New Mexico. Mr. Johnson is employed by GRAM, Inc in Albuquerque, New Mexico

Stephen Koenigsberg is Vice President for Research at Regenesi Bioremediation Products (San Juan Capistrano, CA) and an Adjunct Professor at National University (Irvine, CA). He has a B.S. from The City College of New York (CCNY) and an M.S./Ph.D. from Cornell University. He is the co-inventor of ORC.

## References

- ATEC Associates, Inc. (1993) Minimum Site Assessment Report Shell N. Main Site, Belen, New Mexico, dated in August.
- ASTM RBCA (1994) ES-38: The Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites.
- Geohydrology Associates, Inc. (1994) Investigation of the Shell N. Main Site.
- GRAM, Inc. (1994) ORC<sup>®</sup> Pilot Study Report, Belen, New Mexico, dated December 30.
- Salanitro, J.P. (1993). The Role of Bioattenuation in the Management of Aromatic Hydrocarbon Plumes in Aquifers. Ground Water Monitoring and Remediation, Volume 13: 150-161.
- USEPA (1988). GEOEAS: Geostatistical Environmental Software Users Guide. Environmental Monitoring Systems Laboratory, Office of Research and Development, Las Vegas. EPA/600/4-88/033a:



## Figures

1. Oxygen release kinetics of ORC. The product releases about 10% of the available oxygen in the first few weeks and then releases the balance over a period of six months to a year depending on the level of contaminant flux.
2. Site map showing the location of the remediation system.
3. Detailed site map showing ORC source and monitoring wells.
4. Contour plots of dissolved oxygen at initial (background), 20 days, 47 days, and 93 days. The contour interval is 0.5 mg/L for the initial conditions (0.5-2.0 mg/L) and 3 mg/L for the remaining three.
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6. Mass curve of oxygen and BTEX versus time for the areal distribution.
7. Normalized concentrations of BTEX and oxygen at the large barrier. (The mass was calculated per unit foot of the vertical slice from S-1 through S-16).
8. Groundwater elevation plot at SH-5, which is slightly upgradient of the large barrier.
9. Plot of the hydrocarbon degrading bacteria concentration through the large barrier.

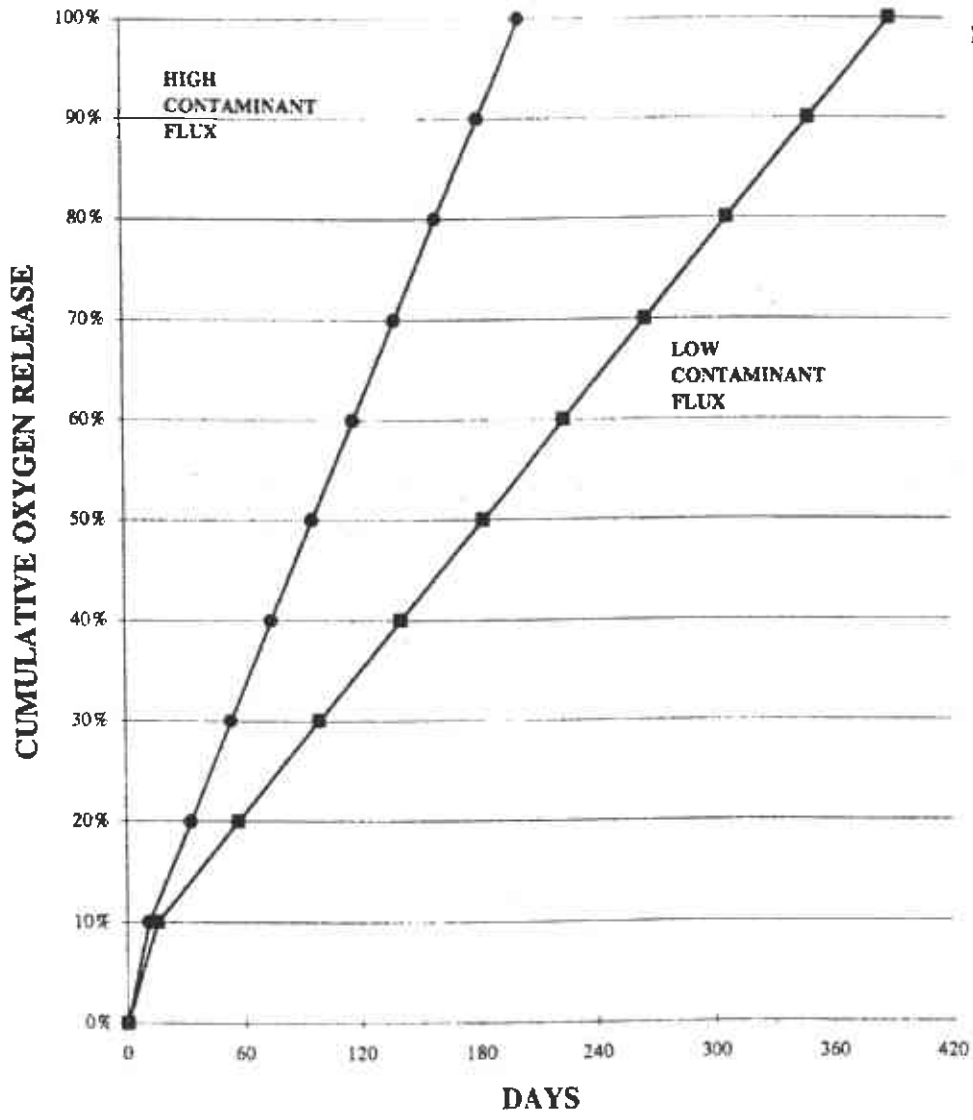


Figure 1

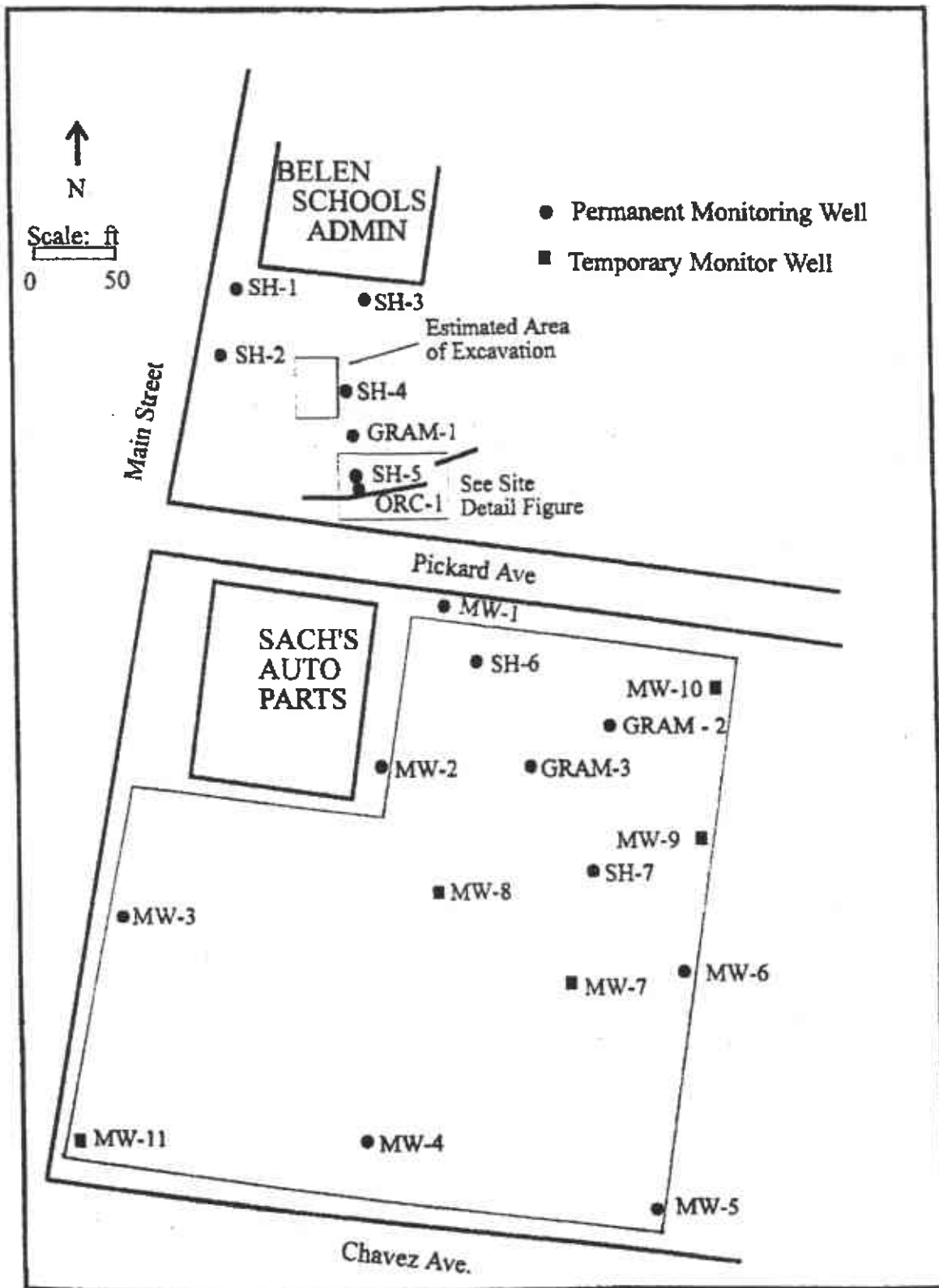


Figure 2

# DETAILED SITE MAP

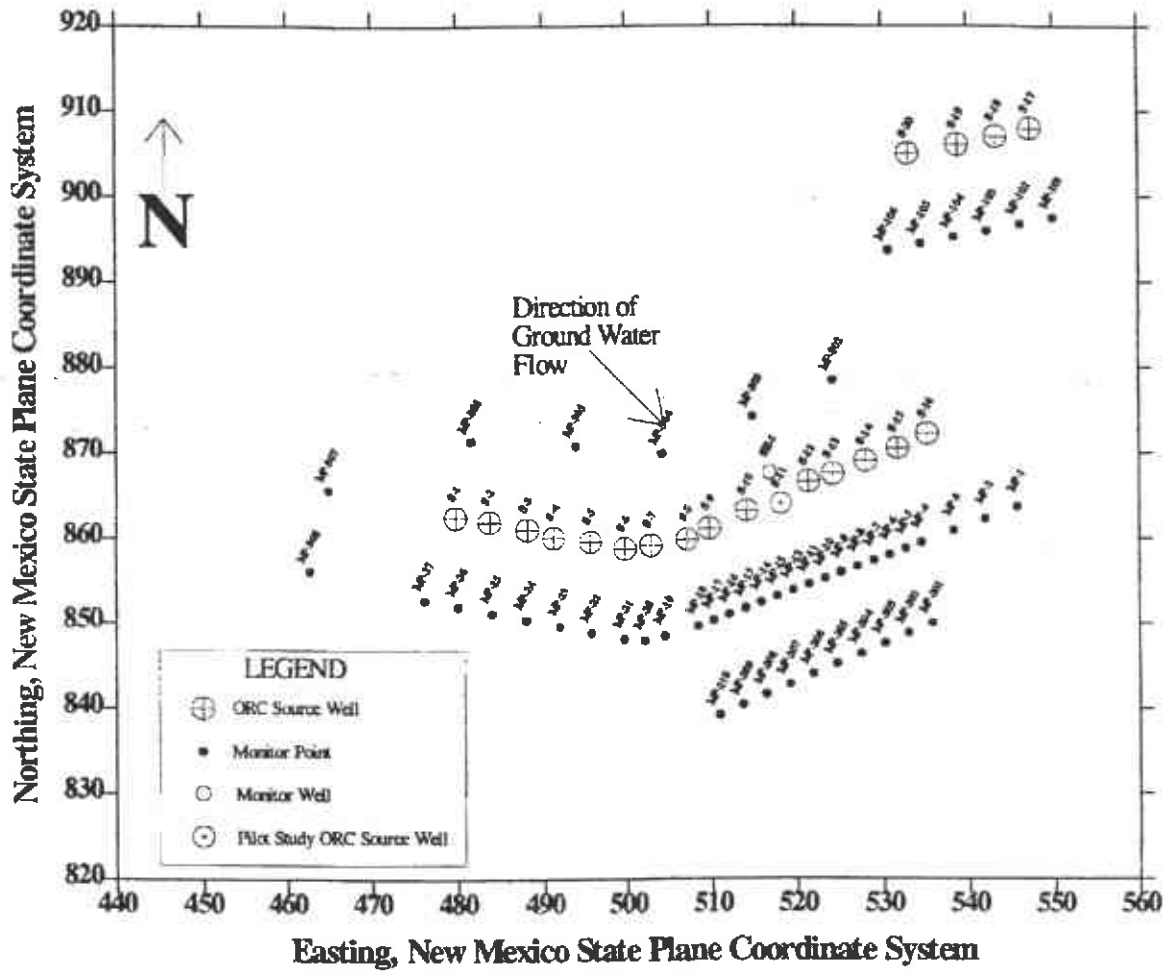
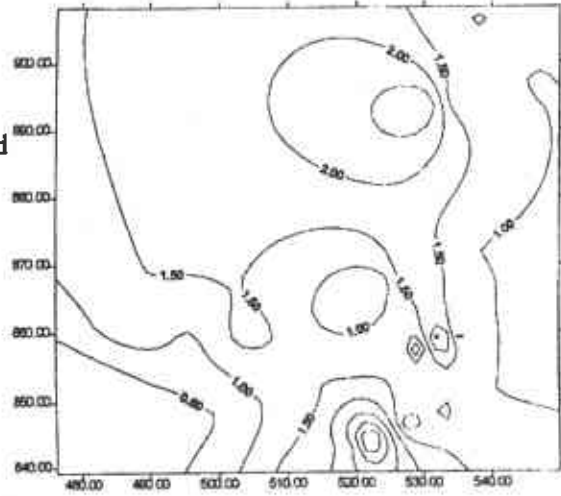


Figure 3

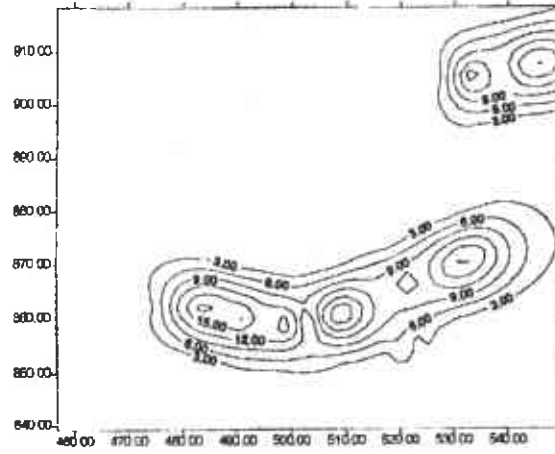
Figure 4

# Oxygen

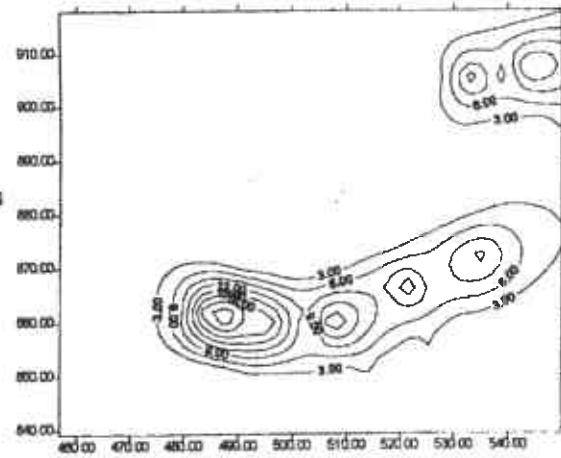
Background



20 days



47 days



93 days

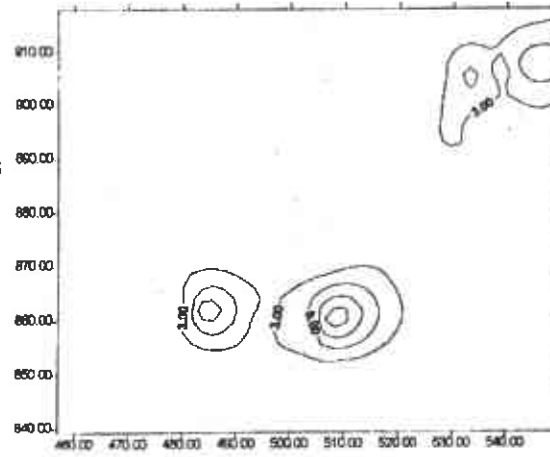


Figure 6

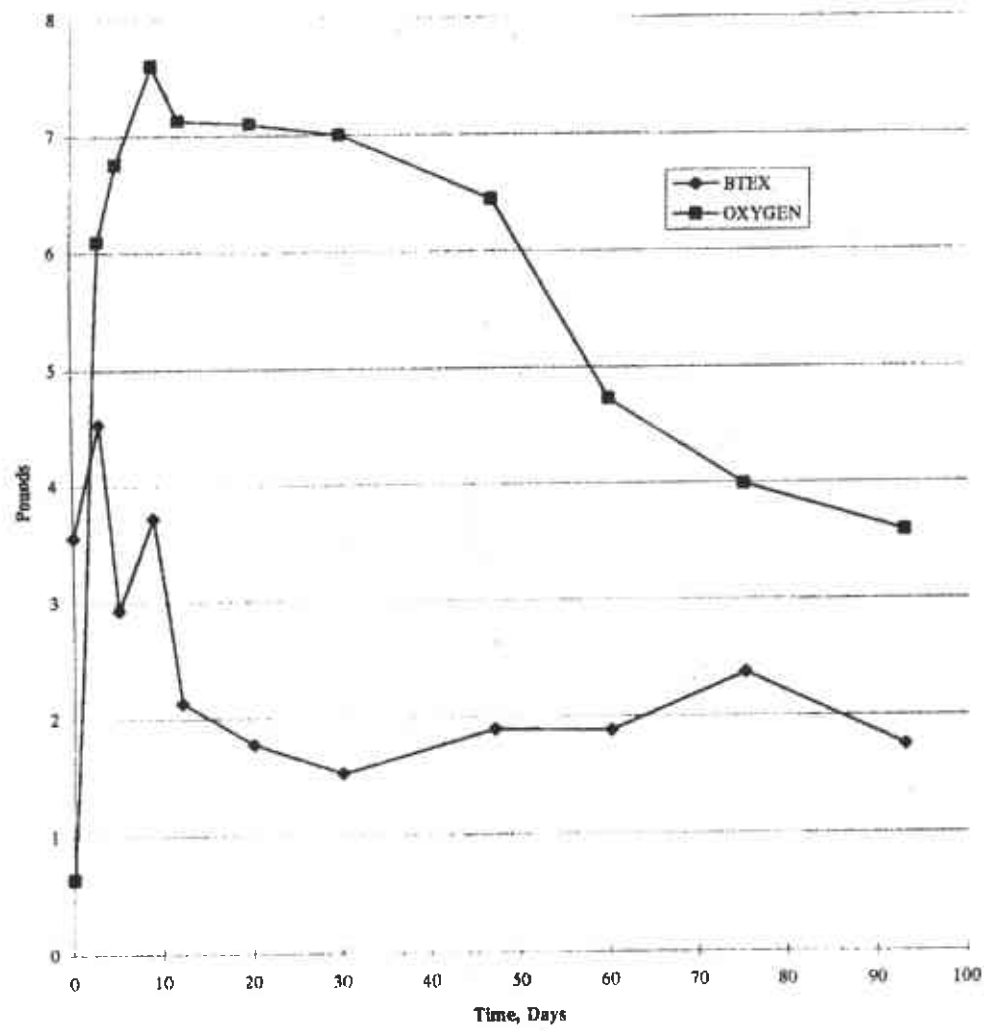


Figure 7

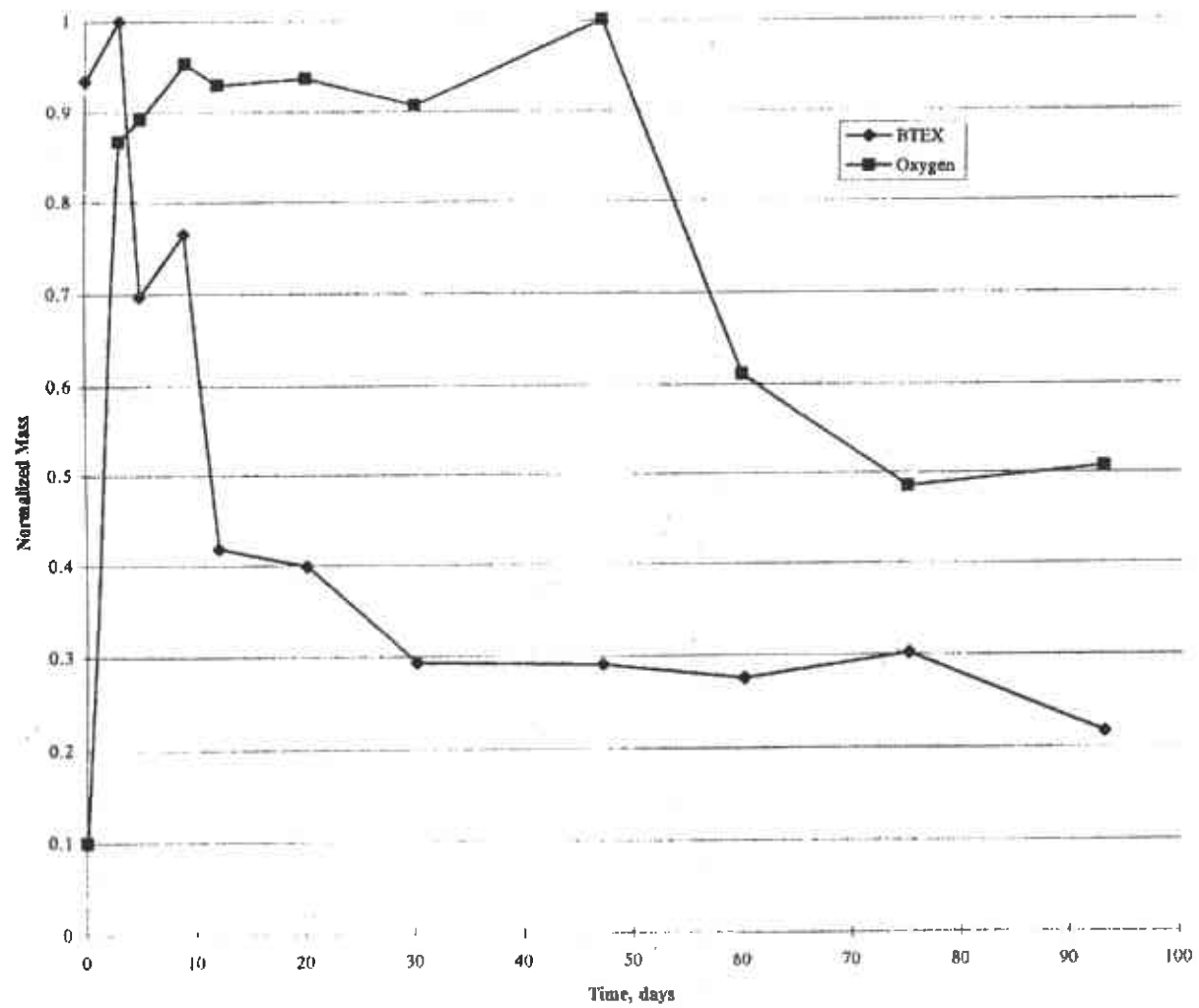


Figure 8

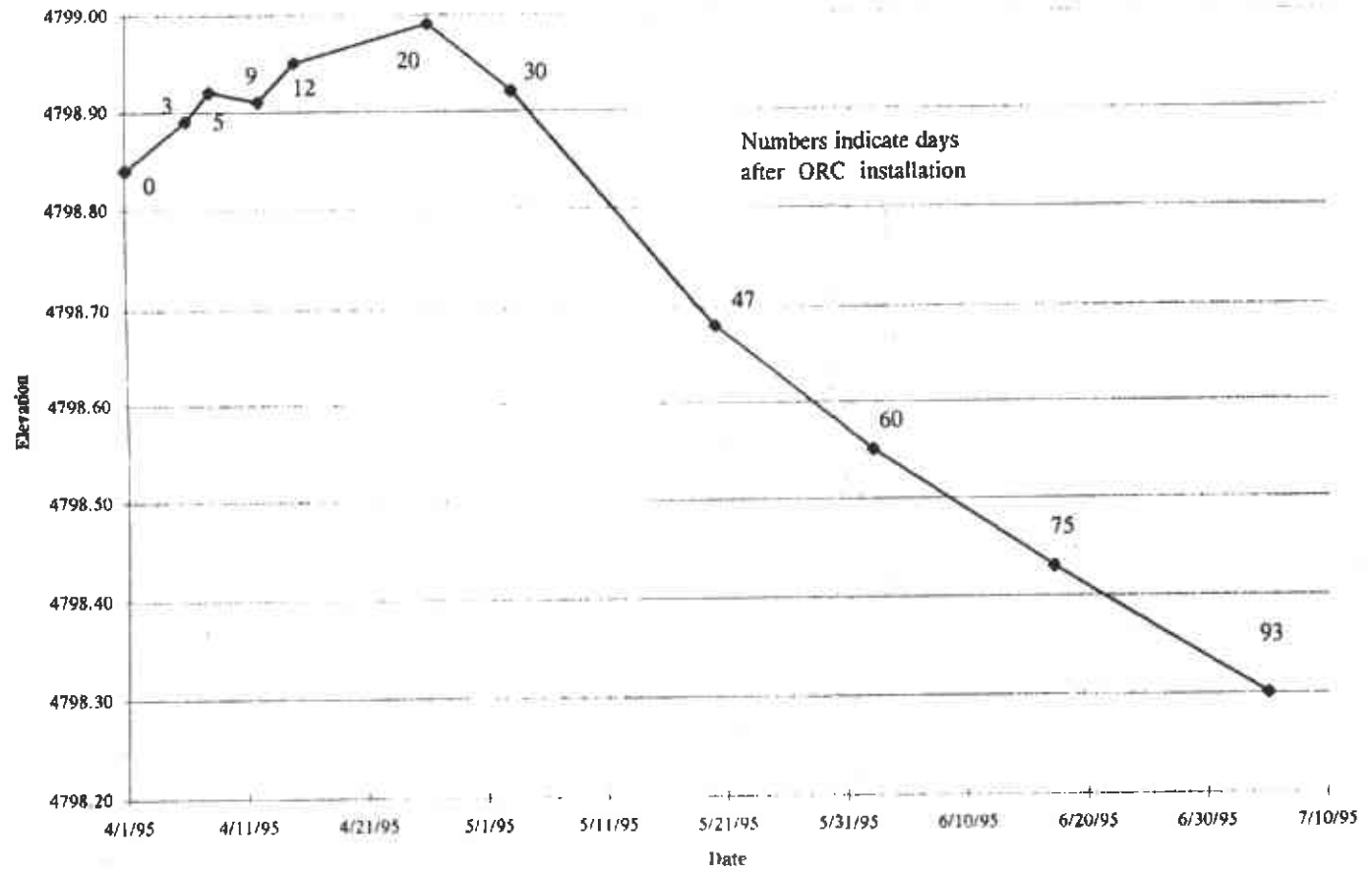
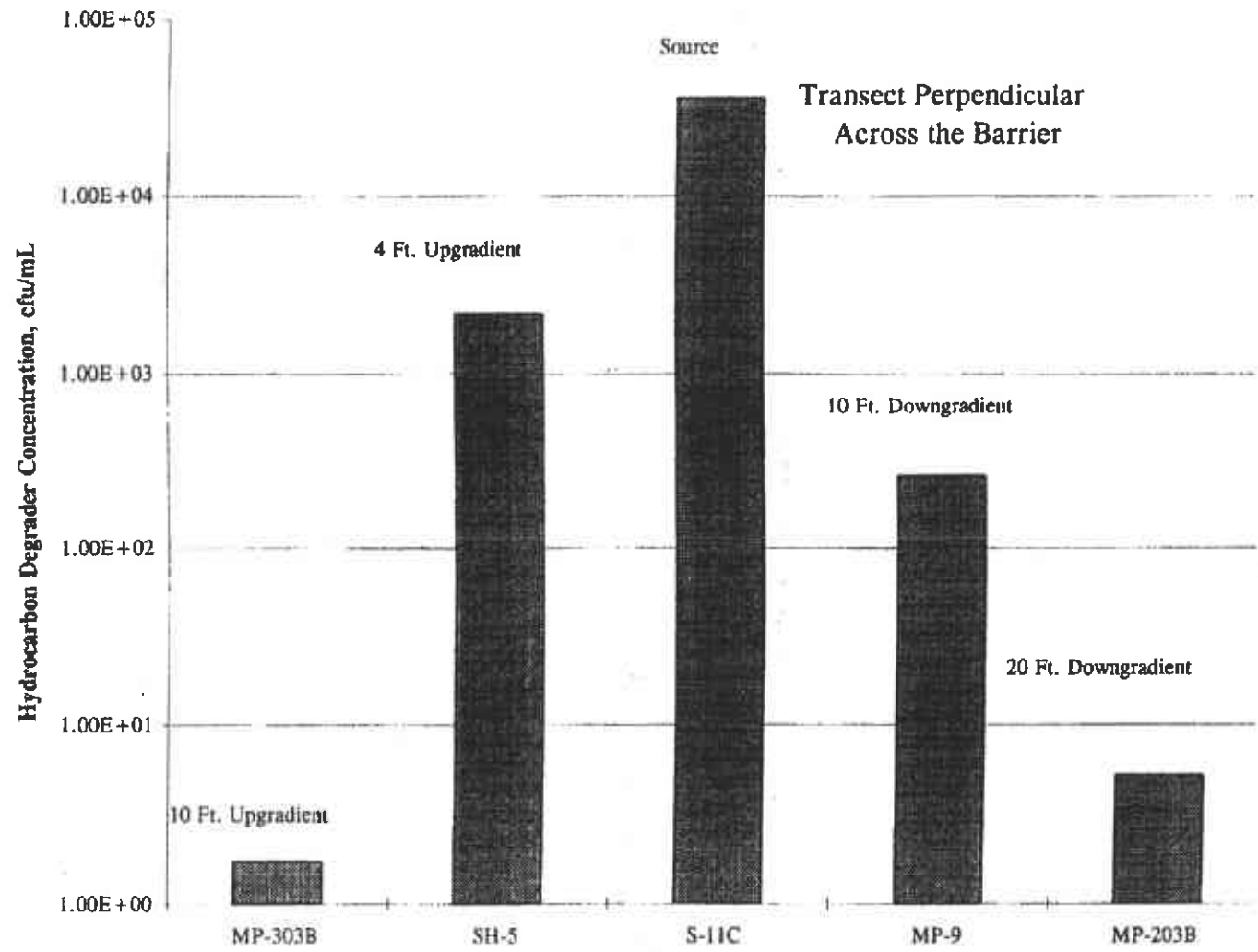




Figure 9



**Pollution  
Engineering**The Source for  
Water, Air and Waste Information

Online

Magazine Article

## Enhanced Intrinsic Bioremediation Speeds Site Cleanup

*Oxygen supplementation accelerates natural degradation by working with natural processes.*

by Thomas C. Morin

The current trend toward the use of natural attenuation or intrinsic remediation (IR) for site cleanup offers significant benefits to both the regulated community and the regulators. It provides environmental consultants with a new tool to offer clients for addressing and managing site cleanups. For some sites the approach is much less expensive than conventional site remediation technologies. It also allows regulators to address sites with an approach that affects true destruction of contaminant mass as opposed to other remedial technologies that transfer contaminants from one medium to the next.

Intrinsic remediation can be used as a site management tool for a range of contaminants. However, many times IR is not an acceptable approach at a site because of the extended time frame required by natural processes to reduce contaminant concentrations to below regulatory limits. At sites where aerobic biodegradation is already occurring, such as petroleum hydrocarbon release sites, it is sometimes possible to enhance and accelerate natural contaminant degradation by supplying additional oxygen to the system. This acceleration of natural biodegradation can reduce contaminant mass at rates that compare favorably to other remedial technologies while offering significant cost savings.

### What is IR?

Intrinsic remediation involves a combination of several natural processes that serve to reduce contaminant concentrations in the environment. In groundwater, these natural processes include biodegradation (aerobic and anaerobic), abiotic transformation, mechanical dispersion, sorption and dilution. IR generally is considered a passive remedial approach because it does not require active engineering controls.

Active remedial technologies used to treat groundwater contamination, such as pump-and-treat methods, ex-situ biotreatment and vapor extraction methods try to reverse natural entropy processes, such as dispersion and dilution, which create contaminant plumes while ignoring in-situ biotransformation processes. Instead of working with the processes and energies inherent in natural systems, these active remediation techniques attempt to overcome them. As a result, active technologies require more effort, energy and cost to accomplish the same goals as IR.

Biodegradation is the key component of IR and occurs when a biologically mediated process changes

APPENDIX C

ORC<sup>®</sup> SOURCE TREATMENT APPLICATIONS

## ORC SOURCE TREATMENT APPLICATIONS

### General

ORC may be used in the source area of the groundwater contamination. This application has two objectives. The first is fast site closure. Since aerobic bioremediation is about 10 to 100 times faster than anaerobic bioremediation, an ORC application results in much faster site closure than natural attenuation which generally operates under oxygen deficient conditions. ORC treatment can also be faster than highly engineered mechanical treatment methods. The second objective is risk reduction. Even if the source is not completely remediated, the application of ORC will collapse the plume and permit compliance at a point closer to the source.

In this application, ORC can be applied in completed monitoring wells using retrievable filter socks or into direct push holes using an ORC slurry mixture. The ORC slurry can be back filled or injected into direct-push bore holes, or back filled into augered holes. Using any one of these methods, a saturated zone source treatment with an ORC slurry targets dissolved phase contamination plus sorbed material within the saturated, capillary fringe, and smear zones. It is important that the entire vertical distance of these contaminant zones be covered by the ORC.

Specific installation instructions for mixing the slurry, for back-filling and for ORC injection are contained in the Installation Instruction section of this software.

### Source Treatment Slurry Back-Fill Application

For the ORC Back-Fill Application, the software calculates the amount of ORC necessary to remediate the known dissolved phase hydrocarbon contamination plus an additional oxygen demand factor of your choice to handle unquantified sorbed hydrocarbons and additional COD and BOD oxygen requirements. In sites with groundwater flow, some oxygen provided by ORC placed at the edge of the source area may move out of the target contaminated zone and begin to treat the downgradient contamination. You need to consider all of these elements when selecting the demand factor. Based on detailed studies, field experience, and customer data that has been made available, Regenesys normally recommends a treatment factor of about 8 since permanent wells are not being drilled which would permit replacement of spent ORC.

Given the demand and the ORC required, the software asks you for the size of the direct-push or augured bore holes you will be drilling. The software calculates the number of bore holes and spacing that is required. If there are too many boreholes for your site or the holes can not be placed properly due to obstructions, etc., then you have some alternatives:

1. Use a larger diameter direct-push bore hole.
2. Consider a second application of ORC in the hottest zones can be considered.
3. Select the ORC Slurry Injection Application which will require less bore holes.

### ORC Source Treatment Slurry Injection Application

In this application the ORC slurry is applied under pressure into the contaminated groundwater, capillary fringe and smear zones. After calculating the hydrocarbon load and the ORC required, the software will ask you for the bore hole spacing that you desire on the site and the number of ORC bore holes will be calculated. If too many are required, the solids content may be decreased

## About Source

which permits wider ORC dispersion and, hence, wider bore hole spacing. The dispersion of the oxygen from the ORC must be considered. A thorough discussion of this subject is found in Regenes Technical Bulletins 4-1.0 through 4-1.3. In general, to get overlapping oxygen coverage the bore holes need not be placed less than six feet on center. Twenty feet on center is about the maximum spacing which will provide overlapping zones of oxygen.

### Solute Transport Model

The ORC Application Software, version 2.0, contains a Dominico-Schwartz Attenuation model, published by Tim Buschek of Chevron. This model is useful in estimating the amount of dissolved phase contamination at a downgradient monitoring, or compliance, point. After the required mass of ORC has been calculated and the groundwater velocity and distance to the compliance point have been entered, you are asked to input the ratio of ORC provided to ORC required (which will be less than 100%). You may vary this ratio and obtain the estimated contaminant levels at the compliance point. If above the contaminant level you may decrease the ratio (or, if below increase the ratio). This permits the user to tailor the amount of ORC applied to the specific requirements at a downgradient compliance point.

### ORC Source Treatment in Replacement Wells

ORC can be used in completed monitoring wells installed in the proper area and which are screened through the vertical portion of the saturated zone, the capillary fringe and the smear zone. In this application, a mixture of ORC and inert silica sand is contained in filter socks. After 6 months, when the oxygen is depleted, the socks should be removed from the wells. Additional factors to account for unknown oxygen demands are not as important in these applications since the socks may be replaced. However, a safety factor of about 2 is recommended for unknown oxygen sinks. Since monitoring wells are expensive to drill and permit, cost can be minimized when the treatment objective is risk reduction with compliance at a point downgradient. The ORC filter socks can be replenished until downgradient compliance is achieved and compliance is achieved and maintained.

Once the basic site characteristics are entered, the software will ask for your desired well diameter, desired number of wells, distance to the downgradient compliance point and the number of change-outs desired. From this data, a calculation of percent oxygen available to oxygen required is generated. If this number is greater than 1.0, there is theoretically enough oxygen provided by the system to remediate the hydrocarbon load after all of the planned ORC changeouts have been completed. It should be noted that actual treatment efficiencies may vary downgradient due to discrete variability in the hydraulic conductivity, groundwater velocity, hydrocarbon mass present, and the spreading of dissolved oxygen from the source. If the ratio of oxygen required to oxygen available is less than 1.0 then the program calculates the projected hydrocarbon concentration at the downgradient compliance point using a variation of the Dominico-Schwartz attenuation model, published by Tim Buschek of Chevron. The effect of more ORC changeouts is to reach a lower contamination level at the downgradient compliance point.

If hydrocarbon load is too high or the required spacing of the wells be too close or inappropriate for the site, then there are some alternatives:

1. Increase the number of ORC changeouts.
2. Increase the well diameter.
3. Add more wells or multiple lines of wells.
4. The wells may be spaced further apart; if contaminant break-through is measured, install additional wells just at those points. This iterative approach may be most economical, allowing a "mid-course" correction based upon actual field experience.

APPENDIX D

PROTOCOL FOR USE OF ORC<sup>®</sup> FOR IN-SITU BIOREMEDIATION

## Protocol For Use Of ORC® For IN SITU Bioremediation

### 1.0 INTRODUCTION

The following protocol was developed as a guide for designing *in situ* bioremediation projects specifying the use of Oxygen Release Compound (ORC®). The basic data required to apply natural attenuation is included in this protocol because the combined use of ORC and the RBCA process usually represents an attractive alternative to aggressive site remediation. This protocol will assist in developing remedial designs with inherent monitoring processes to control the application of *in situ* bioremediation technologies.

The protocol is designed to be flexible in respect to the degree of effort expended for each project. The appropriate level of control to match the scale of the project can be determined by selecting the type and amount of data collected. Lists of suggested parameters for data collection are provided below. Not all data is available or appropriate for each site, but the minimum required data is identified in the protocol by an asterisk (\*). An emphasis was placed on those parameters that could be monitored with minimal costs using field instrumentation.

### 2.0 PRE-SCREENING MODEL

Plume delineation is essential to ensure that appropriate remediation steps are taken. The responsible party and/or consultant should determine whether the plume representing the Compounds of Concern (COC) is shrinking, stable in size, or spreading.

The majority of the site specific data required to pre-screen a site for applicability of ORC technology will be available from the assessment efforts. The specific data requirements for investigations can vary substantially from state to state and over time. If historical investigation reports do not contain the all of the required information, some of the qualitative data can be inexpensively collected in the field with monitoring equipment. The data groups required to pre-screen a site are:

#### A. Lithologic/Hydrogeologic/Microbiological Data

##### Minimum Required Data\*

- Aquifer soil texture\*
- Groundwater flow direction and velocity\*
- Dissolved oxygen (DO)\*
- pH\*
- Temperature\*

##### Additional Data for Greater Control

- Concentration of alternate terminal electron acceptors (nitrate, iron, manganese, sulfate)
- Soil microbial enumerations of contaminant degrading bacteria
- Biological oxygen demand (BOD)
- Oxidation/Reduction (RedOx) potential or Eh
- percent porosity (*total and effective* )
- Conductivity
- Total minerals

#### B. Compounds of Concern (COCs) Data.

##### Minimum Required Data\*

- Dissolved concentrations of COCs\* (i.e., BTEX, MTBE, TPH-G, TPH-D)

##### Additional Data for Greater Control

- Adsorbed concentrations of COCs in the capillary fringe or vadose zone soils that will contact groundwater

The soil texture and porosity data are used to calculate the mass of dissolved COCs and the mass of oxygen required to bioremediate the COCs. A significant component of the COC mass consists of COCs adsorbed to the soil. Besides the solubility of the COC the mass of adsorbed material is usually related to the soil type, texture and carbon (organic/inorganic) content. For example, typically a well graded sand with little or no silt or clay will have a smaller adsorbed component than soil types composed primarily of silt and clay. In order to account for unknowns such as the adsorbed COC mass as well as non-target BOD and COD we assign a demand factor. This demand factor ranges from 8x for a sand with little or no silt or clay to 11x for soil types composed primarily of silts and clays.

Groundwater flow and velocity are used to estimate the flux of COCs and potential for dispersion of dissolved oxygen. Typically, the greatest efficiency of DO transport downgradient is achieved via advective flow (greater than 0.3 ft/day). Advective transport of DO through a heterogeneous aquifer material also enhances DO distribution in the aquifer. A low/no velocity site will primarily rely on chemical diffusion rather than advective flow to distribute the dissolved oxygen. Dissolved oxygen data is used to establish baseline conditions for subsequent respirometry events. The pH, temperature, and conductivity data are used to pre-screen for sites that are not conducive to bioremediation technologies. Although adverse conditions related to pH, temperature, and conductivity are rare, it should be noted that fluctuation in groundwater temperature as well as very low or high pH levels can significantly affect the results of an ORC application. A decrease of 10°C in groundwater temperature over a typical ORC release period of six months will likely decrease the biodegradation activity by one-half. In addition, pH levels of less than 5 or greater than 10 can affect the release rate of ORC. Levels of pH less than 5 can cause a release of DO at a moderately accelerated rate while pH levels of greater than 10 will moderately slow the DO release rate.

The concentration of alternate terminal electron acceptors, e.g. NO<sub>3</sub>, Fe, Mn, SO<sub>4</sub>, data is used to establish the potential for application of natural attenuation. Microbial enumerations of soil samples by plate count methodology confirms the presence of bacterial populations with the capacity to use the COCs as a carbon and energy source. This data is usually not included in standard investigation reports, but the concentration of DO can be used to infer the presence of adequate bacterial populations when low DO concentrations mirror the extent of high COCs concentrations.

The BOD data is used to estimate any organic-based oxygen demand other than the COCs. Non-target BOD also acts as a DO "sink" because the non-target biodegraders compete with the targeted degraders for the DO. This DO "sink" may compete with the targeted biodegraders to the extent that additional ORC applications will be necessary. Eh data indicates the areas of highly reduced conditions which may require additional ORC applications. Highly reduced conditions exert a significant COD on ORC. This COD competes with the biodegraders for DO. This non-target DO "sink" may compete with the biodegraders to the extent that additional ORC applications will be necessary. Alkalinity measurements were not included due to the complexity of carbonate chemistry in aquifers and the substantial variability between geographic locations for this parameter.

The concentration of dissolved COCs is used to estimate the mass of hydrocarbons to be bioremediated. The adsorbed COCs concentrations are used to estimate the total mass of hydrocarbons that will be remediated over time in the aquifer (see above).



## 4.0 REGULATORY APPROVAL

The regulatory approval of both the ORC technology and RBCA process should be investigated prior to further design. Currently, ORC and RBCA are approved by most state environmental lead agencies. There is often a substantial variability between individuals in a state or local lead agency regarding any remedial technology and application of risk based closure. For this reason, it is prudent to initiate communications with site case workers regarding the intended use of ORC and RBCA closure at the onset of the project.

## 4.0 BASELINE PARAMETERS

The following list of parameters should be collected from a series of existing monitoring wells at each site. It is recommended that the array of monitoring wells to be used for the baseline analyses are also used for subsequent treatment monitoring. For that reason the number of wells will greatly influence total analytical costs. It is recommended that a minimum of three wells in the treated area and one upgradient well be included in the monitoring array.

The following parameters are recommended for baseline assessment:

### A. Microbiological/Respirometry Data

#### Minimum Required Data\*

- Biological oxygen demand (BOD)\*
- Oxidation/Reduction (RedOx) potential or Eh\*
- Dissolved oxygen (DO)\*
- pH, temperature and conductivity\*
- total minerals\*
- concentration of alternate terminal electron acceptors (nitrate, iron, manganese, sulfate)\*

#### Additional Data for Greater Control

- soil microbial enumerations of contaminant degrading bacteria

### B. Compounds of Concern (COCs) Data.

- dissolved concentrations of COCs\* (i.e., BTEX, MTBE, TPH-G, TPH-D)

## 5.0 APPLICATION PROTOCOL

The ORC application approach should reflect the remedial goals for the site. In some cases application of ORC is necessary across the entire plume "footprint", while other sites may require only a limited source area application. However, a limited application of ORC should be carefully considered prior to site implementation. Application of ORC at levels below the modeled parameters may lead to under-performance. Under-performance may be the result of numerous factors. Typically it is the result of underestimation of the DO requirements of the COC mass or aquifer COD. A scaled back approach equates to a scaled back result. Typically, multiple applications of ORC are necessary.

The use or application of ORC should reflect specific site objectives. These objectives may range from RBCA clean up levels to MCL's. Prior to implementation, the following list of issues should be addressed:

Vertical (thickness of the contaminated saturated zone) and lateral extent of the hydrocarbon plume. The vertical extent is critical because ORC releases oxygen which moves laterally from ORC. Where you put ORC is where you will provide the oxygen. DO does not rise

through the water column; it remains within the interval in which the ORC is placed.

· Evaluation and selection of an optimal application approach.

REGENESIS application software should be used to estimate the hydrocarbon mass present within the system as well as the amount of DO/ORC necessary to remediate the calculated hydrocarbon mass.

- It is important to evaluate the DO/ORC requirement based on the mass of the hydrocarbons present as well as the proper distribution of DO in the aquifer. Evaluation of a site based on the hydrocarbon mass alone will not provide a correct answer.
- Fewer source points containing large dosages of ORC (DO) are less effective in plume reduction than greater numbers of point sources containing smaller dosages of ORC (DO).

ORC applications can be divided into two general categories: 1) mass reduction ("source treatment") and 2) containment ("oxygen barrier treatment").

Mass reduction applications consist of the following:

1. Tank Excavation Backfill Amendment--use as an admixture into excavation backfill material.
2. Slurry Injection or Backfill--physical distribution of an ORC slurry directly into the aquifer via a direct push or hollow stem augered hole placement of the ORC array immediately upgradient and/or proximal to the source area will allow aerobic degradation processes to occur within the plume's anaerobic core.

Containment applications consist of the following:

1. Application of ORC filter socks into wells or an ORC slurry into bore holes. The wells or bore holes should be placed along the downgradient property boundary. The ORC source points should be placed perpendicular to groundwater flow and the distance between the points should be appropriately spaced. This application must account for the hydrocarbon concentration as well as groundwater velocity.

### 6.0 POST APPLICATION--TREATMENT MONITORING

The treatment monitoring process is designed to quantify the degradation of dissolved COCs.

Respirometry measurements also provide evidence that bioremediation is the primary mode of destruction of the COCs. The respirometry monitoring is monthly for the first quarter, quarterly for the remainder of the first year, semi-annually for the second year, and annually for any additional years. It should be noted that ORC applications can be designed to reduce concentrations of COCs over a flexible time frame. It is recommended that an economic analysis of ORC applications compared to monitoring costs for long term RBCA activities be conducted to realize maximum remedial efficiency.

The following parameters are recommended to analyze treatment monitoring:

#### A. Microbiological/Respirometry Data

##### Minimum Required Data\*

- Biological oxygen demand (BOD)\*
- Oxidation/Reduction (RedOx) potential or Eh\*
- Dissolved oxygen (DO)\*
- pH, temperature and conductivity\*
- Total minerals\*

## Protocol

- Concentration of alternate terminal electron acceptors (nitrate, iron, manganese, sulfate)\*

### Additional Data for Greater Control

- Soil microbial enumerations of contaminant degrading bacteria

### B. Compounds of Concern (COCs) Data.

- Dissolved concentrations of COCs\* (i.e., BTEX, MTBE, TPH-G, TPH-D)

## 7.0 ESTABLISH RATE CONSTANTS FOR ORC APPLICATION AND RBCA PROCESS

The remediation of hydrocarbons using ORC over a wide range of site conditions will provide baseline data to establish relative rate constants. These data should be collected and analyzed during initial ORC applications at various sites, under various hydrogeologic conditions. This will provide a more reliable degradation rate constant for standard applications of ORC, compared to obtaining site specific rate constants. The current ORC applications software uses a first order decay rate constant, and this effort should provide an alternative rate constant for future designs.

APPENDIX E

ORC® INSTALLATION INSTRUCTIONS, GEOPROBE INJECTION INTO THE SOIL  
MATRIX

## Slurry Injection

### **REGENESIS** Bioremediation Products

#### **ORC® Slurry Installation Instructions Geoprobe® Injection into the Soil Matrix**

##### **SAFETY:**

Pure ORC is shipped to you as a fine powder rated at -325 mesh (passes through a 44 micron screen). It is considered to be a mild oxidizer and as such should be handled with care while in the field. Field personnel should take precautions while applying the pure ORC. Typically, the operator should work upwind of the product as well as use appropriate safety equipment. These would include eye and respiratory protection, and gloves as deemed appropriate by exposure duration and field conditions.

Personnel operating the field equipment utilized during the installation process should have appropriate training, supervision and experience.

##### **GENERAL GUIDELINES:**

ORC may be installed in the contaminated saturated zone in the ground utilizing hand augered holes, Geoprobe® type hydraulic punch equipment, or hollow stem augers. This set of instructions is specific for Geoprobe equipment. Alternate instructions may be obtained from the Regensis Technical Support Department.

For optimum results the ORC slurry installation should span the entire vertical contaminated saturated thickness, including the capillary fringe and "smear zone".

Two general installation approaches are available. The first is to backfill only the probe hole with slurry. This is a simple approach, in that it is easy, straightforward, and the location of the ORC slurry is precisely known after installation. However, this method requires significantly more probe holes than the alternative, and may take more time for the completion of the remediation process. A separate set of instructions for this method utilizing Geoprobe equipment is available from Regensis.

The second method is to inject the slurry through the probe holes into the contaminated saturated zone. This method requires fewer probe holes, is less disruptive to the site, and aids the spread of oxygen by spreading the ORC source material. However, it may be difficult to know the exact, final disposition of the ORC installed with this method. This is the method described in these instructions.

Note: It is important that the installation method and specific ORC slurry point locations be established prior to field installation. It is also important that the ORC slurry volume and solids content for each drive point be predetermined. The Regensis Technical Service Department is available to discuss these issues, and Helpful Hints at the end of these instructions offers relevant information. Regensis also has available Technical Bulletins covering source treatments with ORC.

##### **SPECIFIC INSTALLATION PROCEDURES:**

## Slurry Injection

- 1) Identify the location of all underground structures, including utilities, tanks, distribution piping, sewers, drains, and landscape irrigation systems.
- 2) Identify surface and aerial impediments.
- 3) Adjust planned installation locations for all impediments and obstacles.
- 4) Pre-mark the installation grid point locations, noting any that have special depth requirements.
- 5) Set up the Geoprobe unit over each specific point, following the manufacturer recommended procedures. Care should be taken to assure approximate vertical probe holes.
- 6) Penetrate surface pavement, if necessary, following standard Geoprobe procedures.
- 7) Drive the 1 1/2" (one-and-one-half inch) pre-probe (part #AT-148B) with the expendable tip (part #AT142B) to the desired maximum depth. Standard 1" (one inch) drive rods (part #AT104B) should be used, after the pre-probe. (Hint: Pre-counted drive rods should be positioned prior to the installation driving procedure to assure the desired depth is reached.)
- 8) Disconnect the drive rods from the expendable tip, following standard Geoprobe procedures.
- 9) Mix the appropriate quantity of ORC slurry for the current drive point. (See separate Directions for ORC® Slurry Mixing and Helpful Hints). **Note: Do not mix more slurry than will be used within a 30 minute period. See Helpful Hint "A.1 Slurry" for mixing suggestions.**
- 10) Set up and operate an appropriate slurry pump according to manufacturer's directions. Based on our experience, a Geoprobe model GS-1000 pump is recommended. Connect the pump to the probe grout pull cap (GS-1054) via a 1 inch diameter delivery hose. The hose is then attached to the 1" drive rod with its quick connector fitting. Upon confirmation of all connections add the ORC slurry to the pump hopper/tank.
- 11) While slowly withdrawing the pre-probe and drive stem 4' (four feet), pump the predetermined amount of ORC slurry into the aquifer (step 13). (Also note Helpful Hints - Operations at end of instructions.)
- 12) Optional pretreatment step. (See Helpful Hints - Operations at end of instructions). Pump one to two gallons of tap water into the aquifer to enhance dispersion pathways from the probe hole, if necessary.
- 13) Pump the predetermined quantity of ORC slurry for the depth interval being injected. Observe pump pressure levels for indications of slurry dispersion or refusal into the aquifer. (Increasing pressure indicates reduced acceptance of material by the aquifer).
- 14) Remove one 4' section of the 1" drive rod. The drive rod will contain slurry. This slurry should be returned to the ORC bucket for reuse.
- 15) Repeat steps 11, 12, 13, and 14 until treatment of the entire affected thickness has been

## Slurry Injection

achieved. It is generally recommended that the procedure extend to the top of the capillary fringe/smear zone.

- 16) Install an appropriate seal, such as bentonite, above the ORC slurry through the entire vadose zone. This helps assure that the slurry stays in place and prevents contaminant migration from the surface. Depending on soil conditions and local regulations, a bentonite seal can be pumped through the slurry pump or added via chips or pellets after probe removal.
- 17) Remove and decontaminate the drive rods and pre-probe.
- 18) Finish the probe hole at surface as appropriate (concrete or asphalt cap, if necessary).
- 19) Move to the next probe point, repeating steps 5 through 18.

### HELPFUL HINTS:

#### A. Physical characteristics A1. Slurry

The ORC slurry is made using the dry ORC powder (rated at -325 mesh). It makes a smooth slurry, with a consistency that depends on the amount of water used.

A thick, but pumpable, slurry that approaches a paste can be made by using 65-67% solids. This material would normally be used for back-filling a bore or probe hole. It is especially useful where maximum density is desired such as where ground water is present in the hole or there are heaving sands.

Thinner slurries can be made by using more water. Typical solids for the thinner slurries content will range from 35% to 62%. Such slurries are useful for injecting through a probe or bore hole into the saturated aquifer. When tighter soils are encountered, or a larger radius of influence around each injection point is desired, an even thinner slurry can be tested in the field. Solids contents as low as 10% (wt:wt) can be used.

As a rule, it is best to mix the first batch of slurry at the maximum solids content one would expect to use. It can then be thinned by adding additional water in small increments. By monitoring this process, the appropriate quantities of water for subsequent batches can be determined.

The slurry should be mixed at about the time it is expected to be used. It is best to not hold it for more than 30 minutes. Thinner slurries, especially, can experience a separation upon standing. All ORC slurries have a tendency to form cements when left standing. If a slurry begins to thicken too much, it should be mixed again and additional water added if necessary.

Care should be taken with slurry that may be left standing in a grout pump or hose. Problems can generally be avoided by periodically recirculating the slurry through the pump and hose back into the pump's mixing or holding tank.

#### A2. Equipment

Most geotechnical grout pumping equipment has a holding tank with a capacity sufficient for injection.

## Slurry Injection

When applying measured volumes of ORC slurry to probe holes, it is sometimes useful to know the volumes and content of the delivery system lines. The following information may be useful in this regard:

Geoprobe pump: At the end of a pump stroke virtually no deliverable slurry remains in the pump.

5/8" O.D. connecting hose (10 feet long):	.2 gallons (26 fluid ounces).
Four foot (4') length of 1" drive rod:	.04 gallons (5 fluid ounces).
Three foot (3') length of 1 1/2" pre-probe:	.03 gallons (4 fluid ounces).

### Cleaning and maintenance:

Pumping equipment and drive rods can be lightly cleaned by circulating clear water through them. Further cleaning and decontamination (if necessary due to subsurface conditions) should be performed according to the equipment supplier's standard procedures and local regulatory requirements.

### B. Operating characteristics

#### B1. Operations - General

Judgment will be needed in the field when injecting ORC slurries. In general, it is relatively easy to inject ORC slurries into sandy soils, and this can usually be accomplished at very moderate pressures. Silts and clays require more pressure, and may accept less slurry.

Careful observation of pressure during slurry pumping is the best indication of the effectiveness of the slurry injection. To test the soil's ability to accept the slurry and to "precondition" the injection point for the slurry, it is sometimes useful to inject a small volume of plain water prior to the slurry. Normally, one-half (0.5) gallons to two (2) gallons would be appropriate.

During injection, increasing pressure and decreasing flow rate are signs of refusal by the soil matrix to accept the slurry. The optional tap water injection (step 12) may be attempted in this situation. The site geologist should determine whether to increase pressure, and possibly fracture ("frac") the soil matrix to achieve ORC slurry installation in a tight site that has refused the slurry at lower pressures.

#### B2. Fill Volumes Probe hole back-filling

Probe hole capacities:

#### Per 10' (Ten Foot) length

	<u>Theoretical Volume</u>	<u>Operating Volume</u>	
	<u>(Gallons/Fluid Ounces/Cubic Inches)</u>	<u>(Gallons/Fluid Ounces)</u>	
	<u>Sand, Silts &amp; Clay</u>	<u>Sand</u>	<u>Silts &amp; Clay</u>
1" Diameter	.41 gal/52 fl. oz./94.2 cu. in.	.61 gal/78 fl. oz.	.51 gal/65 fl. oz.
1 1/2" Diameter	.92 gal/117 fl. oz./212.0 cu. in.	1.38 gal/176 fl. oz.	1.15 gal/146 fl. oz.
2" Diameter	1.63 gal/209 fl. oz./376.8 cu. in.	2.44 gal/313 fl. oz.	2.04 gal/261 fl. oz.



## Slurry Injection

2 1/4" Diameter      2.06 gal/264 fl. oz./476.9 cu. in.

3.09 gal/396 fl. oz.    2.57 gal/330 fl

Note that the operating volumes include a 50% excess above the theoretical volume in sands and 25% in clays and silts. This is important to successful treatment. The additional material allows for a small degree of infiltration of the slurry into the surrounding soil and fractures, as well as hole diameter variability. It is important to assure that the entire contaminated saturated zone is treated (including the capillary fringe), since this is often the area of highest pollution concentration. Failure to treat this area due to improper installation can undermine an otherwise successful remediation effort.

APPENDIX F

DIRECTIONS FOR ORC\* SLURRY MIXING MATRIX

**REGENESIS**

Bioremediation Products

**DIRECTIONS FOR ORC® SLURRY MIXING**

1. OPEN 5 GALLON BUCKET, AND REMOVE PRE-MEASURED BAG OF ORC.
  2. MEASURE AND POUR WATER INTO THE 5-GALLON BUCKET ACCORDING TO THE FOLLOWING DESIRED CONSISTENCY:

65% solids slurry	Mix .63 gallons of water per 10 pounds of ORC powder. Example: Mix 20 pounds of ORC with 1.26 gallons of water. Mix 30 pounds of ORC with 1.89 gallons of water.
60% solids slurry	Mix .79 gallons of water per 10 pounds of ORC powder. Example: Mix 20 pounds of ORC with 1.58 gallons of water. Mix 30 pounds of ORC with 2.37 gallons of water.
50% solids slurry	Mix 1.19 gallons of water per 10 pounds of ORC powder. Example: Mix 20 pounds of ORC with 2.38 gallons of water. Mix 30 pounds of ORC with 3.57 gallons of water.
25% solids slurry	Mix 3.57 gallons of water per 10 pounds of ORC powder. Example: Mix 10 pounds of ORC with 3.57 gallons of water.
  3. ADD THE APPROPRIATE ORC QUANTITY TO THE WATER . Check weight of each bucket (see label). The 5 gallon shipping bucket weighs 2 pounds. An additional 4 pounds of ORC would require one additional quart of water, at the 65% solids level.
  4. USE AN APPROPRIATE MIXING DEVICE TO THOROUGHLY MIX ORC AND WATER. A hand held drill with a "jiffy mixer" or a stucco mixer on it may be used in conjunction with a small paddle to scrape the bottom and sides of the container. Standard environmental slurry mixers may also be used, following the equipment instructions for operation. For small quantities a usable slurry can be mixed by hand, if care is taken to blend all lumps into the mixture thoroughly.
- CAUTION:** ORC MAY SETTLE OUT OF SLURRY IF LEFT STANDING. ALSO, ORC EVENTUALLY HARDENS INTO A CEMENT-LIKE COMPOUND, AND CANNOT BE RE-MIXED AFTER THAT HAS HAPPENED. THEREFORE:  
Mix immediately before using. Do not let stand more than 30 minutes, and re-mix immediately before use, to be sure the mixture has not settled out. If a mechanical slurry mixer attached to a pump is being used, the material may be cycled back through the mixer to maintain slurry suspension and consistency.
5. CHECK SLURRY CONSISTENCY FOR POURABILITY. ADD WATER IF NECESSARY (IN 1 CUP INCREMENTS) TO ACHIEVE THE CORRECT CONSISTENCY .

27130A Paseo Espada, Suite 1407  
San Juan Capistrano, CA 92675  
Tel: (714) 443-3136  
Fax: (714) 443-3140